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Are Homebuyers Inattentive?
Evidence From Capitalization of Energy Costs

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Abstract

This paper explores whether home buyers are attentive to energy costs. The cost-effectiveness of market-based pollution policies crucially depends on whether consumers are attentive to energy costs when purchasing energy-using durables. I exploit energy cost variation from fuel price changes in Massachusetts where there is significant overlap in the geographic and age distributions of oil-heated and gas-heated homes. The results strongly reject that home buyers are unresponsive to energy costs under a wide range of consumption and discount rate assumptions. Furthermore, my preferred specification is consistent with full capitalization of fuel expenditures at discount rates similar to mortgage interest rates.

Keywords: Inattention, Undervaluation, Myopia, Housing Prices, Energy Efficiency Gap
JEL Codes: D12, H25, R31

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1 Introduction

Consumers are often more responsive to changes in purchase price than to less salient product costs such as shipping and handling expenses (Hossain and Morgan, 2006), sales tax (Chetty et al., 2009), and operating costs of appliances (e.g., Hausman, 1979). This type of consumer inattention has important implications for policy measures such as taxation, since in order to affect behavior, policies need to target costs to which people pay attention. In recent years, governments around the world have become interested in designing successful policy instruments for reducing greenhouse gas (GHG) emissions. Whether market-based instruments such as taxes or cap-and-trade programs will be cost-effective crucially depends on whether consumers are responsive to fuel prices in markets for energy-using durables. If people lack information about changes in energy prices or are inattentive to the resulting changes in the operating costs of energy-using durables, they will under-invest in efficiency even under carbon pricing policies. In this case, other more traditional policy instruments, such as information campaigns, efficiency standards for appliances, or building codes, may be more efficient.

This paper asks whether consumers are responsive to changes in energy prices in the housing market. Policymakers have worried that energy costs may not be salient in the housing market, given all of the other important considerations in a home purchase decision, such as the layout of the home, school quality, transportation options, and neighborhood amenities.[1] Determining whether or not consumers are attentive to energy costs in housing has important policy implications since the building sector is large and growing contributor of U.S. GHGs, currently at around 40 percent of annual emissions.[2] As end uses, space heating and cooling contribute almost as much to U.S. greenhouse gas emissions annually

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[1] For example, the SAVE Act [S. 1106] was introduced on June 6, 2013 by Senators Bennet (Democrat from Colorado) and Isakson (Republican from Georgia), which would require federal mortgage agencies to include energy costs in the underwriting process. They believed energy costs were “out of sight and out of mind” in the housing market and wanted to improve the quality of mortgage underwriting by providing a more accurate picture of repayment risk and the expected costs of home ownership.

[2] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, 2011 Buildings Energy Data Book (2012) pp. 1-1.

(13 percent) as personal vehicles (15 percent)[3] and in recent years, consumers spent almost as much on residential natural gas, electricity, and fuel oil as they did on gasoline and motor oil.[4]

In this study, I use exogenous changes in the relative fuel prices of heating oil and natural gas over time as a source of variation in energy costs. Natural gas is used to heat homes in most parts of the United States where substantial heating is required. However, in the northeastern United States 30-40 percent of households still heat with heating oil.[5] For this study, I focus on the state of Massachusetts, where there is significant overlap in the geographic and age distributions of oil-heated homes and gas-heated homes. I compare the transaction price of oil-heated versus gas-heated homes for the period 1990-2011, during which there is significant variation in the relative fuel prices. As the relative fuel price of a home increases, it should sell at a discount compared to homes with less-expensive fuel.

I find little evidence that home buyers are systematically “under-valuing” future fuel costs. I find that a large proportion of the present value of fuel expenditure differences is capitalized under a wide range of assumptions about energy usage and discount rates. In my preferred specification, I cannot reject full capitalization of future fuel costs under a 3.5 percent discount rate, in line with real mortgage interest rates during the sample period.[6] It appears that home buyers are paying attention not only to whether a home heats with oil or gas, but also to the relative prices of those fuels and further, how those relative price differences translate into differences in the net present value of the future stream of payments.

These findings are relevant to a broad literature using capitalization to value attributes such as environmental amenities (see Palmquist (2005) for a review), quality of public schools

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[3] EPA: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012 and EIA: Residential Energy Consumption Survey 2009, Commercial Buildings Energy Consumption Survey 2003.

[4] Bureau of Labor Statistics Consumer Expenditure Survey: Shares of annual aggregate expenditures and sources of income (2005-2014), inflated to 2014 USD.

[5] See American Housing Survey National Summary Table 2-5: Fuels-Occupied Units, years 2005, 2007, and 2009.

[6] As I describe in more detail in the empirical framework, I assume that consumers use a no-change forecast for future energy prices and I use an infinite time horizon for net present value estimates. In addition, I instrument for fuel price using the average fuel price for the home’s vintage.

(see Nguyen-Hoang and Yinger (2011) for a review), property taxes (see Sirmans et al. (2008) for a review), the presence of sex offenders (e.g. Linden and Rockoff (2008)), crime (e.g. Gibbons (2004)), and violence (e.g. Besley and Mueller (2012)). These studies rest on the standard assumption that individuals choose residences that maximize their utility, so that the marginal rate of substitution between housing attributes and other goods will equal the price ratio. Hence, the marginal effect of an attribute on housing price reflects consumers' marginal willingness to pay for that attribute.

My empirical setting offers several advantages for estimating consumer willingness to pay (WTP) for a housing amenity and quantifying attention to that amenity, which are often not available in the literature. First, I observe the sales price of homes that heat with both types of fuel in the same neighborhood in the same year. Therefore, I can interpret the marginal effect of energy cost on housing price as a willingness to pay measure since the change in the energy cost attribute does not affect the gradient of the equilibrium price function as may be the case with changes in community-level amenities such as school quality, environmental quality, property taxes, or crime (Kuminoff et al., 2010). Second, I am estimating the capitalization of energy costs, a quantifiable component of housing cost. Hedonic valuation studies generally aim to recover the value of non-market amenities such as air quality or crime through capitalization into housing prices, and therefore must begin by assuming home buyers are fully attentive to those attributes. Because I can estimate the change in the net present value (NPV) of future fuel costs caused by fuel price movements, I can use the degree of capitalization as a test for consumer inattention.[7]

Another advantage of my empirical setting is that relative fuel price movements create exogenous variation in energy costs. Previous attempts to estimate capitalization rates of energy costs have used utility bills (Johnson and Kaserman, 1983), measures of efficiency (Dinan and Miranowski, 1989), or efficiency letter grades (Brounen and Kok, 2011). One

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[7] I use the term "inattention" to refer to a series of biases that would result in undervaluation of energy costs, such biased beliefs, present bias, or bias toward concentration. As I describe in Section 3, my data cannot distinguish between these biases, but they have the same policy implications for taxation.

limitation of this approach is that home efficiency is not randomly assigned, so that the observed premium for efficient units may be due to unobserved differences in homes rather than the causal effect of energy cost savings.

The findings in this paper are also relevant to the behavioral literature on consumer bias or inattention to certain aspects of product cost. The empirical test of inattention in this paper asks how home buyers tradeoff purchase price with energy costs. Absent any bias the NPV of fuel costs should be fully capitalized, since consumers are indifferent between an additional dollar of purchase price and an additional present discounted dollar of energy expenditure. This approach is similar to studies that quantify inattention to potentially less salient costs such as shipping and handling, sales tax, or automatic electronic payments by comparing the demand response of those costs versus salient, correctly perceived costs (Chetty et al., 2009; Hossain and Morgan, 2006; Finkelstein, 2009). Researchers have also applied this test to energy-using durables, comparing demand response to potentially misperceived future energy costs versus upfront purchase costs (Busse et al., 2013; Allcott and Wozny, 2014; Dubin and McFadden, 1984; Goldberg, 1998; Grigolon et al., 2018; Houde and Spurlock, 2015; Hausman, 1979).

The evidence in the literature on consumer inattention in energy-using durables has been mixed. Consistent with my findings, recent work in car markets suggests that consumers are relatively attentive to future fuel costs. Estimates of implied discount rates for automobile purchases range between 5 percent and 15 percent (Busse et al., 2013; Allcott and Wozny, 2014; Sallee et al., 2016; Grigolon et al., 2018). However, evidence on consumer attention has been varied in the context of appliances. Early work using a discrete choice framework found that consumers substantially discount future energy costs (e.g., Hausman, 1979; Dubin and McFadden, 1984). Rapson (2014), on the other hand, developed a structural model of air-conditioner demand and found that consumers value the stream of future savings from high efficiency units. Houde (2014) found that consumers are highly heterogeneous in how they value future energy prices in the context of refrigerators.

The finding that home buyers are paying attention to fuel prices and how those price movements translate into a stream of future cost differences suggests that fuel costs are well-understood and salient at the point of sale. This has important implications for carbon policy since an increasing proportion of U.S. carbon dioxide emissions come from the residential and commercial buildings sector. Because home buyers appear to be informed about and paying attention to fuel prices, pollution pricing will create incentives to reduce the amount of energy people choose to consume and to convert to cleaner heating fuels. Pollution pricing will also create incentives to increase the efficiency of building shells and appliances. Though, there may be a place for other corrective policies such as information campaigns and standards if home buyers are not as attentive to all other aspects of home energy costs as they are to fuel type and fuel price.

This paper proceeds as follows. Section 2 describes the data, Section 3 details the empirical framework, Section 4 describes the results for the capitalization of energy costs into housing transaction prices, and Section 5 concludes.

2 Data

2.1 Housing Transaction and Characteristic Data

The real estate data firm, CoreLogic, provided the housing transaction and unit characteristic data with over 1,000,000 transactions in the state of Massachusetts between 1990 and 2011. The unit characteristic data contain information on the number of bedrooms, bathrooms, stories, square feet, year built, exterior wall type, heating fuel, and heating system type. The unit characteristic data and the transaction data were compiled by CoreLogic from different sources. As a result, the unit characteristic data provide one snapshot of a home and do not necessarily reflect the attributes at the point of sale. I carefully address this potential for measurement error in the empirical analysis.

Housing units were designated to be in one of 491 geographic units in order to protect the proprietary nature of the data. Each geographic unit is made up of 3-41 census block groups, with a mean size of 10 census block groups. The criteria used to group census block groups into geographic areas were (1) to allow no fewer than 10 sales within a geographic area in a year and (2) not to let the geographic areas cross natural gas utility or county boundaries. The larger geographic areas are less densely populated with fewer transactions.

I drop observations if a unit is sold more than once in a year, or more than 4 times over the 21 year sample period, indicating special circumstances such as foreclosure (about 13 percent of observations). In property records, the "effective age" of a building is adjusted for significant renovations or neglect. Over 99 percent of adjustments to property age in the sample were for improvements, so that the "effective year built" is later than the actual year built. I drop another 8 percent of the remaining sample for these types of large renovations or improvements. I use the middle 99 percent of the distribution of non-zero housing transactions, dropping the top and bottom 1/2 percent most extreme values. The remaining data used have 909,434 transactions with 604,807 housing units sold between 1 and 4 times. About 50 percent of the sample heats with oil and 50 percent heats with gas. Over half of the sample (60 percent) were sold only once during the sample period.

Massachusetts was chosen for this study because there is good geographic overlap between oil and gas houses. Figure 1 shows the proportion of oil homes by the geographic units described above. The white areas are Berkshire and Plymouth counties for which no transaction data were available. The darker areas represent geographies where a higher proportion of homes heat with gas. Very few of the geographies have less than 10 percent of homes heating with oil. This means that even where utility natural gas is available, there are still many houses that heat with oil. In western Massachusetts more homes are heated with oil because there is less population density, and in some areas, there is no utility gas available. Figure 2 displays which towns had utility natural gas service as of 2008.

[Figure 1 about here]

[Figure 2 about here]

Table 1 displays the results of t-tests comparing the means of the characteristics of oil and gas homes. Gas homes differ from oil homes in predictable ways. On average, gas homes are slightly younger, larger, and more expensive than oil homes. In addition, gas heating systems are most likely to use forced air, while oil heating systems are most likely to use forced hot water radiators. Figure 3 displays the distribution of the numbers of bedrooms, bathrooms, square feet, and year built for oil versus gas units. Importantly, there is good overlap in the covariates between the two heating types, so there are good counterfactual comparisons in terms of characteristics as well as geographies.

[Table 1 about here]

[Figure 3 about here]

2.2 Fuel Price Data

The natural gas price data are state-level average annual residential retail prices calculated as the consumption weighted average of state-level monthly prices reported by the EIA. The heating oil price data are the average annual New England (PADD 1A) number 2 heating oil residential retail prices calculated as the consumption weighted average of monthly prices reported by EIA. For both types of fuel, the EIA reports average monthly prices for a geographical area, computed by dividing the reported revenue by its associated sales volume. I inflated all prices to 2012 dollars using the consumer price index. I converted both natural gas and heating oil prices into \$/MMBTU in order to make them comparable. Figure 4 displays the price variation in residential natural gas and heating oil prices from 1990 to 2012. The left side of the figure displays the price series for each fuel. In the mid-1990s, heating oil was less expensive than natural gas. But, starting in the mid-2000s, the price of heating oil began to rise, driven by world oil demand. The price of natural gas was rising in the early 2000s, until the use of hydraulic fracturing techniques began to drive prices down after 2006. The right side of Figure 4 shows the price difference (price of oil-price of gas) between the two fuels over the time period. Importantly, the price difference follows a

"U" shape rather than a simple linear trend allowing me to identify the effects of fuel price variation rather than other trending variables on housing prices.

[Figure 4 about here]

3 Empirical Framework

3.1 Capitalization Estimation

My empirical approach to estimate the effect of fuel price movements on housing transaction price uses the following model.

$$H_{jat} = \gamma p_{jat} + \lambda_{at} + \theta_j + \varepsilon_{jat} \tag{1}$$

The transaction price, H_{jat}, for house j in geographic area a in year t is a function of fuel price (p_{jt}), house fixed effects (θ_j), and geographic area by year fixed effects (λ_{at}). The fuel price, p_{jt}, is the annual residential retail fuel price for Massachusetts and varies by whether house j is oil or gas heated.

The vast majority of capitalization studies use a similar approach. The estimation equation, which models a home's price as a function of the characteristics it embodies can be derived from a discrete choice framework (see online Appendix A1), or a hedonic approach following Rosen (1974). Both approaches assume a competitive market where supply is fixed in the short run and consumers maximize utility from buying a home as a function of its attributes, price, and the individual's characteristics, subject to a budget constraint. In the resulting equilibrium, the marginal effect of the attribute of interest reflects consumers' marginal willingness to pay for an attribute.[8]

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[8] Capitalization studies generally ignore search frictions. However, in a search model setting, sellers of oil-heated homes may not only lower housing prices as fuel costs go up, but they may be willing to spend a longer time on the market as well. If search frictions are significant, the marginal effect of fuel price

With two different primary fuel types, I am able to estimate the gradient of equilibrium price function across both fuels in the same housing market. The geographic area by year fixed effects control for shocks common to all houses in a given geographic area in a given year, which allows me to separate the effect of fuel price movements on housing prices from the effect of trends in other macroeconomic variables. The house specific fixed effects control for any intrinsic differences in quality between oil and gas homes and other time invariant characteristics.

I use one statewide average price for each of these fuels, since more localized price variation may introduce endogeneity if, for instance, utility rates change coincident with some other local market factor affecting housing price. In my model, the coefficient γ, is the effect of a \$1/MMBTU heating fuel price increase on the housing transaction price. As the relative fuel price of a home increases, it should sell at a discount compared to homes with less-expensive fuel. If home buyers correctly perceive future fuel costs, this discount should reflect the change in NPV of fuel costs caused by a \$1/MMBTU heating fuel price increase.

Since there is no cross-sectional variation in fuel price, one fuel price is collinear with year fixed effects, so that the identifying variation is the difference between the price of oil and the price of natural gas from year to year. The identifying assumption for this approach is that oil and gas houses do not systematically differ in an unobservable or inadequately controlled for way that is correlated with the difference in fuel price.[9]

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movements on housing prices may not reflect the full change in willingness to pay. In my setting, this could bias my analysis away from finding "full capitalization" of fuel price movements and toward finding consumer inattention (Williams, 1995; Krainer, 2001; Zahirovic-Herbert and Turnbull, 2008).

[9] Another, equivalent way to set up the estimation would be to regress sale price on the price difference between oil and natural gas interacted with indicators for the type of fuel used to heat the house:

$$H_{jat} = \beta_0 + \beta_1 \mathrm{I}^{\mathrm{oil}}_{jat} \times (p^{\mathrm{oil}}_t - p^{\mathrm{gas}}_t) + \beta_2 \mathrm{I}^{\mathrm{gas}}_{jat} \times (p^{\mathrm{oil}}_t - p^{\mathrm{gas}}_t) + \lambda_{at} + \theta_j + \epsilon_{jat}$$

β_2 drops out of the estimation, since it is collinear with year fixed effects. The estimate of β_1 is equivalent to that in Equation 1. I derive the equivalence of these two approaches in online Appendix A2

3.2 Empirical Test of Inattention

If home buyers are not valuing energy costs, they will pay more for a home with expensive fuel than they would have liked to if they were fully considering the consequences of their decision. This "mistake" might arise through several potential behavioral mechanisms such as costly information acquisition, biased beliefs, present bias (Laibson, 1997) or bias toward concentration (Koszegi and Szeidl, 2013).[10] It could be that a share of the population is attentive to energy costs and a share of the population is exogenously inattentive, as in Chetty et al. (2009). Or consumers may have rational inattention, where they are more likely to pay attention to attributes that are likely to be pivotal to their product choice (Gabaix, 2014; Sallee, 2014). Each of these mechanisms create bias in consumer perception of energy costs or "inattention" to energy costs, which would lead to under-capitalization of fuel price movements (Allcott, 2016).

While it is not possible to identify which behavioral factor is driving bias in this context, quantifying the size of the marginal bias can be valuable for policymakers. Allcott and Taubinsky (2015); Allcott et al. (2014) and Mullainathan et al. (2012) have shown that policymakers can improve welfare by offsetting a wide range of potential biases, with an optimal subsidy set equal to the marginal bias.

The empirical test of inattention in this paper asks how home buyers tradeoff purchase price with energy costs. Absent any bias, consumers would be indifferent between an additional dollar of purchase price and an additional present discounted dollar of energy expenditure and fuel price movements should be fully capitalized.

One of the primary challenges of this type of exercise in the context of energy-using durables is that we do not observe the NPV of future fuel costs nor its underlying parameters directly. The NPV of the stream of expected future fuel payments, F_{jat} for house j in geographic area a in year t, is a function of the relevant time horizon (T), the discount factor

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[10] In a model with bias toward concentration, consumers underweight future cash flows that accrue in small increments over time, such as energy bill savings.

(δ^i), the expected future fuel prices (p_{jai}), and expected future energy consumption (e_{jai}), where i indexes future years as follows.

$$F_{jat} = \sum_{i=t}^{T} \delta^i p_{jai} e_{jai} \tag{2}$$

If fuel price changes are fully capitalized, the coefficient, γ, should be equal to the change in the NPV of future fuel costs due to a change in fuel price, $\frac{\partial F_{jt}}{\partial p_{jt}}$. Given assumptions about the parameters in F_{jat}, it is straightforward to use the estimate of γ to calculate implied discount rates and a measure of the bias, or proportion capitalized.[11]

The implied discount rate is the discount rate that consumers would have to use for the proportion capitalized to be equal to 1 as shown in equation 3. Given an additional assumption about the "correct" discount rate, the proportion capitalized is the ratio of the coefficient, γ and the change in F_{jat} caused by a change in fuel price, or the right-hand side of equation 3.

$$1 = \frac{\gamma}{\frac{\partial F_{jt}}{\partial p_{jt}}} \tag{3}$$

In what follows, I describe my approach for estimating the change in F_{jat} caused by a \$1/MMBTU heating fuel price increase.

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[11] Some researchers have used a two stage approach to estimate biased perception of energy costs: first calculating F_{jat} by making assumptions about its underlying parameters, then estimating the marginal effect of F_{jat} on sales price (e.g., Allcott and Wozny, 2014; Sallee et al., 2016; Grigolon et al., 2018). While this has an advantage of interpretation, there are disadvantages in my setting. I do not observe billing data for each house and estimating F_{jat} as a function of house characteristics as a first stage without house fixed effects or geographic area by time fixed effects will introduce bias in the second stage. I discuss this in more detail and provide results from a model using the 2 stage approach with limited fixed effects in online Appendix A3.

3.2.1 Time Horizon

Houses are long-lived assets with some houses in the sample being over 300 years old. Because the assets are so long-lived, the correct time horizon to consider for the flow of future energy costs, F_{jat}, could potentially be infinite. For this analysis, I provide estimates based on an infinite time horizon, which is a conservative benchmark. If consumers were truly considering a shorter time horizon, assuming an infinite time horizon would lead to higher estimates of implied discount rates, and bias my analysis toward finding consumer inattention.

3.2.2 Beliefs about Future Fuel Prices

For my main specifications, I assume that consumers believe that annual fuel prices follow a no-change forecast, so that contemporaneous annual fuel prices are the best predictor of future annual fuel prices. A recent study by Anderson et al. (2013) finds that consumers believe that gasoline prices follow this type of pattern. In the case of heating oil, a no-change forecast predicts future crude oil prices as well as or better than forecasts derived from futures markets or surveyed experts (Alquist and Kilian, 2010; Alquist et al., 2012).

Another possibility is that consumers use information from crude oil and natural gas futures markets to make projections about fuel prices going forward. Figure 5 shows the spot and forward curves for crude oil (panel A) and natural gas (panel B). The natural gas forward curves reflect seasonality in prices, whereas the crude oil forward curves are much smoother. Panel C of Figure 5 shows the difference in the spot and forward prices between the two fuels (price of oil - price of gas).

One thing to note about the relationship between the spot and future curves of these two fuels is that the forward curves do not deviate substantially from spot prices. Therefore, even if home buyers were and paying attention to trends in futures prices, their beliefs about fuel prices going forward would not differ significantly from no-change beliefs.[12]

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[12] I test this assertion more rigorously by using the discount-factor weighted average futures price rather than contemporaneous price for the analysis. I discuss the estimation procedure and provide results in online Appendix A4.

[Figure 5 about here]

3.2.3 Future Energy Consumption

If consumers believe that 1) future consumption will be a function of future fuel prices and 2) the best predictor of future fuel prices are today's fuel prices, then it is reasonable for them to believe that future consumption will be similar to today's consumption. I approximate the change in expenditure for a \$1/MMBTU change in fuel price at \$92 using the mean household consumption value for oil and gas-heated homes in the northeast census region, 94 MMBTU per year, and a price elasticity -.3 to changes in average price.[13] In what follows, I examine the sensitivity of capitalization rates to both a 10 percent higher and a 10 percent lower change in expenditure for a \$1 change in fuel price.

3.2.4 Full Capitalization

This paper tests for inattention by asking whether home buyers optimally tradeoff purchase price with energy costs. Therefore, the relevant benchmark for implied discount rate estimates is a consumer's private discount rate.[14] Most home buyers use a loan to buy their home, meaning their private discount rate, or the rate at which a home's purchase price is amortized over future years is best reflected by the mortgage interest rate. The real mortgage interest rates ranged from 1-6 percent over the sample period, with a sales-weighted average across all years of 4 percent.[15]

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[13] The usage information comes from the Residential Energy Consumption Survey: Table CE2.2 "Household Site Fuel Consumption in the Northeast Region, Totals and Averages, 2009." Residential energy consumption is relatively inelastic and -.3 is in line with recent empirical estimates of natural gas elasticity, (Auffhammer and Rubin, 2018). There is strong evidence that consumers are more responsive to average rather than marginal changes in utility prices (Ito, 2014). I assume a locally linear demand curve and the mean fuel price in the sample, \$14.67/MMBTU, to calculate the change in consumption due to a \$1 change in price.

[14] An alternative benchmark would be the social discount rate, which policymakers use to optimally calculate the present value of policies, taking into account the cost and benefits for future generations. Even if consumers are "fully attentive" (in terms of making privately-optimal decisions), they may still "under-react" according to the social discount rate benchmark.

[15] The real interest rate is estimated by subtracting the annual inflation rate from the nominal interest rate. Inflation measure is derived from the consumer price index. Nominal mortgage interest rate data come from Freddie Mac.

Figure 6 shows the NPV of the difference in expenditure due to the fuel price difference for each year in the sample. I assume an infinite time horizon, a no-change expectation for future energy prices, \$92 as the change in annual energy expenditure caused by a \$1/MMBTU change in heating fuel price as described above. The figure displays the NPV of the difference in expenditure for a discount rate of 4 percent, the average real mortgage interest rate, and discount rates of 7 percent and 10 percent, in the range of recent estimates of implied discount rates for car markets. The difference in expected future fuel expenditure for a 4 percent discount rate ranges between $-\$10,000$ and \$32,000, close to 10 percent of the mean sales price of \$332,000.

[Figure 6 about here]

If the price of oil gets high enough compared to natural gas, it could be the case that the net present value of fuel expenditure difference between heating with oil and heating with natural gas exceeds the typical cost of conversion. In that case, economic theory would predict that the housing transaction price differential would not exceed the cost of conversion. The cost of converting from oil to gas can vary widely from a few thousand dollars to over \$10,000 (Notte, 2012). The cost of conversion depends on several factors including the system you choose to install, whether or not you have an underground oil tank that needs to be removed, and the cost of connecting to the main supply line. Conversion can be much more costly in areas that do not have access to the main supply line for natural gas. In many cases, utilities will extend the supply line only if residents are willing to pay for it.

If the conversion cost ceiling were a large biasing factor in this analysis, the cost of conversion would act as a limit on the level of pass-through of the expenditure differential, particularly in later years when the fuel price difference is large. As I show in the results section, this does not appear to a major concern, since later years have similar implied discount rates to earlier years.

4 Results

4.1 Basic Specification

In this section, I estimate the effect of relative fuel price shifts on relative transaction price and calculate the implied discount rates from the estimates. Table 2 displays the results from the estimation of the preferred specification, including house fixed effects and geographic area by time fixed effects as in Equation 1 (column 5) as well as several models with less flexible controls (columns 1-4). The first two columns show estimates for a model that includes year fixed effects with and without housing attribute controls. Housing attribute controls include flexible controls for decade built, number of stories, number of bedrooms, number of bathrooms, exterior wall type, heating system type, and square footage binned for every 500 square feet for unit i. The estimates in columns 3-4 come from models with geographic area by year fixed effects and housing unit fixed effects respectively. Robust standard errors are two-way clustered at the house and geographic area by year levels to account for both autocorrelation between sales and correlation due to geographic area-specific shocks.

[Table 2 about here]

The results indicate that home buyers are not inattentive to energy costs. When the relative cost of heating goes up by $1/MMBTU, it leads to a $1000-$1200 discount in relative housing transaction price. The last row of the table shows the implied discount rate for the coefficient estimate, assuming a increase in annual energy expenditure of $92 per $1/MMBTU increase in fuel price over an infinite time horizon. The results imply that home buyers use a 8-10 percent discount rate, which suggests that they do not strongly under-value future heating fuel costs when purchasing houses. These results are consistent with recent work on automobile purchases that also find no evidence of strong undervaluation, with implied discount rates ranging between 5 percent and 15 percent (Busse et al., 2013; Allcott and

Wozny, 2014; Sallee et al., 2016; Grigolon et al., 2018).[16]

Figure 7 displays the relationship between the housing transaction price difference for oil versus gas homes and the the net present value of the difference in annual expenditure from heating with gas as opposed to oil. The left side of Figure 7 plots this relationship over the sample period. I estimate the NPV of the difference in fuel expenditure between heating with oil and gas over an infinite horizon using the estimate of a change in annual expenditure of \$92 per \$1 difference in relative fuel price and a 9.5 percent discount rate from the preferred estimation in Table 2. In addition, I depict the housing transaction price difference between gas and oil homes from the preferred specification with geographic area by year fixed effects and unit fixed effects by plotting coefficients on the year-specific gas intercepts ($\beta_1 - \beta_{22}$) from the following regression.[17]

$$\mathrm{H}_{jat} = \textstyle\sum_{t=1}^{22} \beta_t \mathrm{I}_{ja}^{\mathrm{gas}} + \lambda_{at} + \theta_j + \epsilon_{jat} \tag{4}$$

The housing transaction price H_{jat} for house j in geographic area a in year t is regressed on house fixed effects, θ_j, geographic area by time fixed effects, λ_{at}, and year-specific gas intercept terms where $\mathrm{I}_{ja}^{\mathrm{gas}}$ indicates the home heats with gas and ϵ_{jat} is the idiosyncratic error term. In the left side of Figure 7, the variation in housing price difference tracks the NPV of the difference in expenditure closely over the sample period. Importantly, the housing transaction price difference follows the the fuel price difference down in early years as well as up in the later years. This means the results are not being driven by differential trends between oil and gas houses in the later years that coincide with the housing crisis. As I

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[16] The estimation procedure does not appear to be sensitive to the particular energy usage assumptions nor the use of contemporaneous rather than futures prices. In online Appendix A3 I estimate a two-stage procedure, first predicting usage based on housing characteristics, then estimating capitalization rates, with a limited set of fixed effects. The implied discount rate estimate is quite close, 10 percent, suggesting that the results using a single estimated annual usage are a good approximation of the implied discount rate for the average home in the sample. In online Appendix A4, I show that the futures prices are close enough to spot prices that estimates using a discount-factor weighted average of futures prices rather than contemporaneous prices yield the same implied discount rate as the preferred specification (9.5 percent).

[17] The value of the coefficient for the omitted reference year (1990) is set to the NPV of the fuel expenditure difference in that year, \$2823 rather than \$0, in order to make the two lines comparable.

show in online Appendix A5, the results from a sub-sample of pre-crisis years (1990-2007) are quite close to to those reported in Table 2.

The right side of Figure 7 plots the fuel price difference against the corresponding NPV of the difference in fuel expenditure for each year in the sample. If the housing transaction price difference was precisely the estimated NPV of the difference in fuel expenditure, each dot would fall on the 45 degree line. The fitted line through the scatter plot shows that the NPV estimate of the fuel expenditure difference using a 9.5 percent discount rate is a close fit for the housing transaction price difference.

[Figure 7 about here]

4.2 Robustness Tests

One potential worry with this approach is that the pattern in relative housing transaction prices is caused by a differential trend in homes with a particular heating fuel rather than by the relative fuel price variation. For example, since oil homes are older on average, the results might be explained by the declining value of a vintage over time. In other words, when oil is getting most expensive relative to natural gas in later years, oil homes are also getting older on average compared to natural gas homes. This trend in age difference might partially explain some of the observed discount for oil homes compared to natural gas homes.

Table 3 displays results for two additional controls for addressing the potential for differential trends in particular types of homes. Column 1 replicates the results from the preferred specification from Table 1 for reference. In column 2, I include an oil-heat linear trend. If my results were the result of a differential trend in homes that heat with oil rather than fuel price variation, the inclusion of the trend would substantially change the estimates. Second, for the estimates in column 3, I flexibly control for the age of the home with age fixed effects where age is defined by the sales year minus year built. Age fixed effects allow me to control flexibly for trends in value of houses as they age. While the estimates do not change substantially with these controls, they are somewhat attenuated. This suggests that homes aging over time or a trend in prices for oil homes may drive some of the observed variation. The attenuation may also be driven in part by measurement error in the heating fuel type, which I explore further in the next section.

One potential issue with using the Massachusetts residential retail price for the natural gas price measure is that some of the variation maybe driven by local demand variation rather than shocks to supply. Gas supplies to the northeastern U.S. can become constrained in the winter, which may introduce some endogeneity to the fuel price measure. In order to address this issue, I instrument for Massachusetts natural gas residential retail prices with the national wellhead natural gas price in each year. Columns 4-6 show the results of the two-stage least squares estimates. Column 4 shows results for the preferred specification, and columns 5 and 6 display results including an oil-specific linear time trend and both the oil-specific linear time trend and age fixed effects. The fuel price coefficient does not significantly change when instrumenting for the retail natural gas price with the national wellhead price. The two natural gas price measures are highly correlated, suggesting that the identifying variation is driven mostly by exogenous supply side shocks to price.

[Table 3 about here]

4.3 Addressing Measurement Error

Another potential concern with my approach is the measurement error introduced by the housing unit characteristic data. As is the case with most real estate transaction data, the unit characteristic data provide only a single snap shot of a house's attributes even though the transaction data span over 20 years. Therefore, there is a potential for measurement error in the characteristics at the point of sale. Measurement error, particularly in the heating fuel, could potentially bias the estimates.

If the measurement error were classical, it would attenuate the estimates toward zero and make it more likely to find evidence consistent with undervaluation of energy costs. However, in this context it is likely that the measurement error is non-classical. The more recent housing transactions are more likely than earlier transactions to have the correct housing characteristics. In later years as the price of oil increases compared to natural gas, a significant number of homes may have converted from oil to gas.[18]. This has the potential to bias the estimates toward finding high levels of capitalization and away from finding consumer inattention. The intuition is that in early years, when there is more likely to be measurement error, the estimate of the mean difference in housing transaction prices is more likely to be attenuated, while in later years, the difference in housing transaction price is likely to be more precise. Since the biggest change in fuel prices is in later years, some of the difference in housing transaction price attributed to change in fuel price may be driven instead by the increasing precision of the estimates.

Another source of potential bias stems from the fact that homeowners may be improving other aspects of the home that are unobserved in the data when they are changing heating fuel. For example they may choose to put in new flooring or new kitchen appliances such as a gas stove. Then houses may have an unobservably higher quality after they convert than before. If conversions are correlated with the price difference and are accompanied by other major renovations, it will exacerbate the non-classical measurement error problem, biasing the estimates away from zero, making it more likely to find evidence of capitalization.[19]

In order to address this issue and the issue of non-classical measurement error while controlling for trends in oil and vintage, I consider an instrumental variables approach, creating an instrument for heating fuel. I exploit temporal variation in the fuel type of new construction in order to isolate variation in fuel choice that is exogenous to the fuel price difference. Figure 8 displays the proportion of homes in the sample built with oil for each vintage year from 1900 to 2011. It is clear that there is variation in fuel choice that is

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[18] Using panel data on the housing characteristics of homes in the northeast census region from the American Housing Survey, I estimate that around 11 percent of homes converted from oil to gas heat from 1987 to 2011. I describe the data and method for this calculation in online Appendix A6.

[19] As stated in the data section, in the initial data construction, I did remove any houses that appear to have had major upgrades, possibly reducing the prevalence of homes with major endogenous upgrades. However the instrumental variables approach addresses potential bias arising from their presence in the sample.

separable from a linear trend in vintage. Figure 8 depicts several clear breaks in the data, which are associated with policy changes that are exogenous to the local housing market.

[Figure 8 about here]

In late 1953, piped natural gas began to be delivered to New England. Prior to 1953, the region almost exclusively used manufactured gas (Castaneda, 1993). There is a sharp kink in the proportion of homes built with oil starting in 1953. After 1953, more and more homes are built with gas until about 1974. The price control policy lead to shortages in supply in the mid-1970's. The way that many utilities dealt with these shortages was to restrict access to new customers rather than by rationing existing consumers (Davis and Kilian, 2011). Between 1974 and 1978, there was an increase in homes built with oil due to supply shortages of natural gas. In 1978, wellhead price controls were lifted, which increased natural gas supply, and the proportion of homes built with oil dropped. Since then, natural gas has been getting more common with the exception of a brief increase in homes built with oil in the mid-1980's following the crude oil price collapse of 1986.

Using this variation, the instrument for price is the proportion of homes built with oil in the year a particular house was built times the oil price in the year it was sold plus the proportion of homes built with gas in the year a particular house was built times the gas price in the year it was sold. Using this instrument, the local average treatment effect will come from a comparison of vintages when gas was more or less readily available. I include an oil specific trend and flexibly control for the age of the house.[20]

The results from this estimation are displayed in Table 4. The first column shows the results of the first stage estimation. The coefficient on the instrument is close to one since on average, the instrument closely predicts fuel price. Column 2 shows the results of the two-

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[20] As with the basic specification, an equivalent approach would be to estimate

$$H_{jat} = \beta_0 + \beta_1 \mathrm{I}^{\mathrm{oil}}_{jat} \times (p^{\mathrm{oil}}_t - p^{\mathrm{gas}}_t) + \lambda_{at} + \theta_j + \epsilon_{jat}$$

where the proportion of homes built with oil in the year a particular house was built times the price difference between oil and gas is the instrument for oil times the price difference between oil and natural gas.

staged least squares estimation. The point estimate of the price coefficient using two-staged least squares is much larger than that using OLS. This suggests that the measurement error, even though it is non-classical, may have served to attenuate rather than bias the estimates upward. The implied discount rate for the two-staged least squared estimate is around 3.5 percent, close to recent mortgage interest rates. Though, the discount rates implied by the 95 percent confidence interval (2.1-11.6 percent) do not rule out values as high as those suggested by the OLS estimation.

[Table 4 about here]

4.3.1 Sensitivity Analysis

Table 5 shows the capitalization rate, or the proportion of the NPV of the fuel price difference over an infinite time horizon that is capitalized into the value of the home. As a baseline estimate of capitalization, I use the annual sales-weighted mean mortgage interest rate for the time period, 4 percent, as a discount rate and \$92 as the change in annual energy expenditure caused by a \$1/MMBTU change in heating fuel price. Using the coefficient on fuel price from the 2SLS estimation in Table 4, the capitalization rate is 1.04, close to 1, under these assumptions. I explore the sensitivity of the capitalization rate to discount rates of 2, 3 and 5 percent as well as a 10 percent increase or decrease in my estimate of changes in annual expenditure. Since capitalization rates can be sensitive to assumptions about the underlying parameters, it is difficult to explicitly test the hypothesis of full capitalization. While the baseline capitalization estimate is close to 1, a single percentage point change in the discount rate or a 10 percent change in the annual energy expenditure can move the capitalization rate by as much as 20 percent. However, it is clear that home buyers are responding to future fuel costs. A significant proportion of the net present value of future energy costs is capitalized under a wide range of assumptions about consumption and discount rates.

[Table 5 about here]

4.3.2 Placebo Test

The reduced form of the IV regression compares the relative housing prices for vintages with a high proportion of oil-heated homes to vintages with a low proportion of oil-heated homes as oil prices move relative to gas prices, controlling for age fixed effects, house fixed effects and geographic area by time fixed effects. The exclusion restriction therefore requires that, conditional on the controls, the only way the proportion of oil built in a particular year affects housing price is through fuel price. In what follows, I perform a placebo test to probe the validity of this assumption.

I remove gas-heated homes from the sample and perform the IV estimate on just oil-heated homes. I define oil homes built in years where more than half of homes built were oil-heated as “placebo oil” and oil homes built in years where fewer than half of homes built were oil-heated as “placebo gas” The reduced form is exactly the same as before, the only difference being gas homes have been removed. If the exclusion restriction did not hold and other unobserved or inadequately controlled for characteristics about vintages with a high/low proportion oil heating were driving the results, then the placebo test should yield negative and significant results as in Table 4.

Table 6 displays the results from this placebo test. The point estimate is more than an order of magnitude lower and is statistically indistinguishable from zero. This suggests that the exclusion restriction holds, and the capitalization rates in Table 4 are driven by fuel price variation and not by unobservable or inadequately controlled for trends in vintage.

[Table 6 about here]

5 Conclusion

This paper explores how shifts in energy costs affect housing transaction prices to see if home buyers are inattentive to energy costs. I use changes in natural gas and heating oil prices over time to isolate exogenous variation in home energy costs. I use housing transaction data from Massachusetts, where roughly an equal number of homes heat with oil as heat with natural gas. This allows me to estimate the effect of a change in relative energy costs on a change in relative housing prices, while controlling for changes in the macroeconomic environment and in the value of different housing characteristics over time.

I find that home buyers are relatively attentive to future fuel costs and can strongly reject that they are unresponsive. My results show that a large proportion of the present value of fuel expenditures is capitalized into housing prices under a wide range of assumptions about energy usage and discount rates. In my preferred specification, I cannot reject full capitalization of future fuel costs under a 3.5 percent discount rate, which is consistent with real mortgage interest rates during the sample period. Home buyers are paying attention to shifts in relative fuel prices and are aware of how changes in fuel prices translate into changes in the net present value of the future stream of payments. My findings suggest that since home buyers are attentive to and informed about fuel prices, market-based pollution policies such as taxes and cap-and-trade programs will create incentives not only to reduce the amount of energy people choose to consume, but to convert to cleaner heating fuels, and possibly increase the efficiency of building shells and appliances as well.

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Tables

Table 1: Covariate Comparison Between Fuel Type

	Gas	Oil	P-value of Diff
Sale Price	$342,104	$322,718	0.00
Number of Bedrooms	3.11	3.19	0.00
Number of Bathrooms	2.36	2.20	0.00
Number of Stories	1.78	1.73	0.00
Square Feet	1912.90	1889.70	0.00
Year Built	1956.59	1947.94	0.00
Exterior Wall Type			
Wood	45%	46%	
Vinyl	32%	33%	
Aluminum	11%	12%	
Other	13%	9%	
Heat Type			
Forced Air	50%	26%	
Forced Hot Water	38%	60%	
Steam	8%	13%	
Other	3%	1%	
Observations	303,802	301,005	

Characteristic and transaction data are from CoreLogic for the state of Massachusetts (1990-2011). All prices are inflated to 2012 dollars.

Table 2: Estimation of the Effect of Relative Fuel Prices on Relative Transaction Prices

	Sales Price	Sales Price	Sales Price	Sales Price	Sales Price
Fuel Price	-1186.4	-1002.4	-1122.1	-1074.7	-1064.7
	(198.8)	(242.6)	(115.1)	(167.1)	(131.7)
Oil Heat Indicator	-15334.4	-8165.6	1311.1		
	(1066.5)	(1157.8)	(978.3)		
Year FE	Yes	Yes	No	Yes	No
Attribute Controls	No	Yes	Yes	No	No
Geographic Area × Year FE	No	No	Yes	No	Yes
Unit FE	No	No	No	Yes	Yes
Observations	909434	870567	870504	529156	529008
R^2	0.0854	0.461	0.675	0.860	0.884
Implied Discount Rate Infinite Horizon	8.4%	9.1%	8.6%	9.4%	9.5%

Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic, years 1990-2011. Price is the average annual residential retail fuel price for oil or natural gas in dollars per MMBTU. All prices are inflated to 2012 dollars. Standard errors are two-way clustered at the house and geographic unit by year level and are in parentheses.

Table 3: Estimation of the Effect of Relative Fuel Price on Relative Transaction Price: Robustness Checks

	Sales Price (OLS)	Sales Price (OLS)	Sales Price (OLS)	Sales Price (2SLS)	Sales Price (2SLS)	Sales Price (2SLS)
Fuel Price	-1064.7	-793.5	-701.1	-1113.7	-851.8	-771.3
	(131.7)	(184.8)	(155.1)	(141.1)	(199.3)	(166.7)
Geographic Area × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Unit FE	Yes	Yes	Yes	Yes	Yes	Yes
Oil Linear Trend	No	Yes	Yes	No	Yes	Yes
Age FE	No	No	Yes	No	No	Yes
Observations	529008	529008	528642	529008	529008	528642
Implied Discount Rate Infinite Horizon	9.5%	13.1%	15.1%	9.0%	12.1%	13.5%

Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic years 1990-2011. Price is the average annual residential retail fuel price for oil or natural gas in dollars per MMBTU. The instrument for natural gas price is the U.S. natural gas wellhead price as reported by the EIA. All prices are inflated to 2012 dollars. Standard errors are two-way clustered at the house and geographic unit by year level and are in parentheses.

Table 4: IV Estimation of the Effect of Relative Fuel Price on Relative Transaction Price

	First Stage	2SLS
(Dependent Variable)	(Fuel Price)	(Sales Price)
Fuel Price IV	1.092	
	(0.0267)	
Fuel Price		-2730.5
		(940.0)
F-stat	849.0	
R^2	0.886	
Unit FE	Yes	Yes
Geographic Area × Year FE	Yes	Yes
Oil Linear Trend	Yes	Yes
Age FE	Yes	Yes
Observations	528642	528642
Implied Discount Rate Infinite Time Horizon		3.5%

Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic years 1990-2011. Price is the average annual residential retail fuel price for oil or natural gas in dollars per MMBTU. The instrument for price is the proportion of homes built with oil in the year a particular house was built times the oil price in the year it was sold plus the proportion of homes built with gas in the year a particular house was built times the gas price in the year it was sold. All prices are inflated to 2012 dollars. Standard errors are two-way clustered at the house and geographic unit by year level and are in parentheses.

Table 5: Sensitivity of Capitalization Rates to Parameter Estimates

Discount Rate	Average Use	10 Percent more than Average Use	10 Percent less than Average Use
2 percent	0.58	0.53	0.65
3 percent	0.86	0.79	0.96
4 percent	1.14	1.04	1.26
5 percent	1.41	1.28	1.57

I estimate that the change in energy expenditure caused by a $1/MMBTU change in heating fuel price is $92/year. This table shows the capitalization share of the $92 change in annual energy expenditure for an infinite time horizon calculated for discount rates of 2 percent, 3 percent, 4 percent, and 5 percent. In addition, I examine the sensitivity of capitalization share to +/- 10 percent in the $92 change in energy expenditure calculation. I use the coefficient from the 2SLS estimation in Table 4.

Table 6: Placebo IV Estimation of the Effect of Relative Fuel Price on Relative Transaction Price

(Dependent Variable)	First Stage (Placebo Fuel Price)	2SLS (Sales Price)
Fuel Price IV	3.753	
	(0.0185)	
Placebo Fuel Price		-37.96
		(346.0)
F-stat	23454.2	
R^2	0.976	
Unit FE	Yes	Yes
Geographic Area × Year FE	Yes	Yes
Oil Linear Trend	Yes	Yes
Age FE	Yes	Yes
N	247932	247932

Only oil heated homes are included in this regression. A placebo oil indicator is defined as homes built in years where more than 50 percent of homes built are heated with oil. The placebo fuel price is defined as the oil price if the placebo oil indicator is 1 and the gas price otherwise. The instrument for placebo price is the proportion of homes built with oil in the year a particular house was built times the oil price in the year it was sold plus the proportion of homes built with gas in the year a particular house was built times the gas price in the year it was sold. All prices are inflated to 2012 dollars. Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic years 1990-2011. Standard errors are two-way clustered at the house and geographic unit by year level and are in parentheses.

Figures

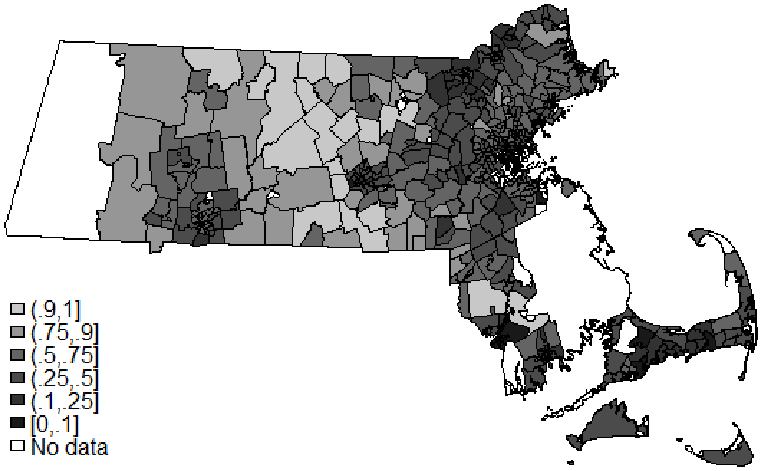


Figure 1: Proportion of Homes Heated With Oil

Notes: Housing characteristic data for the state of Massachusetts are from CoreLogic

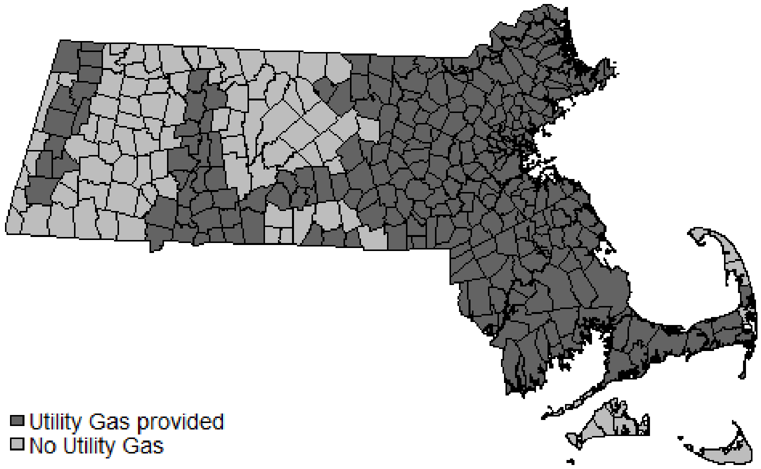


Figure 2: Utility Natural Gas Provision: 2008

Notes: Natural gas utility territory data for the state of Massachusetts are from MassGIS

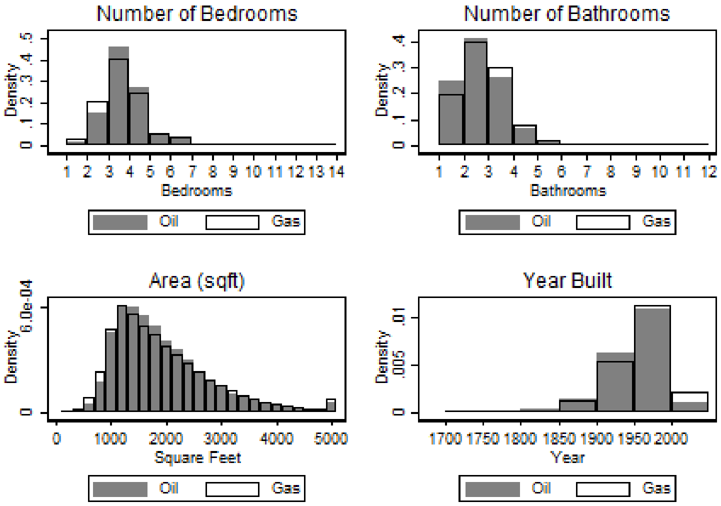


Figure 3: Overlap of Covariates

Notes: Housing characteristic data for the state of Massachusetts are from CoreLogic

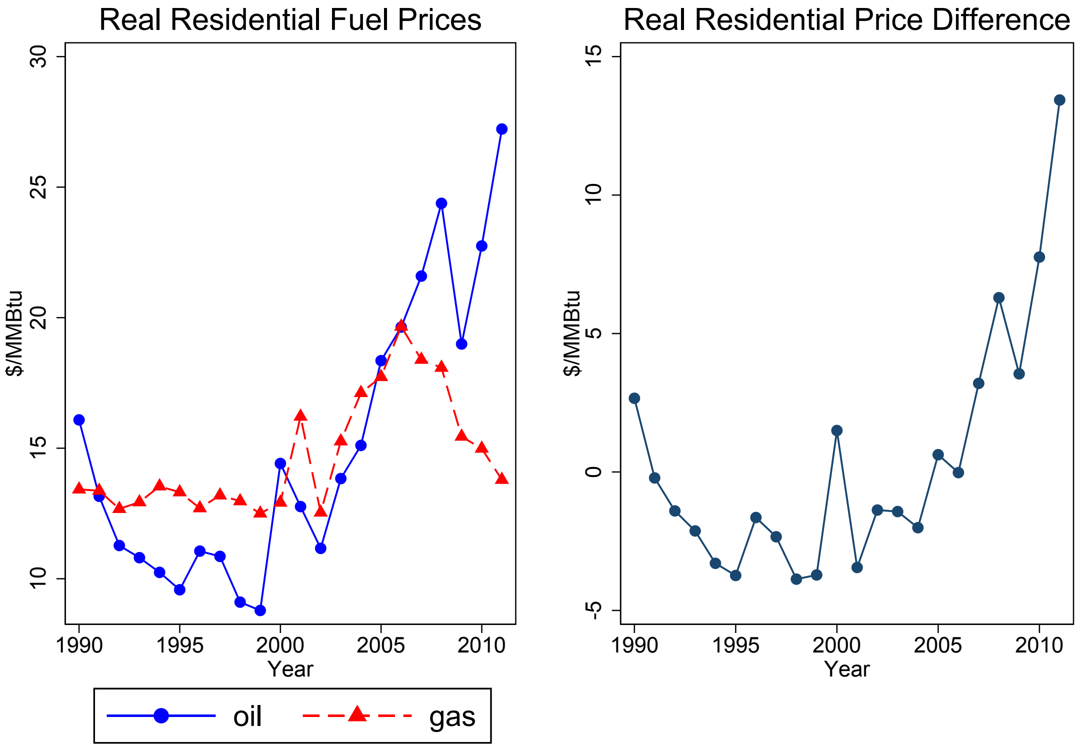
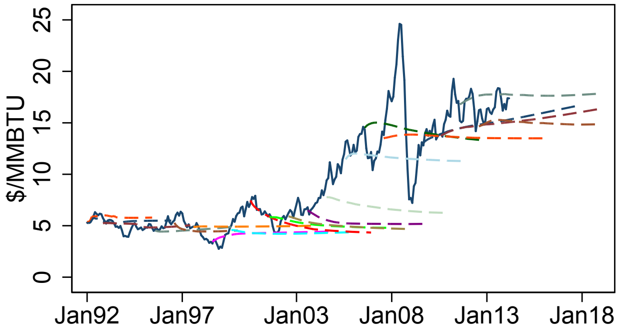


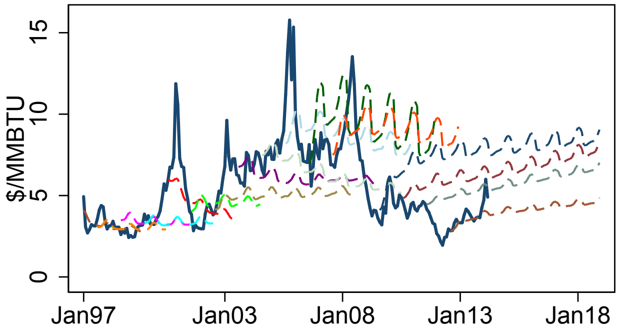
Figure 4: Real Residential Fuel Prices and Difference (2012 USD)

Notes: The prices are average annual retail prices ($/MMBTU) for the state of Massachusetts from EIA. This price difference is the price of oil minus the price of natural gas. All prices are inflated to 2012 dollars.

Panel A: Crude Spot and Futures Prices: 2012 USD



Panel B: Natural Gas Spot and Futures Prices: 2012 USD



Panel C: Difference Between Crude and Natural Gas Spot and Futures Prices: 2012 USD

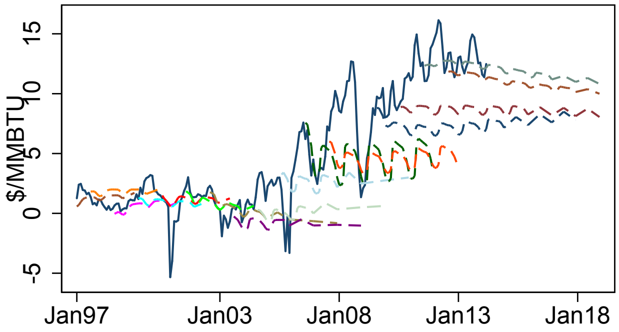


Figure 5: Spot and Futures Prices

Notes: The solid line in Panels A an B are the spot price and the dashed lines are forward curves taken every June. Panel C displays crude spot and futures prices minus natural gas spot and futures prices. All prices are in 2012 dollars. Forward curves are inflated according to the trade date. Source: NYMEX

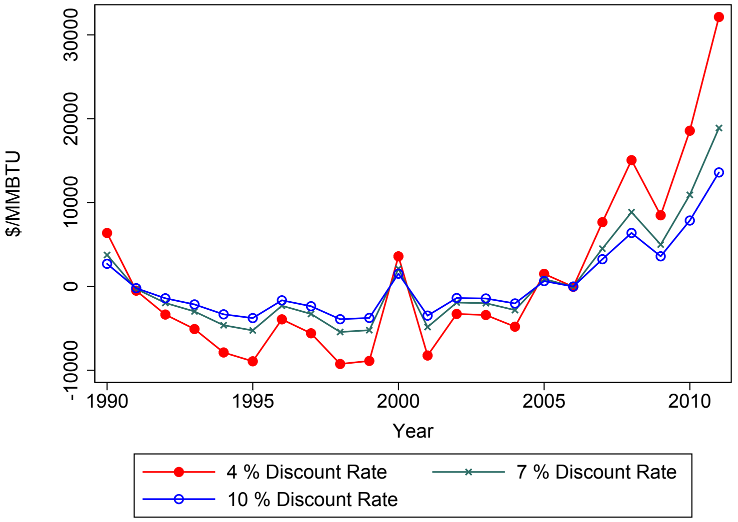


Figure 6: Net Present Value of the Fuel Expenditure Difference For Oil vs. Gas Houses Over Infinite Horizon With 9.5% Discount Rate and the Difference in Housing Transaction Prices

Notes: The graph depicts the difference in the net present value (NPV) of fuel expenditure between oil and gas houses assuming discount rates of 4, 7, and 10%. This assumes an infinite time horizon, no-change expectation of future fuel prices and a change in expenditure of $92 for a $1/MMBTU increase in price.

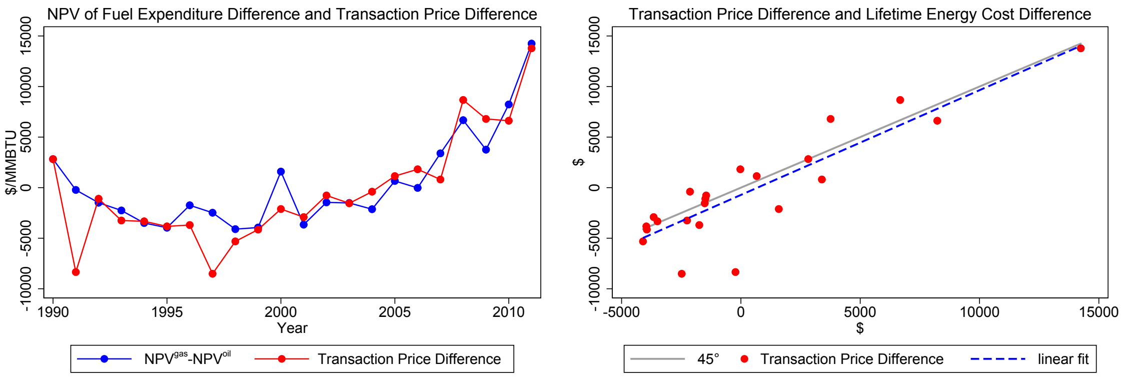


Figure 7: Net Present Value of the Fuel Expenditure Difference For Oil vs. Gas Houses Over Infinite Horizon With 9.5% Discount Rate and the Difference in Housing Transaction Prices

Notes: The graph on the left depicts the difference in the net present value (NPV) of fuel expenditure between oil and gas houses and the mean difference in transaction prices conditional on house and geographic area by time fixed effects. The graph on the right plots each mean difference in transaction prices conditional on house and geographic area by time fixed effects, against the difference in the NPV of fuel expenditure between oil and gas houses for each year. All prices are inflated to 2012 dollars.

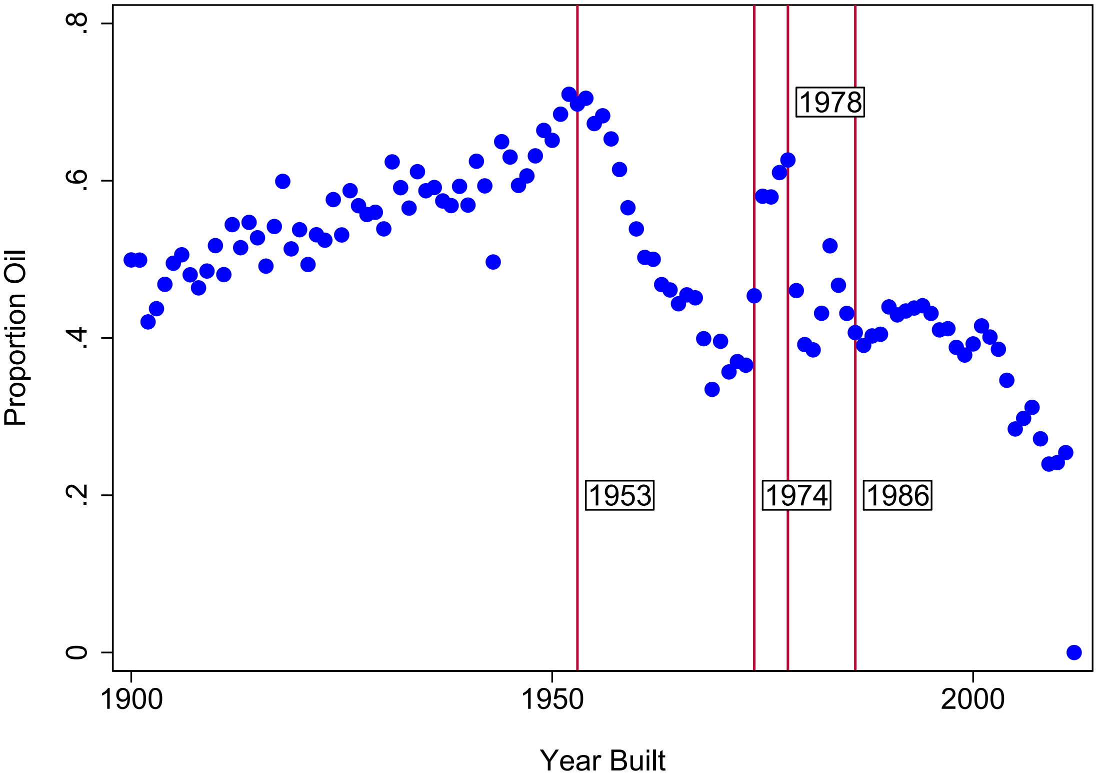


Figure 8: Proportion of Homes Built with Oil by Year Built

Notes: The graph depicts the proportion of homes of built with oil for each vintage year between 1900 and 2011. There are several clear breaks in the data, which are associated with policy changes that are exogenous to the local housing market. Starting in 1953 piped natural was imported into New England for the first time. Between 1974 and 1978, there was an increase in homes built with oil due to supply shortages of natural gas. In 1978, wellhead price controls for gas were lifted, which increased natural gas supply, and the proportion of homes built with oil dropped. Since then, natural gas became more common with the exception of a brief increase in homes built with oil in the mid-1980's following the crude oil price collapse of 1986. The housing transaction price data are provided by CoreLogic for the state of Massachusetts.

Appendix

For Online Publication

A1 Derivation of Estimation Equation

In what follows, I develop a discrete choice framework where home buyer (i) chooses house (j) in geographic area (a) in year (t) from a choice set with budget constraint w_i. The consumer has an outside option of not buying a house with a utility level normalized to zero. Consumer i's indirect utility from the purchase of a home is a function of the cost, which has two components: 1) the transaction price, H_{jat}, and 2) the net present value (NPV) of the expected stream of future fuel payments, F_{jat}. Utility is also a function of observable home attributes, $\mathbf{X}_{jat}$, unobservable home attributes, $\tilde{\xi}_{jat}$, neighborhood-year specific amenities, $\tilde{\lambda}_{at}$, and individual taste ε_{ijat} as follows.

$$U_{ijat} = \eta(w_i - H_{jat} - \gamma F_{jat}) + \mathbf{X}'_{ja}\tilde{\beta} + \tilde{\xi}_{ja} + \tilde{\lambda}_{at} + \varepsilon_{ijat} \tag{A1}$$

The marginal utility of money is represented by η. The implied discount rate is the discount rate that consumers would have to be using for $\gamma = 1$. If the implied discount rate is higher than the borrowing rate for the marginal dollar, then consumers are inattentive energy costs.[21] In other words, demand for homes with high fuel costs is too high relative to what would be optimal.

The choice to sell or buy a home in any given year is driven by exogenous events such as changes in employment or changes in family composition. All potential home buyers in geographic area a in year t have the same income and face the same choice set of homes, where they are trading off the price of a home versus attributes such as square footage or

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[21] The word "inattentive" means that consumers are undervaluing a dollar spent on future energy costs relative to a dollar spent in upfront price. This "mistake" might arise through several potential mechanisms such as imperfect information, biased beliefs, present bias, or bias toward concentration.

number of bedrooms and bathrooms. Assume a traditional representative consumer logit model where ε_{ijat} is distributed i.i.d. extreme value. Integrating over ε_{ijat} and taking the natural log of both sides gives the following relative choice probability as a function of prices and characteristics.

$$\frac{1}{\eta}(ln\phi_{jat} - ln\phi_{0at}) = H_{jat} - \gamma F_{jat} + \mathbf{X}'_{ja}\beta + \xi_{ja} + \lambda_{at} \tag{A2}$$

On the left hand side is the choice probability for a house, ϕ_{jat}, relative to the choice probability of the outside option, ϕ_{0at}. Dividing by η gives the new variables $\mathbf{X}'_{ja}\beta$, ξ_{ja}, and δ_{at}, which can be interpreted as dollar value of the utility represented by $\mathbf{X}'_{ja}\tilde{\beta}$, $\tilde{\xi}_{jt}$, and $\tilde{\delta}_{at}$.

This can be rearranged into an econometric estimating equation of transaction price as a function of fuel costs and a set of fixed effects as follows:

$$H_{jat} = \gamma F_{jat} + \lambda_{at} + \theta_{ja} + \epsilon_{jat} \tag{A3}$$

Variation in the probability of choosing the outside option over time and across space is absorbed by geographic area by year fixed effects λ_{at}, which also control for shocks common to all houses in a given geographic area in a given year. House specific fixed effects (θ_{ja}) control for time invariant observable (X_{ja}) and unobservable characteristics (ξ_{ja}). Since the same house is sold more than once, it is being perceived by different sets of buyers across time periods. The new error term $\epsilon_{jat} = ln\phi_{jat}$ represents the idiosyncratic changes in the preferences for particular house due to the buyers in a particular period, and is uncorrelated with fuel price. This is a similar theoretical approach to that taken in Allcott and Wozny 2014 in the context of car markets, which uses cross-sectional variation in fuel economy interacted with variation over time in gasoline prices to get plausibly exogenous variation in lifetime fuel costs of cars. In this analysis, I use relative fuel price movements of oil and natural gas as a plausibly exogenous instrument for F_{jat}.

A2 Equivalence of Two Estimation Approaches

In what follows I describe the equivalence of two estimation approaches for estimating the difference-in-differences of interest: the difference in housing price between oil and gas heated homes from one year (e.g. high price difference) to the next (e.g. low price difference).

Let α be the individual effects of each fuel price/fuel type combination as follows:

$$\begin{aligned} Outcome_{jat} = \beta_0 + \alpha_1(\mathrm{I}^{\mathrm{oil}}_{jt} \times p^{\mathrm{oil}}_t) + \alpha_2(\mathrm{I}^{\mathrm{oil}}_{jt} \times p^{\mathrm{gas}}_t) + \alpha_3(\mathrm{I}^{\mathrm{gas}}_{jt} \times p^{\mathrm{oil}}_t) + \alpha_4(\mathrm{I}^{\mathrm{gas}}_{jt} \times p^{\mathrm{gas}}_t) \\ + \lambda_{at} + \theta_j + \epsilon_{jat} \end{aligned} \tag{A4}$$

Following the notation in the paper *Outcome*, is the outcome for unit j in geographic area a in year t. The annual fuel price is p with oil and gas indicated with superscripts, "I" indicates the primary heating fuel with oil and gas as superscripts. λ_{at} are geographic area by year fixed effects, θ_j are individual fixed effects, and ϵ_{jat} is the error term.

Factoring out the fuel indicators in Equation A1 yields the following estimation equation:

$$Outcome_{jat} = \beta_0 + \beta_1 \mathrm{I}^{\mathrm{oil}}_{jt} \times (p^{\mathrm{oil}}_t - p^{\mathrm{gas}}_t) + \beta_2 \mathrm{I}^{\mathrm{gas}}_{jt} \times (p^{\mathrm{oil}}_t - p^{\mathrm{gas}}_t) + \lambda_{at} + \theta_j + \epsilon_{jat} \tag{A5}$$

The coefficient β_1 in the following equation estimates difference-in-differences of interest. Since one of these terms, e.g. $\mathrm{I}^{\mathrm{gas}}_{jt} \times (p^{\mathrm{oil}}_t - p^{\mathrm{gas}}_t)$ is collinear with year fixed effects, the estimate of $\beta_1 = (\alpha_1 - \alpha_2) - (\alpha_4 - \alpha_3)$.

The estimation procedure used in the paper yields equivalent results, where this time the terms from Equation A1 are gathered slightly differently:

$$\begin{aligned} Outcome_{jat} = \beta_0 + \beta_1(\mathrm{I}^{\mathrm{oil}}_{jt} \times p^{oil} + \mathrm{I}^{\mathrm{gas}}_{jt} \times p^{gas}) + \beta_2(\mathrm{I}^{\mathrm{gas}}_{jt} \times p^{oil} + \mathrm{I}^{\mathrm{oil}}_{jt} \times p^{gas}) \\ + \lambda_{at} + \theta_j + \epsilon_{jat} \end{aligned} \tag{A6}$$

Again, one term will be collinear with year fixed effects, e.g. $\mathrm{I}^{\mathrm{gas}}_{jt} \times p^{oil} + \mathrm{I}^{\mathrm{oil}}_{jt} \times p^{gas}$. I simplify the first term to p_t since $p_t = \mathrm{I}^{\mathrm{oil}}_{jt} \times p^{oil} + \mathrm{I}^{\mathrm{gas}}_{jt} \times p^{gas}$. β_1 yields and equivalent difference-in-differences, i.e. $\beta_1 = (\alpha_1 - \alpha_4) - (\alpha_3 - \alpha_2)$.

A3 Two Stage Approach

A3.1 Data

I use energy expenditure data from the residential energy consumption survey (RECS) for the two-stage procedure detailed below. RECS is an in-home survey, which provides detailed information on housing unit characteristics as well as energy usage and expenditures by fuel type and end-use. The price and expenditure data are verified with households' residential energy suppliers to ensure their reliability.

The survey is conducted approximately every five years and is designed to be a nationally representative cross-section of U.S. housing units. I use data from 6 surveys performed between 1990 and 2009 in my analysis. I use data from the Northeast Census region to predict energy expenditure as a function of household income controlling for size and other housing characteristics. I limit the sample to owner-occupied, single family houses in the northeast census region–a total of 1545 housing units.

A3.2 Empirical Approach and Results

Since I do not directly observe billing data for each house, estimating the NPV of the stream of future fuel costs, F_{jat}, as a function of house characteristics as a first stage has the potential to introduce bias in the second stage. If the second stage included any variables that affect energy expenditure, and these variables are not included in the first stage, it would introduce mechanical correlation between the first stage residuals and those variables only included in the second stage.[22] This is the same argument as to why the same exogenous covariates need to be included in both the first and second stage in any two stage least squares (2SLS) estimation (Wooldridge, 2010).

For example, residential energy consumption surveys (RECS) provide a repeated cross-section of energy expenditure, energy consumption, heating fuel type, and housing characteristics. However locational information is limited to large areas such as census regions, which are aggregations of several states. Therefore, it is not possible to estimate the first stage with either house fixed effects or geographic area-by-time fixed effects. If the fixed effects are included in the second stage, but not the first stage, they will likely be correlated with the first stage residuals since unobservable factors that affect housing price likely also affect energy consumption. The inconsistency from the correlation can spillover to all coefficient estimates in the second stage. For completeness, in what follows I provide two-stage estimates. However, since it is not possible to control for location-specific trends or unit fixed effects, the interpretation of the estimates will be affected.

I estimate a two sample two-staged least squares (TS2SLS) model, a variant of the two sample instrumental variables (TSIV) procedure discussed in Angrist and Krueger (1992, 1995).[23] This two-sample IV procedure addresses concerns about measurement error in the NPV of fuel expenditure, but the limitation still exists that the only exogenous covariates

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[22] A simulation exercise demonstrating the empirical importance of the bias in this setting can be provided upon request.

[23] Angrist and Krueger (1992) show that consistent instrumental variables estimation is still possible if one sample contains the outcome, another distinct sample contains the exogenous regressor, and both samples contain the instrumental variable and other exogenous variables included in the model. Their two sample instrumental variables (TSIV) estimator is: $\hat{\beta}_{TSIV} = (Z_2'X_2/n_2)^{-1}(Z_1'Y_1/n_1)$, where Y is the outcome, X contains the endogenous regressor and other exogenous variables, and Z is the matrix of valid instrumental variables, n is the number of observations and subscripts denote the samples 1 and 2. Inouue and Solon (2010) show that $\hat{\beta}_{TS2SLS} = (\hat{X}_1'\hat{X}_1)^{-1}\hat{X}_1'Y_1$ and $\hat{\beta}_{TSIV}$ as proposed by Angrist and Krueger (1992, 1995) have the same probability limit, though TS2SLS is more asymptotically efficient in finite samples due an implicit correction for differences in the distribution of Z between the two samples.

that can be included as controls must be present in both samples.

In the first stage, I use the RECS data to estimate the effect of heating fuel price movements on energy expenditures as a function of unit characteristics. Then, I estimate a variant of Equation 1 by regressing housing price from the CoreLogic data on the estimated expenditure and unit characteristics. The first stage of the estimation is as follows.

First Stage

$$Exp_{jt} = \beta_0 + \beta_1 p_t + \beta_2 \mathrm{I}^{\mathrm{oil}}_{jt} + \mathbf{X}_{jt}\beta + \delta_t + \epsilon_{jt} \tag{A7}$$

The dependent variable is expenditure on the primary heating fuel, Exp, for unit j in survey year t. The annual fuel price is p, $\mathrm{I}^{\mathrm{oil}}_{it}$ indicates oil as the primary heating fuel. As with the main estimation, I use one statewide average price for each of these fuels. δ_t are year fixed effects. X_{jt} is a matrix of covariates and ϵ_{jt} is the error term. The covariates for this estimation include, the number of rooms, bathrooms and stories, flexible controls for square footage, binned by 1000 square foot increments, and indicators for decade built. They were chosen because they were available and in both surveys and are comparable between the two samples. The second stage estimation is as follows, where estimates of expenditure, $\hat{Exp}_{jt}$, are a function of the house characteristics in the transactions data and the coefficients estimated in the first stage. The coefficient of interest, $\hat{\gamma}$ can be interpreted as the effect of a \$1 increase in the present value of annual fuel expenditure on housing price.

Second Stage

$$H_{jt} = \alpha_0 + \hat{\gamma}\hat{Exp}_{jt} + \alpha_1 \mathrm{I}^{\mathrm{oil}}_{jt} + \mathbf{X}_{jt}\beta + \delta_t + \epsilon_{jt} \tag{A8}$$

The results from the estimation are displayed in Table A1. The first stage estimate shows that a \$1 increase in the annual MA residential fuel price leads to an increase of \$100 in annual expenditure for houses in the northeast census region. The reduced form estimate and the implied discount rate of 10% are quite close to the basic estimation in the main analysis.

A4 Estimation Using Futures Prices

I examine the sensitivity of the basic estimation to using the discount factor-weighted mean of future fuel prices rather than contemporaneous price. Crude oil and natural gas are traded for as much as 7 to 13 years in advance for later years in the sample. These years will have the largest impact on perceived prices in NPV terms. The discount factor-weighted mean is constructed as follows.

$$\frac{\sum_{i=t}^{T} \delta^i \cdot p_{ijt}}{\sum_{i=t}^{T} \delta^i} \tag{A9}$$

Future periods are indexed by i, the discount factor is δ^i, and the fuel price for house j for future year i in year t is p_{ijt}. If the time horizon of the decision were limited to the number of future periods that derivatives are traded T, this would be the perceived price for an agent using the futures market to forecast price. I inflate forward prices according to the trade date and transform crude oil and natural gas prices into residential heating oil and natural gas prices using the average historical relationships between the traded fuel and the residential price. Specifically, I predict the average historical relationship using simple linear regressions of levels of residential retail prices on levels of crude oil or Henry Hub natural gas spot prices. The reason I do this is residential gas prices do not have a separate futures market and residential heating oil is not traded for time horizons of more than 2 to 3 years.

A sensitivity test using the discount factor-weighted average futures prices incorporates all of the information available in the futures market, but implicitly assumes that home buyers will use the discount-weighted average of the prices in traded years for periods beyond the last year for which there are trade data. I replicate Table 2 using the discount factor-weighted average futures price. The results are displayed in Table A2. The magnitude of the point estimates are quite close to those using contemporaneous prices. For the preferred specification (column 5) with geographic area by time and house fixed effects, the estimates using the discount factor-weighted mean futures price actually yield the same implied discount rate of 9.5% as the estimates using contemporaneous price. Futures prices tend to not deviate too far from spot prices, meaning even if consumers were paying attention to them, their decisions would not deviate significantly from a consumer using contemporaneous prices.

A5 Estimation Using Pre-Crisis Data

I examine the sensitivity of the basic estimation to using the sub-sample of data from before the financial crisis (1990-2007). The results are displayed in Table A3. The first column displays results from the preferred estimation with geographic area by time fixed effects and house fixed effects (Equation 1). Column 2 includes results from a model with an oil-specific linear time trend and column 3 includes the results of a model with both an oil-specific linear time trend and age FE. The magnitude of the point estimates and implied discount rates are quite close to those using the full data set. Therefore, it appears the results are not being driven by differential trends in oil and gas homes during the housing crisis.

A6 Estimation of Rates of Conversion from Oil to Gas

A6.1 Data

I use data from the national American Housing Survey (AHS) from 1985 to 2011 to estimate rates of conversion from oil to gas. The AHS is a nationally representative survey, performed every two years. The AHS reports data on many attributes of a housing unit, including primary heating fuel. Importantly, the same housing units are surveyed every two years (with additions to reflect new construction). In the publicly available national survey, the only information on the location of the home is the census region.

Therefore, in order to get a sense of how many housing units are converting from oil to gas in Massachusetts over the period, I focus on the Northeast Census region.[24]

A6.2 Method

I begin by limiting the sample to the 16,896 single family homes in the northeast census region. Next, I drop any homes that have ever had a main heating fuel listed other than oil or gas, or have appeared to switch fuel type more than once, so that I have 10,934 remaining homes. Of those homes, 37% (4007) have oil listed as the primary heating fuel for the first observation of that home. Of the homes that begin with oil as the primary heating fuel, 450, or around 11% list gas as the primary heating fuel in later surveys.

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[24] The Northeast Census region, region 1, is comprised of the following states: Maine, New Hampshire, Vermont, New York, Massachusetts, Connecticut, Rhode Island, Pennsylvania, and New Jersey.

Appendix Tables

Table A1: Two Sample 2SLS: Estimation of the Effect of Relative Annual Energy Costs on Relative Transaction Prices Instrumented with Fuel Price

	First Stage	Reduced Form	Second Stage
(Dependent Variable)	(Annual Fuel Expenditure)	(Sales Price)	(Sales Price)
Fuel Price	100.4***	-1082.4***	
	(12.92)	(291.0)	
Estimated Annual Fuel Expenditure			-10.79**
			(4.89)
Oil Heat Indicator	-157.6***	-6067.9	-7767.7
	(39.23)	(4852.7)	(5144.28)
F-stat	20.42		
R^2	0.363		
Attribute Controls	Yes	Yes	Yes
N	1515	909434	909434
Implied Discount Rate Infinite Horizon			10%

Notes: First stage regression data are from the Residential Energy Consumption Survey (RECS), northeast census division, survey years 1990, 1993, 1997, 2001, 2005, and 2009. the second stage regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic, years 1990-2011. Price is the average annual residential retail fuel price for oil or natural gas in dollars per MMBTU. All specifications control flexibly for the house vintage, number of rooms, bedrooms and bathrooms, square footage and year fixed effects. All prices are inflated to 2012 dollars. Standard errors are bootstrapped with 10,000 iterations, clustered at geographic area, and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Table A2: Estimation of the Effect of Relative Fuel Prices on Relative Transaction Prices

	Sales Price	Sales Price	Sales Price	Sales Price	Sales Price
Mean Futures Price	-1160.5***	-1028.1***	-1216.3***	-972.9***	-1058.6***
	(179.4)	(202.3)	(119.0)	(153.2)	(121.7)
Oil Heat Indicator	-15644.3***	-8458.9***	955.0		
	(1055.0)	(1174.8)	(1029.9)		
Year FE	Yes	Yes	No	Yes	No
Attribute Controls	No	Yes	Yes	No	No
Geographic Area × Year FE	No	No	Yes	No	Yes
Unit FE	No	No	No	Yes	Yes
N	909434	870567	870504	529156	529008
Implied Discount Rate Infinite Horizon	8.6%	9.8%	8.2%	10.4%	9.5%

Notes: Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic, years 1990-2011. The Mean Futures Price is calculated by weighting all traded futures prices by the discount factor and is measured in dollars per MMBTU. All prices are inflated to 2012 dollars. Standard errors are two-way clustered at the house and geographic unit by year level and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Table A3: Estimation of the Effect of Relative Fuel Prices on Relative Transaction Prices: Pre-Crisis Years

	Sales Price	Sales Price	Sales Price
Fuel Price	-1213.7***	-833.8***	-767.1***
	(258.0)	(284.4)	(244.0)
Geographic Area × Year FE	Yes	Yes	Yes
Unit FE	Yes	Yes	Yes
Oil Linear Trend	No	Yes	Yes
Age FE	No	No	Yes
N	412690	412690	412468
Implied Discount Rate Infinite Horizon	8.2%	12.4%	13.6%

Notes: Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic, years 1990-2007. Price is the average annual residential retail fuel price for oil or natural gas in dollars per MMBTU. All prices are inflated to 2012 dollars. Standard errors are two-way clustered at the house and geographic unit by year level and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.