EI @ Haas WP 273R

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Revised January 2017

Revised version published in
***American Economic Journal: Economic Policy*, 11(2): 165-188, 2019**

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January 12, 2017

Abstract

This paper explores whether home buyers are myopic about future energy costs. I exploit variation in energy costs in the form of fuel price changes in Massachusetts where there is significant overlap in the geographic and age distributions of oil-heated homes and gas-heated homes. I find that relative fuel price shifts cause relative changes in housing transaction prices that are consistent with full capitalization of the present value of future energy cost differences under relatively low discount rates. These findings are similar across the income spectrum and are consistent with home buyers being attentive to energy costs and are not consistent with myopia.

Keywords: Myopia, Inattention, Undervaluation, 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 price based instruments such as taxes or cap-and-trade programs will be effective crucially depends on whether consumers are responsive to fuel prices in markets for energy-using durables.

This policy motivation has prompted researchers to estimate the responsiveness of purchase price to gasoline price movements for cars, which account for close to 15% of U.S. GHG emissions annually.[1] If people lack information about changes in gasoline prices or are myopic about the resulting changes in the operating costs of their car, they will underinvest in fuel economy even under carbon pricing policies. If people are mis-optimizing in this way, other more traditional policy instruments, such as corporate average fuel economy (CAFE) standards may increase welfare relative to a tax alone. However, the results from this work suggest that car buyers are relatively attentive to future fuel costs. Estimates of implied discount rates for automobile purchases range between 5% and 15% (Busse et al., 2013; Allcott and Wozny, 2014; Sallee et al., 2016; Grigolon et al., 2014). These findings have important policy implications, suggesting that it is preferable to address pollution externalities through gasoline taxes rather than CAFE standards, which mandate increases in the average fuel economy over time.

This paper asks whether consumers are responsive to changes in energy prices in the housing market. The building sector is another large contributor of U.S. GHGs. A growing proportion of annual emissions, around 40%, come from the residential and commercial

[1] EPA: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012

buildings sector.[2] As end uses, space heating and cooling contribute almost as much to U.S. greenhouse gas emissions annually (13%) as personal vehicles (15%).[3] In recent years, consumers spent an average of $272 billion/year, on residential natural gas, electricity, and fuel oil, almost as much as they did on gasoline and motor oil.[4]

Consumers might be less myopic about gasoline purchases as opposed to residential fuels. Gasoline is one of the most salient products that consumers buy. Obtaining information about gasoline prices is relatively costless, since they are prominently posted at gas stations, and many people purchase gas one or more times in a week. In addition, people tend to know how much it would cost to drive from one place to another by car. Residential fuel costs may not be as well understood or salient for consumers. Households only receive energy bills on a monthly basis, making it harder to translate consumption of particular energy services into costs. In addition, consumers receive bills where natural gas is combined with electricity in many areas, potentially muddling individual effects. Therefore, it is important to investigate whether consumers are myopic about future energy costs in the housing market to determine whether Pigouvian taxes alone would be appropriate for regulating emissions or whether appliance standards and building codes could improve welfare.

It can be challenging to estimate whether home buyers are attentive to energy costs. Previous attempts have used hedonic approaches to see if utility bills (Johnson and Kaserman, 1983), measures of efficiency (Dinan and Miranowski, 1989), or efficiency letter grades (Brounen and Kok, 2011) are capitalized into housing sales. In general, these studies find that more efficient homes with lower fuel costs receive premiums in the housing market, which are consistent with relatively low implied discount rates. One limitation of this approach is that home efficiency is not randomly assigned, so that more efficient homes may be more likely to have renovations or other improvements that are unobservable to the researcher,

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

[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.

but appreciated by home buyers. Therefore, the observed premium for efficient units may be due to unobserved differences in homes rather than the causal effect of energy cost savings.

This study is the first to estimate the effect of plausibly exogenous variation in energy costs on housing prices. I use 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% 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. With two dominant heating fuels I am able to control for unobserved variation in the macroeconomic environment with year fixed effects. In addition, I observe multiple sales of homes, which allows me to control for time-invariant characteristics of a home with unit fixed effects. 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 are not myopic about future fuel costs, this discount should reflect the net present value of the difference in fuel expenditure.

I find little evidence that home buyers are systematically "under-valuing" future fuel costs. When the relative cost of heating goes up by $1/MMBTU, it leads to a $1000-$1200 discount in relative housing transaction price. These results are consistent with full capitalization of the present value of fuel expenditure differences under a 8-10% discount rate.[6] These results are consistent across the income distribution, suggesting that rich and poor home buyers are similarly cognizant of home heating costs. It appears that home buyers are paying attention not only to whether a home heats with oil or gas, but the relative prices of those fuels and further, how those relative price differences translate into differences in

[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.

the net present value of the future stream of payments.

These findings are relevant to the literature on consumer myopia in energy using durables. Consistent with the possible role of salience, evidence on consumer myopia has been more varied in the context of appliances, where energy costs are smaller in magnitude than for cars or home heating. For example, 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, to convert to cleaner heating fuels, and possibly to increase the efficiency of building shells and appliances.

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, Characteristic and Demographic 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% of observations). In property records, the “effective age” of a building is adjusted for significant renovations or neglect. Over 99% 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% of the remaining sample for these types of large renovations or improvements. I use the middle 99% of the distribution of non-zero housing transactions, dropping the top and bottom 1/2% most extreme values. The remaining data used have 909,434 transactions with 604,807 housing units sold between 1 and 4 times. About 50% of the sample heats with oil and 50% heats with gas. Over half of the sample (60%) 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% 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.

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 vs. 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.

For analysis of heterogeneous treatment effects, I use block group level data from the 2000 decennial census to create an average measure of median household income for each geographic area in the sample.

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. I inflated all prices to 2012 dollars using the consumer price index. Both natural gas and heating oil prices were converted 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. 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. Figure 5 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.

2.3 Energy Consumption Data

The housing characteristic data do not contain information about energy expenditure and usage. When I analyze how consumption varies across income quartiles, I use data from the Residential Energy Consumption Survey (RECS). RECS is an in-home survey, which provides detailed information on housing unit characteristics and household demographics 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 with utility-verified usage data–a total of 1131 housing units.

3 Empirical Framework

A general test researchers have used for systematic misperception of potentially less salient costs such as shipping and handling, sales tax, or automatic electronic payments is to compare the demand response of those costs versus salient, correctly perceived costs (Chetty et al., 2009; Hossain and Morgan, 2006; Finkelstein, 2009). Researchers have applied this test to energy using durables, comparing demand response to potentially misperceived future energy costs versus upfront purchase costs (Allcott and Wozny, 2014; Dubin and McFadden, 1984; Goldberg, 1998; Grigolon et al., 2014; Houde and Spurlock, 2015; Hausman, 1979). The intuition is that consumers should be indifferent between an additional dollar of purchase price and an additional present discounted dollar of energy expenditure, since total lifetime cost should be the relevant metric.

3.1 Theoretical Framework

In this paper I take a similar approach, estimating how home buyers' tradeoff purchase price and energy costs. 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.

$$U_{ijat} = \eta(w_i - H_{jat} - \gamma F_{jat}) + \mathbf{X}'_{ja}\tilde{\beta} + \tilde{\xi}_{ja} + \tilde{\lambda}_{at} + \varepsilon_{ijat} \tag{1}$$

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 myopic. In other words, demand for homes with high fuel costs is too high relative to what would be optimal.

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 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.

$$\frac{1}{\eta}(ln\phi_{jat} - ln\phi_{0at}) = H_{jat} - \gamma F_{jat} + \mathbf{X}'_{ja}\beta + \xi_{ja} + \lambda_{at} \tag{2}$$

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:

$$H_{jat} = \gamma F_{jat} + \lambda_{at} + \theta_{ja} + \epsilon_{jat} \tag{3}$$

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}). The new error term $\epsilon_{jat} = ln\phi_{jat}$ represents the idiosyncratic period-specific deviation from a home's average choice probability. 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}.

One of the primary challenges of this type of exercise in the context of energy using durables is that we do not observe F_{jat} nor its underlying parameters directly. The NPV of the stream of expected future fuel payments, F_{jat}, is a function of the relevant time horizon (T), the discount factor (δ^i), the expected future fuel prices (p_{jai}), and expected future energy consumption (e_{jai}), where i indexes years into the future as follows.

$$F_{jat} = \sum_{i=t}^{T} \delta^i p_{jai} e_{jai} \tag{4}$$

In order to estimate F_{jat}, I have to make assumptions about consumers beliefs about p_{jai}, T, δ^i and e_{jai}, since this information is unobservable. Importantly, the choices I make about these parameters will mechanically affect my estimates of consumer myopia. For example, if I assume too long of a time horizon for the lifetime of the house, F_{jat} will be too high, biasing implied discount rates up. Since small changes in these assumptions could have non-trivial effects on the estimates consumer myopia, I will begin by estimating the reduced form for my fuel price instrument.

The advantage of starting with the reduced form is the coefficient $\tilde{\gamma}$, is readily interpretable as the effect of contemporaneous fuel price movements on housing prices. It is also straightforward to use this estimate to calculate implied discount rates in equation 3 given assumptions about F_{jat}, which I discuss in detail below. The estimation equation for the reduced form is as follows.

$$H_{jat} = \tilde{\gamma} p_{jt} + \lambda_{at} + \theta_{ja} + \epsilon_{jat} \tag{5}$$

The fuel price, p_{jt}, is the annual residential retail fuel price for Massachusetts and varies whether house j is oil or gas. 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.

The coefficient $\tilde{\gamma}$, 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 F_{jat} caused by a \$1/MMBTU heating fuel price increase. In what follows, I describe my approach for estimating this change and for exploring the sensitivity of implied discount rate estimates to a range of parameter assumptions.

3.2 Beliefs about Future Fuel Prices

For this analysis, 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. A no-change forecast is a reasonable belief for home buyers, particularly in the case of heating oil, since a no-change forecast predicts future crude oil prices as well or better than forecasts derived from futures markets or surveyed experts (Alquist and Kilian, 2010; Alquist et al., 2012).

Another possibility is that consumers are more sophisticated, using information from crude oil and natural gas futures markets to make projections about fuel prices going forward. Figure 6 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. Figure 6 Panel C shows the difference in the spot and forward prices between the two fuels (price of oil - price of gas).

There are two things to note about the relationship between the spot and future curves of these two fuels. First, the forward curves do not deviate substantially from spot prices. Therefore, even if home buyers were more sophisticated and paying attention to trends in futures prices, their beliefs about fuel prices going forward would not differ significantly from no-change beliefs. Second, the futures price difference between oil and natural gas is lower than the spot price difference in a significant part of the sample, particularly when oil is most expensive compared to natural gas. In periods where future price differences are lower than spot price differences, the assumption that consumers believe prices follow a no-change forecast when in fact consumers are truly sophisticated and paying attention to futures markets, would bias the analysis toward finding myopia.

3.3 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. If so, a good approximation of the change in the NPV fuel expenditure (F_{jat}) caused by a small changes in today's price would be the sum of the present value of the change in today's price times the discounted present value of today's quantity summed over each year in the relevant time horizon.

$$\frac{\partial F_{jat}}{\partial P_{jt}} = \left(\sum_{i=t}^{T} \delta^i e_{jat} \right) \cdot \Delta p_{jt} \tag{6}$$

For larger price differences, home owners may consume less energy and have a lower NPV of future fuel expenditure as a result of this elasticity. However, as I demonstrate below, demand for residential energy tends to be relatively inelastic, so incorporating reasonable estimates for demand elasticity changes expected future expenditure little.

Home transaction and characteristics data are not available paired with energy consumption data, making it difficult to estimate house specific usage. Therefore, I will approximate consumption for the mean household using the value reported by the Residential Energy Consumption Survey (RECS) for single family homes in the northeast census region that heat with oil or gas, 94 MMBTU per year.[7]

If homes were perfectly inelastic, a $1/MMBTU price difference would result in an annual reduction in energy expenditure of $94 per year. Changing the assumed elasticity from zero to the higher end of residential fuel elasticity estimates, -.6, lowers the estimated annual change in expenditure from a $1/MMBTU fuel price increase a small amount from $94/year to $90/year.[8] In the analysis, I will take the middle of this range, $92, to calculate implied discount rates. I will also look at the sensitivity of these estimates to a +/− 10% difference in this approximated change in annual expenditure.

3.4 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. If consumers were truly considering a shorter time horizon, assuming an infinite time horizon would lead to higher estimates of implied discount rates, lower γ and bias the analysis toward finding consumer myopia. I will begin by assuming an infinite time horizon, but will examine the sensitivity of estimates of the implied discount rates to two other time horizons: 1) the typical mortgage period, 30 years, and 2) the average life expectancy of a furnace, 18 years.[9]

3.5 Estimating Implied Discount Rates

Given assumptions about: 1) beliefs about future fuel prices, 2) future energy consumption, and 3) the relevant time horizon, it is straightforward to estimate an implied discount rate

[7]Residential Energy Consumption Survey: Table CE2.2 "Household Site Fuel Consumption in the Northeast Region, Totals and Averages, 2009."

[8]This range of elasticity estimates is consistent with demand for residential electricity (e.g., Reiss and White, 2008; Ito, 2014; Jessoe and Rapson, 2014) and my own estimates of demand elasticity for heating fuel using the Residential Energy Consumption Survey presented in Table 7. 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 change in price.

[9]The life cycle cost estimator developed by the EPA and the DOE for evaluating savings from Energy Star Furnaces assumes an 18-year life for conventional furnaces.

given the reduced form estimation in equation 5.

The coefficient $\tilde{\gamma}$ is the effect of a change in fuel price on the housing transaction price. If consumers correctly perceive future fuel costs, $\tilde{\gamma}$ should be equal to the change in the NPV of future energy cost caused by the change in price ($\frac{\partial F_{jat}}{\partial P_{jt}}$). The implied discount rate is the discount rate that consumers would have to use for this to be true and the following to hold.

$$1 = \frac{\tilde{\gamma}}{\frac{\partial F_{jt}}{\partial p_{jt}}} \tag{7}$$

3.6 Cost of Conversion from Oil to Natural Gas

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 reduced form effect of relative fuel price shifts on relative transaction price and calculate the implied discount rates from the estimates. My preferred specification includes house fixed effects and geographic area by time fixed effects (equation 5). As the relative fuel price of a home increases, it should sell at a discount compared to homes with less expensive fuel, reflecting the net present value of the difference in fuel expenditure.

The coefficient of interest, $\tilde{\gamma}$ is the estimate of the effect of a \$1/MMBTU heating fuel price increase on the housing transaction price. Since there is no cross-sectional variation in price for a given fuel, year fixed effects are collinear with one fuel price, so that the identifying variation is the difference in price between oil and gas. The identifying assumption is that oil units do not systematically differ from gas units in unobservable or inadequately controlled for ways that are correlated with the difference between the price of oil and the price of gas.

Table 2 displays the results from the estimation of the preferred specification (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. I_i^{oil} indicates whether unit i heats with oil. The estimates in columns 3-4 come from models with geographic area by year fixed effects and housing unit fixed effects respectively. The estimates in column 5 for the preferred specification include both geographic area by year and housing unit fixed effects. The results indicate that 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 two rows of the table show the implied discount rate for the point estimate and 95% confidence interval of the point 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% discount rate, which suggests that they are not strongly myopic regarding future heating fuel costs when purchasing houses. These results are consistent with recent work on automobile purchases that also find no evidence of strong myopia. Recent estimates of implied discount rates for automobile purchases range between 5% and 15% (Busse et al., 2013; Allcott and Wozny, 2014; Sallee et al., 2016; Grigolon et al., 2014).

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 $1 difference in relative fuel price and a 9.5% discount rate from the preferred estimation in Table 2. In addition, I depict the housing transaction price difference between gas and oil homes from the preferred specification with geographic area by year fixed effects and unit fixed effects by plotting coefficients on the year-specific gas intercepts ($\beta_1 - \beta_{22}$) from the following regression.

$$\mathrm{H}_{jat} = \textstyle\sum_{t=1}^{22} \beta_t \mathrm{I}_{ja}^{\mathrm{gas}} + \lambda_{at} + \theta_{ja} + \epsilon_{jat} \tag{8}$$

The housing transaction price H_{jat} for house j in geographic area a in year t is regressed on house fixed effects, δ_{ja}, geographic are by time fixed effects, γ_{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.

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% discount rate is a close fit for the housing transaction price difference.

4.2 Sensitivity to Parameter Estimates

Table 3 shows the sensitivity of the implied discount rate estimate of 9.5% from the preferred specification to two other time horizons (30 years and 18 years) and to +/- 10% of the estimated annual energy consumption of 92 MMBTU/year. Estimates for the 95% confidence interval from the preferred specification are in parentheses.

Since housing is such a long-lived asset, it may be that considering an infinite time horizon is optimal. However, if consumers are considering shorter time horizons such as the length of a typical mortgage (30 years) or the lifetime of a furnace (18 years), estimates of the implied discount rate may be biased upward. Changes in the time horizon have a non-linear effect on estimates of implied discount rates with the same change in years having smaller effects for longer time horizons than shorter time horizons. Moving from an infinite time horizon to a 30 year time horizon drops the implied discount rate by about 1%, while moving from a 30 year horizon to an 18 year horizon drops the implied discount rate by another 2.5-3%. Using 10% more or 10% less than the average estimated annual consumption raises and lowers implied discount rates by about 1-1.5% respectively. Overall, estimates of implied discount rates are not markedly sensitive to the parameter estimates, outside of considering short time horizons of less than 20 years.

4.3 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.

However, in Figure 7, the housing transaction price difference closely follows the U-shape of the NPV of the difference in fuel expenditure. In early years, the transaction price difference falls when it is less expensive to heat oil homes as compared to gas homes. Then in later years, the transaction price difference increases as oil homes get more expensive to heat than gas homes. The relationship does not appear to be driven just by the later years, where one might worry that the difference in housing transaction prices were being driven by differential trends in fuel type.

In order to address the issues of differential trends more rigorously, columns 1 and 2 of Table 4 display results for two robustness tests of the identifying parallel trends assumption between oil and gas houses. First, for the estimates in column 1, I included 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. However, the estimates do not change substantially with the inclusion of an oil specific linear trend.

Second, for the estimates in column 2, 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. Homes are grouped in 5 year bins for homes that are 20 years or older, because there are relatively few observations for each vintage in early years. For homes younger than 20 years, I use the actual year built, because there are more observations for each vintage year and the value of newer homes is likely much more sensitive to smaller age differences. Here too, the coefficients of interest change little, suggesting that differences in the capitalization rates are driven by the price variation and not by unobservable trends in the age of the structure.

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 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 myopia. 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, people maybe converting from oil to gas. This has the potential to bias the estimates toward finding high levels of capitalization and away from finding myopia. 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.

With this type of non-classical measurement error, one might expect that the slope of the housing transaction price difference in Figure 7 would get steeper compared to the NPV of the difference in fuel expenditure in the later years relative to early years. However, the housing transaction price difference follows the NPV of the difference in fuel expenditure fairly uniformly for the entire sample period, indicating that non-classical measurement error is unlikely to be a significant driver of my results.

Further, in columns 3 and 4 of Table 4, I estimate the same two models as in columns 1 and 2, except that I limit my sample to homes that are 18 years and younger by 2011. The average lifetime of a furnace is 18 years. If the furnace would not need to be replaced yet, homeowners may be less likely to convert heating fuel, thus reducing the chance measurement error of fuel type in newer houses. The results for the newer houses have higher point estimates than those for the full sample. However, with a smaller sample size the effects are not as precisely estimated, and the standard errors are relatively large. Consistent with the full sample estimates, when the sample is limited to newer houses that are less likely to have measurement error in fuel type, consumers do not appear to be particularly myopic about fuel costs in housing purchases.

4.4 Instrumental Variables Approach

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. If these types of upgrades were driving the results, one would again expect that the slope of the housing transaction price difference in Figure 7 would be steeper compared to the NPV difference in later years as compared to earlier years. Since this is not the case, it is unlikely that endogenous upgrades are a significant issue. In addition, as stated in the data section, in the initial data construction, I removed any houses that appear to have had major upgrades. This removes houses where the characteristics changed significantly over time, possibly reducing the prevalence of homes with major endogenous upgrades.

However, in order to address this issue and the issue of non-classical measurement error more rigorously, 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 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. 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. As with my approach in the robustness tests, I include an oil specific trend and flexibly control for the age of the house.

The results from this estimation are displayed in Table 5. 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-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%, close to recent mortgage interest rates. However, given the 95% confidence interval on the point estimates, I cannot rule out the implied discount rates from the OLS estimation. With these results taken together, it seems unlikely that home buyers are strongly myopic regarding future heating fuel prices.

4.5 Heterogeneous Treatment Effects

In the analysis thus far, I have focused on the capitalization of relative fuel price movements into housing price for the mean house in the sample conditional on controls. However, the capitalization rate likely varies by household demographics and housing characteristics, such as household income and the size of the house. For example, larger homes require more energy for space heating, so all else equal, we would expect to see these homes receive larger discounts for increases in relative fuel prices than smaller homes. Even conditional on the size of the home, the capitalization rate may vary by income due to usage differences or differences in borrowing rates. For example richer areas may have higher capitalization rates of fuel price changes than poorer areas since people with more disposable income may consume more energy all else equal. In addition, richer people often have access to capital at lower interest rates than poorer people, which would lead to less myopia and higher capitalization rates.

On the other hand, it might be the case that poorer areas have higher capitalization rates of fuel price changes than richer areas. Houses in these areas may not be as well insulated and may contain less efficient appliances leading to higher energy consumption all else equal. Poorer people may also be more attentive to fuel costs than richer people because energy is a larger proportion of their spending, making them less myopic.

In what follows, I explore some of this heterogeneity and its drivers. I use block group level data from the 2000 decennial census to create an average measure of median household income for each geographic area in the sample. I estimate heterogeneous treatment effects by quartile of this income measure with the following model:

$$\mathrm{H}_{jat} = \beta_0 + \sum_{q=1}^{4} \{\beta_q \mathbb{1}(quartile_a = q) \times \mathrm{P}_{jt}\} + \lambda_{at} + \theta_{ja} + \epsilon_{jat} \tag{9}$$

where, again, H_{jat} is the transaction price for house j in geographic area a in year t. The indicator function, ($\mathbb{1}(quartile_a = q)$) indicates whether the geographic area, a falls into income quartile, q. This is interacted with P_{jt}, the annual residential retail fuel price for Massachusetts, which varies whether unit j is oil or gas. In addition, I control for house fixed effects δ_i and geographic area by time fixed effects γ_{at}. The term ϵ_{it} is the idiosyncratic error.

The results from this estimation are in column 1 of Table 6. The 4th quartile has a much higher coefficient estimate than the other three. This implies that for areas with the highest 25% of income, a \$1 increase in relative fuel price leads to a \$2044 discount in housing price. The point estimate of the effect is almost four times as large as the point estimates for quartiles 1 and 3 and twice as large as the point estimate for the mean house as presented in Table 2. The estimated effects for quartiles 1-3 are not statistically distinguishable from one another, though the standard errors are relatively large, particularly for quartile 3.

The larger effect size in the highest income areas maybe a combination of bigger house size, usage pattern differences, and lower borrowing rates as discussed above. I do two things to control for the effect of house size. First, I include a year specific trend in square footage to control for the effect of square footage on prices, allowing it to change flexibly across years in the sample. I also include the interaction between the sample demeaned square footage and price. This controls for the difference in house price for oil homes relative to gas homes conditional on the square footage of the house. Demeaning the square footage variable allows for a convenient interpretation of the quartile specific coefficient estimates. They each indicate the discount a home receives for a \$1 increase in fuel price, specific to each quartile, for the mean-sized house in the sample.

The results of the estimation controlling for house size are in column 2 of Table 6. The quartile-specific capitalization estimates are more proportional to one another than in column 1. The coefficient estimate for the 4th quartile is no longer the biggest and none of the four estimates are statistically distinguishable from one another. This is consistent with the differences in column 1 being largely driven by richer households living in bigger houses. However, without information on how energy usage varies with income, it is difficult to draw any further conclusions about how consumer myopia might vary with income.

While there is no energy usage information associated with the housing transaction data, the Residential Energy Consumption Survey (RECS) contains the information necessary to estimate the effect of income on energy consumption, controlling for house size and characteristics. The RECS has data on household level income and usage as well as housing characteristics for a repeated cross-section of housing units. The usage data reflect actual usage, not reported usage, as I limit the sample to single family, owner-occupied households with utility-verified usage levels. I use a similar strategy to estimate the effect of fuel price movements on energy usage as I have been using to estimate its effects on housing prices.

$$\mathrm{E}_{jt} = \beta_0 + \textstyle\sum_{q=1}^{4} \{\beta_q \mathbb{1}(quartile = q) \times \mathrm{P}_{jt}\} + \beta_5 sqft_{jt} \times \mathrm{P}_{jt} + \beta_6 \mathrm{I}^{\mathrm{oil}}_{jt} + \mathbf{X}'_{jt}\beta + \alpha_t \times sqft_{jt} + \epsilon_{jt} \qquad (10)$$

Here, the outcome of interest is expenditure E on the primary heating fuel for unit j in year t. As in Table 6, I control for the effect of housing size on expenditure flexibly with year specific trends in square footage. In addition, I include the interaction between demeaned square footage, $sqft_{jt}$ and fuel price, P_{jt}. Fuel price varies whether the unit is oil or gas. The vector of covariates, $\mathbf{X}_{jt}$, includes flexible controls indicating decade built, number of stories, number of bedrooms, number of bathrooms, $\mathrm{I}^{\mathrm{oil}}_{jt}$ indicates that the house heats with oil, and ϵ_{jt} is the error term. The outcomes of interest are the coefficients on the interaction terms between income quartile and fuel price. These coefficients can be interpreted as the increase in energy expenditure caused by a $1 increase in fuel price, specific to each quartile, for the mean-sized house in the sample. With these data, it is not possible to control for housing unit fixed effects, since the data are a repeated cross-section. In addition, the only geographic data available are at the census region level, so it is not possible to control for geographic by time fixed effects.

If there are large differences in usage across income quartiles, there may be differences in myopia across the income spectrum. For example, if richer houses use much more energy than poorer households all else equal, then similar capitalization rates of fuel prices imply that poor people are less myopic than rich people.

The results for these estimates are displayed in column 1 of Table 7. The point estimates on the quartile by fuel price interaction terms are somewhat higher for the top income quartile. However, the effect sizes are not statistically distinguishable among quartiles, suggesting that there are not large differences in usage among income quartiles after controlling for house size.

Column 2 in Table 7 shows the results of the same estimation with heating fuel usage rather than expenditure as the outcome variable. These results are consistent with the the expenditure estimates in column 1. There are not large differences in elasticity between rich and poor households after controlling for the size of the home. While the point estimates are slightly larger for the lower income quartiles than the higher income quartiles, they are not statistically distinguishable from one another.

While a linear estimation of the effect of a \$1 increase in fuel price on energy use is most useful for this analysis, it is typical to report the effect of price increases on demand in terms of elasticity. As a point of comparison, column 3 shows the result of estimating the log-log form of equation 10. Here too, it does not appear that poorer households are much more elastic than rich households. The point estimates range from $-.3$ to $-.33$ with the bounds of the 95% confidence intervals ranging from a low of $-.45$ to a high of $-.17$, but they are not statistically distinguishable from one another. These short-run elasticity estimates for heating oil and natural gas consumption are close in magnitude to empirical estimates of short-run elasticities for electricity, which range from $-.1$ to $-.5$ (e.g., Reiss and White, 2008; Ito, 2014; Jessoe and Rapson, 2014).

It is difficult to directly compare the implied discount rates across income quartiles accounting for differences in usage, since the usage data come from a different sample than the housing transaction data. However, the evidence presented here is not consistent with poorer people being much more myopic than rich people. Remarkably, there are not large differences between rich and poor households in terms of energy use or fuel price capitalization rates after controlling for the size of the home.

5 Conclusion

This paper explores how shifts in energy costs affect housing transaction prices to see if home buyers are myopic about energy costs. I use shifts 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. They are paying attention to shifts in relative fuel prices and are aware of how changes in fuel price translate into changes in the net present value of the future stream of payments. The implied discount rates from the estimates range between 8 and 10%, which are consistent with recent work on automobile purchases (e.g. Busse et al. (2013); Allcott and Wozny (2014)).

In addition, I explore heterogeneous treatment effects across income. Controlling for house size, I find no evidence that poorer households are more myopic than richer households. My findings suggest that since home buyers across the income spectrum are attentive to and informed about fuel prices, pollution pricing 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***
bedrooms	3.32	3.36	0.00***
bathrooms	2.37	2.21	0.00***
stories	1.78	1.73	0.00***
square ft.	1922.51	1902.47	0.00***
year built	1956.59	1947.94	0.00***
exterior wall			
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	

Notes: 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***	-1106.2***	-1163.2***	-1074.7***	-1064.7***
	(317.7)	(284.0)	(161.1)	(286.0)	(208.1)
I^{oil}	-15334.4**	-10535.4**	323.9		
	(6522.4)	(4114.6)	(1127.1)		
Year FE	Yes	Yes	No	Yes	No
Attribute Controls	No	Yes	Yes	No	No
Geo. AreaxYear FE	No	No	Yes	No	Yes
Unit FE	No	No	No	Yes	Yes
N	909434	863480	863416	529156	529008
Implied Discount Rate	8.4%	9.1%	8.6%	9.4%	9.5%
95% Confidence	5.4-19.6%	5.9-20.8%	6.6-12.2%	6-21.9%	6.7-16.3%

Notes: 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 $/MMBTU. All prices are inflated to 2012 dollars. Standard errors are clustered at the geographic unit level and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Table 3: Sensitivity of Implied Discount Rates to Parameter Estimates

Time Horizon (years)	Average Use	10% more than Average Use	10% less than Average Use
∞	9.5%	10.5%	8.5%
	(6.7-16.3%)	(7.4-18.2%)	(6-14.4%)
30	8.6%	9.8%	7.4%
	(5.1-16.1%)	(6-18.1%)	(4.1-14.1%)
18	6.7%	8.2%	5.3%
	(2.5%-15.2%)	(3.7-17.3%)	(1.3-13%)

Notes: 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 net present value of the $92 change in energy expenditure calculated over 3 time horizons: 1) infinite horizon, 2) 30 years, and 3) 18 years. In addition, I examine the sensitivity of these estimates to +/- 10% in the $92 change in energy expenditure calculation. I use the coefficient and confidence intervals from preferred reduced form estimation with unit FE and geographic area by time FE. Estimates using the 95% confidence intervals are in parentheses.

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

Dep. Var. Sales Price	Full Sample	Full Sample	Newer	Newer
price	-793.5***	-751.9***	-2375.9**	-1327.7
	(195.5)	(174.4)	(933.1)	(818.5)
Unit FE	Yes	Yes	Yes	Yes
Geo. AreaxYear FE	Yes	Yes	Yes	Yes
Oil Linear Trend	Yes	Yes	Yes	Yes
Year FExVintage FE	Yes	Yes	Yes	Yes
N	529008	528642	90532	90532
Implied Discount Rate	13.1%	13.9%	4%	7.4%
95% Confidence	8.5-29%	9.2-29%	2.2-20.5%	3.2-100%

Notes: Regressions are based on transaction and unit characteristic data for the state of Massachusetts from CoreLogic years 1990-2011. The Full Sample includes all housing vintages and Newer includes homes built between 1994 and 2011. Price is the average annual residential retail fuel price for oil or natural gas in $/MMBTU. All prices are inflated to 2012 dollars. Standard errors are clustered at the geographic unit level and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Table 5: IV Estimation of the Effect of Relative Fuel Price on Relative Transaction Price

(dep. var.)	First Stage (fuel price)	2SLS (sales price)
fuel price IV	1.080***	
	(0.0471)	
fuel price		-3544.8***
		(1313.8)
F-stat	264.9	
R^2	0.886	
Unit FE	Yes	Yes
Geo. AreaxYear FE	Yes	Yes
Oil Linear Trend	Yes	Yes
Age FE	Yes	Yes
N	528642	528642
Implied Discount Rate		2.7%
95% Confidence		1.5-10.6%

Notes: 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 $/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 clustered at the geographic unit level and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Table 6: Heterogeneous Effect of Relative Fuel Prices on Relative Transaction Prices

	sales price	sales price
income quartile 1 x fuel price	-566.4**	-726.9**
	(271.8)	(305.7)
income quartile 2 x fuel price	-762.5**	-1178.5***
	(311.4)	(290.0)
income quartile 3 x fuel price	-490.5	-634.4*
	(369.9)	(352.3)
income quartile 4 x fuel price	-2044.4***	-1141.2***
	(500.1)	(411.1)
demean sqft x fuel price		-1.259***
		(0.351)
Geo. AreaxYear FE	Yes	Yes
Unit FE	Yes	Yes
Year Specific Sqft Trend	No	Yes
N	529008	529008

Notes: 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 $/MMBTU. Geographic areas are assigned the average median income across the census block groups they contain from the 2000 Decennial Census. All prices and incomes are inflated to 2012 dollars. Standard errors are clustered at the geographic unit level and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Table 7: Heterogeneous Effect of Fuel Prices on Heating Fuel Consumption

	2012 USD ($)	MMBTU	MMBTU
income quartile 1 x fuel price	82.52***	-2.229***	
	(8.910)	(0.607)	
income quartile 2 x fuel price	79.03***	-2.547***	
	(9.959)	(0.629)	
income quartile 3 x fuel price	78.46***	-2.580***	
	(9.285)	(0.637)	
income quartile 4 x fuel price	87.96***	-2.097***	
	(8.449)	(0.614)	
income quartile 1 x log fuel price			-0.296***
			(0.0639)
income quartile 2 x log fuel price			-0.326***
			(0.0641)
income quartile 3 x log fuel price			-0.318***
			(0.0659)
income quartile 4 x log fuel price			-0.302***
			(0.0639)
demean sqft x fuel price	0.0380**	0.00137	
	(0.0187)	(0.00138)	
demean sqft x log fuel price			0.178
			(0.397)
I^{oil}	-138.7***	-2.548	-0.0726***
	(52.50)	(3.434)	(0.0247)
Year Specific Sqft Trend	Yes	Yes	Yes
N	1127	1127	1127

Notes: Data are from the Residential Energy Consumption Survey (RECS), northeast census division, survey years 1990, 1993, 1997, 2001, 2005, and 2009. RECS probability sampling weights are used. The unit of observation is housing unit × year. Fuel prices are the consumption weighted average residential retail price for states in the northeast census region. All usage and expenditure information is verified by the local utility. All prices are inflated to 2012 dollars. All specifications control flexibily for the house vintage, number of rooms, bedrooms and bathrooms, and year specific square footage trends. Standard errors are robust to heteroskedasticity and are in parentheses. ***, ** and * denote statistical significance at the 1, 5 and 10 percent levels.

Figures

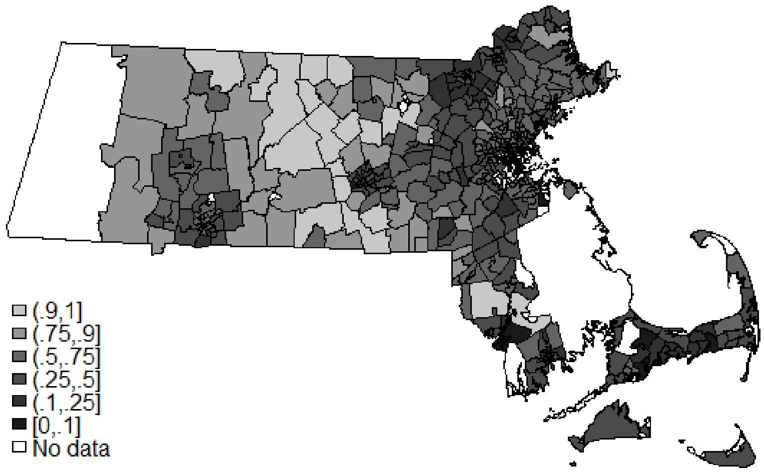

Figure 1: Proportion of Homes Heated With Oil

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

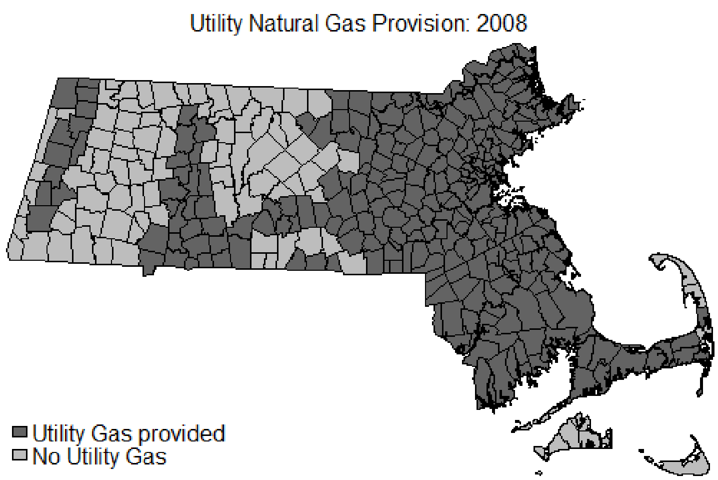

Figure 2: Utility Natural Gas Provision: 2008

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

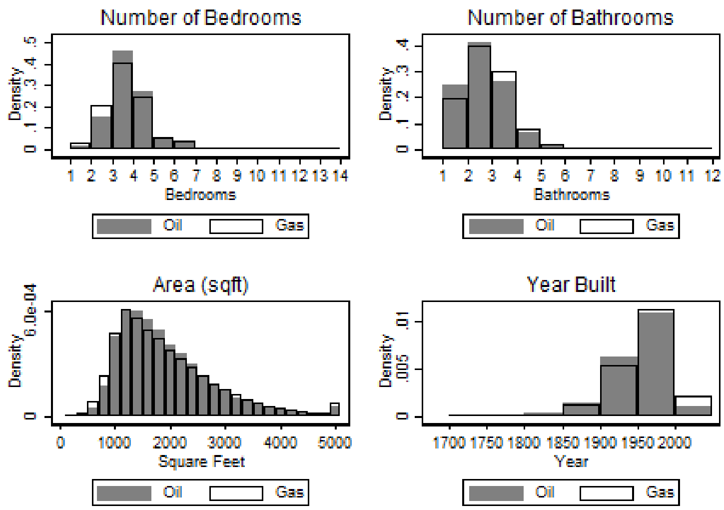

Figure 3: Overlap of Covariates

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

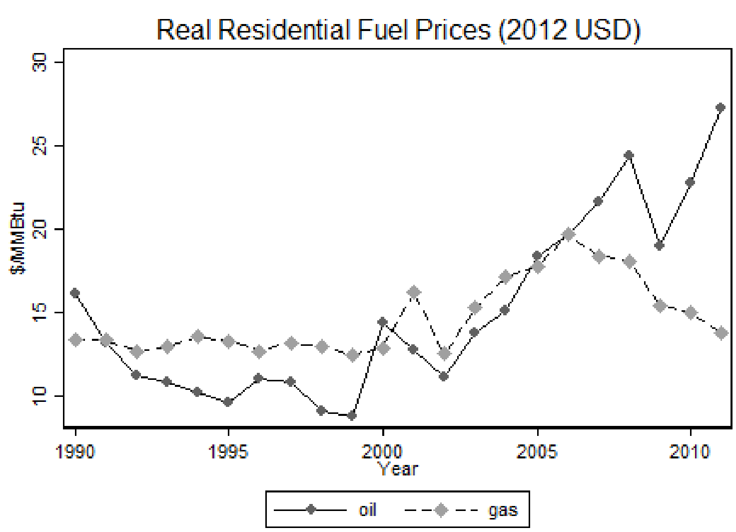

Figure 4: Real Residential Fuel Prices (2012 USD)

Notes: The prices are average annual retail prices ($/MMBTU) for the state of Massachusetts from EIA. All prices are inflated to 2012 dollars.

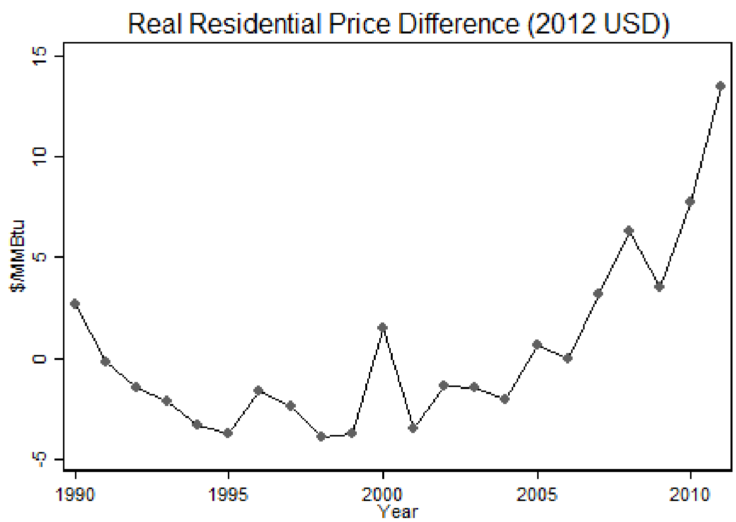

Figure 5: Real Residential Price Difference (2012 USD)

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

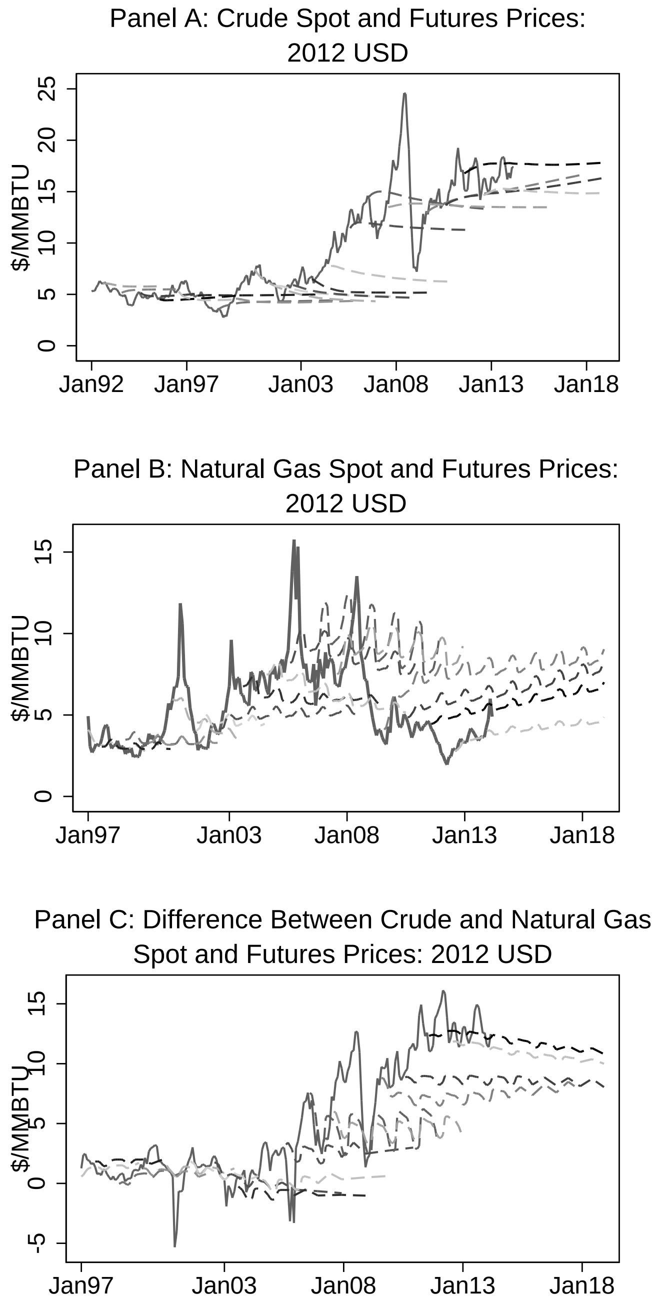

Figure 6: Spot and Futures Prices

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

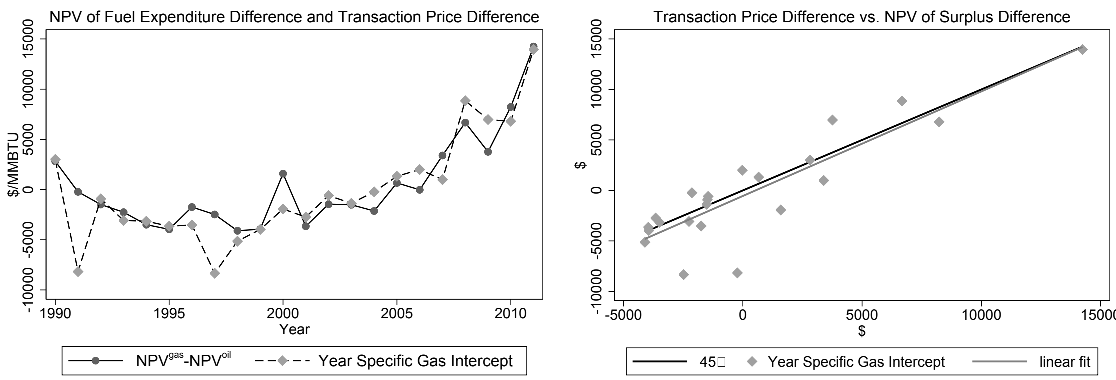

Figure 7: Net Present Value of the Fuel Expenditure Difference For Oil vs. Gas Houses Over Infinite Horizon With 9.5% Discount Rate and the Difference in Housing Transaction Prices

Notes: The graph on the left depicts the difference in the net present value of fuel expenditure between oil and gas houses and the difference in transaction prices. The graph on the right plots each mean difference in annual transaction price against the difference in the NPV of fuel expenditure between oil and gas houses for each year. All prices are inflated to 2012 dollars

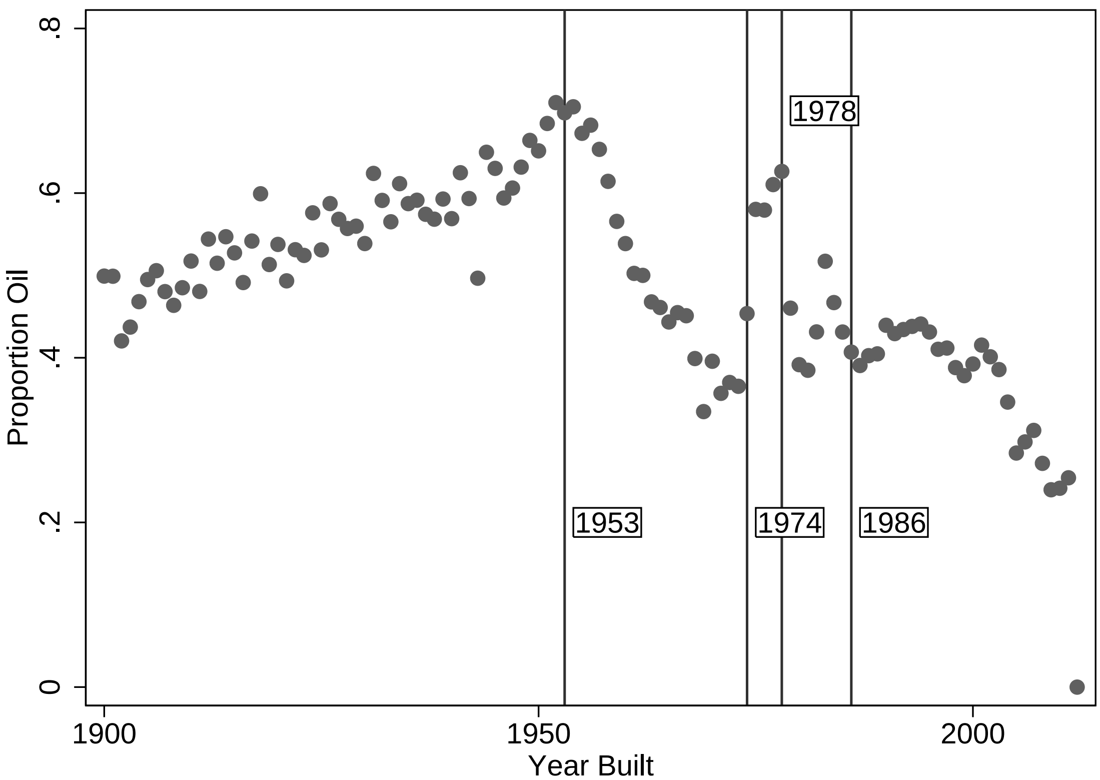

Figure 8: Proportion of Homes Built with Oil by Year Built

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.