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ABSTRACT

Residential natural gas customers in the United States face volumetric charges for natural gas that average about 30% more than marginal cost. The large markup on natural gas – which is used to cover the fixed infrastructure and operating costs of the local distribution companies – is widely recognized to be inefficient. Nonetheless, attempts to reduce volumetric charges, and cover the revenue shortfall through increased fixed monthly fees, have faced opposition based on the belief that current rate schedules have desirable distributional consequences. We evaluate this claim empirically using nationally-representative household-level data. We find that natural gas consumption is weakly correlated with household income, so current rate schedules are only mildly progressive. Under current rate schedules, high-volume customers pay a disproportionately large share of fixed costs, but these exhibit a weak correlation with high-income households. The correlation is somewhat weaker still when we consider alternative indicators of household financial stress, such as poverty status or number of children in the household. We show, for example, that poor households with multiple children would receive lower bills on average under marginal cost pricing. We present evidence that one cause of the weak redistributional impact of the current pricing policy is that the poor tend to live in less energy efficient homes.

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1 Introduction

In regulated markets there is a temptation to use price schedules to pursue distributional objectives. This is often in direct conflict with efficiency, which requires that prices be set equal to marginal cost for all customers.[1] This tradeoff between equity and efficiency is particularly acute in markets with large fixed costs such as energy, water, transportation and telecommunications.

Residential sales of natural gas exemplify this issue. A large part of the total cost of household natural gas consumption is the cost of transportation and distribution. Local distribution companies (LDCs) in the United States spend billions annually installing and maintaining the distribution grid and metering infrastructure, as well as in processing bills, taking customer service calls and other functions. Many of these costs are fixed with respect to the number of customers served or the volume they consume. As a result the LDC functions are widely considered to exhibit declining average costs within a geographic region, a classic natural monopoly. Exactly the same issue comes up in electricity, water and, until recently, wired phone service.

The challenge in regulating markets with declining average costs is that a single price set equal to marginal cost does not provide enough revenue to pay for fixed costs. Coase (1946) was among the first to consider the question of what efficient pricing would look like in such markets. His solution was to use two-part tariffs. In the simplest case, the tariff has two components, a volumetric charge and a fixed monthly fee. The volumetric charge is set equal to marginal cost and the fixed monthly fee is set equal to each customer's share of fixed costs.

In practice, natural gas rate schedules in the United States differ substantially from this theoretical ideal. Although the norm is indeed to use two-part tariffs, typically this takes the form of low fixed monthly fees and high volumetric charges. We find that, on average, volumetric charges for residential customers are marked up by about 30% above marginal cost. These markups impose deadweight loss by leading existing natural gas customers to consume too little natural gas, and imply that high-volume customers pay a larger share of fixed costs than low-volume customers.

A natural approach to address these departures from marginal cost pricing would be to reduce the markups and increase fixed monthly fees commensurately. Although it is widely understood that efficiency could be improved by moving closer to marginal cost pricing, attempts at rate reform face substantial political opposition because of a widespread perception that current rate schedules have desirable distributional consequences. Poor people consume less natural gas, it is argued, so rebalancing revenue collection towards the fixed monthly fee would disproportionately harm them. Although this view is widely held by regulators and rate-payer protection groups, we are aware of

[1] This is true in the absence of other distortions. We discuss second-best issues later in the paper.

little direct empirical evidence that supports it.

In this paper we use a nationally representative household-level dataset to calculate the distributional impact of a transition to marginal cost pricing. Our analysis shows that rebalancing rates would indeed cause low-volume customers to pay more and high-volume customers to pay less. We also find, however, that high-volume and high-income are not synonymous; the correlation between natural gas consumption and household income is positive, but surprisingly weak. Consequently, current price schedules deliver only a modest amount of redistribution from high-income to low-income households. For example, we find that under marginal cost pricing households in the lowest (first) income quintile would pay an average of $44 more per year for natural gas, while households in the fifth quintile would pay an average of $58 less. These bill impacts are fairly small when viewed as a fraction of household natural gas expenditure or as a fraction of total household income.

Our paper highlights two confounding factors that help explain the weak correlation between natural gas consumption and household income. First, we document a positive correlation between household income and energy efficiency. Controlling for geographic region, low-income households tend to have older furnaces, live in poorly insulated homes, and have single-pane windows. This may be explained, in part, by the fact that low-income households are more likely to be renters and the principal-agent problem between landlords and tenants leads to underinvestment in energy efficiency. Second, we show that low-income households are more likely to have children in the home. Households with children are more likely to be home during the day and more likely to keep their homes at higher temperatures. With more energy efficient homes and fewer children, high-income households tend to use less natural gas than would be expected due to the income effect alone.

We evaluate the distributional consequences of rate reform using several different measures of household need, beginning with household income. Household composition is an important factor in measuring financial need, so we also measure redistribution by the ratio of income to the poverty line for the specific household's composition of adults, children and elderly. Using this needs-adjusted measure of household income we find even smaller distributional impacts. In addition, we focus directly on households with different numbers of children, finding that households with children would pay less on average under marginal cost pricing, and households with two or more children would pay substantially less.

We also consider a variety of different assumptions about the price elasticity of demand. The first set of results is calculated assuming that customers exhibit zero elasticity to this change in prices. Then we expand the analysis to recognize that customers faced with lower volumetric charges will consume more natural gas. Incorporating efficiency gains into the analysis makes the welfare impact of a change to marginal cost pricing more positive (or less negative) for all households. Under the most plausible behavioral responses, we find that the average household in the lowest quintile would see its consumer surplus fall by $21 per year, while the average household in the highest quintile would gain $69 per year.

Moreover, we assess how the distributional consequences of rate reform would be affected by energy assistance programs. The largest such existing program, the Low Income Home Energy Assistance Program (LIHEAP) operates in all 50 states with a $4.5 billion dollar budget in 2009. We discuss some of the challenges inherent in administering such programs, but also provide evidence indicating that needs-tested programs can substantially mitigate the negative distributional effects of a transition to marginal cost pricing. We show that even a relatively modest energy assistance program ($10 per month) would more than offset the distributional impact of rate reform for most low-income households.

This paper is related to a rich existing theoretical literature on the efficiency and equity of two-part tariffs. Coase (1946) is a response to Hotelling (1938) which argues that all prices in an economy should be set equal to marginal cost, with fixed costs paid for with government subsidies from income, inheritance, and property taxes. In cases where it is impractical to pay for fixed costs using government subsidies, Baumol and Bradford (1970) derive elasticity-based conditions following Ramsey (1927) to describe how prices should be marked up above marginal cost.[2] Feldstein (1972) incorporates equity into the analysis, showing how by assuming a functional form for the social welfare function one can derive formulas for the socially optimal two-part tariff. Auerbach and Pellechio (1978) build on the model described by Feldstein, taking into account that prices affect the number of customers in a market and that these changes along the extensive margin may be important for efficiency.

The paper proceeds as follows. Section 2 describes relevant background information about the structure of the residential natural gas distribution market. Section 3 discusses the data used for the analysis. Section 4 describes current natural gas rate schedules in the United States and presents estimates of volumetric charges and fixed monthly fees. Section 5 performs the key counterfactual in the paper, calculating the changes in bills that would be experienced in a transition to marginal cost

[2]Baumol and Bradford focus broadly on departures from marginal cost pricing in the economy but point out that their main results are applicable for two-part tariffs in regulated markets. Ng and Weisser (1974) make this application explicit, deriving conditions that describe the optimal two-part tariff in the presence of a budget constraint when the number of customers is not fixed. A related literature including Oi (1971) and Schmalensee (1981) examines two-part tariffs in unregulated monopoly markets.

pricing. Section 6 extends this analysis, incorporating efficiency effects and discussing implications for related markets including the market for greenhouse gas emissions. Finally, Section 7 concludes by summarizing the key lessons of the analysis.

2 The Natural Gas Distribution Market

The natural gas market in the United States consists of gas producers, interstate pipeline operators, and local distribution companies (LDCs). Our analysis focuses on LDCs, a segment of the market for which costs are well understood. The main cost for LDCs is the commodity cost of natural gas, which is measured by the "city gate price", the price at which the LDC receives natural gas at the entrance to its distribution network. Once the gas enters the distribution network, very small quantities are lost to leakage and used to power the compressors that push the gas through the system, but these represent a negligible fraction of total costs.[3]

Natural gas distribution is a large market that directly affects over 60% of U.S. households. Between 2000 and 2009, total expenditure on natural gas by residential customers averaged $53 billion annually. Of this, $20 billion on average went to costs incurred by LDCs above and beyond the cost of natural gas itself.[4] The large size of the market suggests that both the efficiency and equity implications of rate schedule adjustments could be significant. In this section, we briefly describe the organization of the market, highlighting the features that are relevant for the analysis.[5]

In addition to commodity costs, LDCs face the fixed and sunk costs of installing and maintaining the pipeline network, installing and maintaining gas meters, processing bills and taking customer service calls. These costs are virtually all fixed with respect to the level of consumption of natural gas. Some of these are "customer-level" fixed costs – which scale approximately with the number of customers served, such as billing and meter installation/maintenance – while others are "system-level" fixed costs, which are largely invariant to the number of customers.

Natural gas LDCs are regulated by state utility commissions which set rate schedules for each customer class. Using traditional rate-of-return techniques, regulators determine rate schedules to equate total revenues from all customer classes with total costs. A standard result in regulation

[3]According to U.S. Department of Energy (2008), in 2005 44 billion cubic feet of natural gas was used by LDCs for pipeline and storage compressors, new pipeline fill, and other uses associated with the operation of the distribution grid. Another 19 billion cubic feet was lost out of the distribution grid from leaks, damage, and accidents. However, all of this together represents only 0.5% of the natural gas transported by LDCs. Therefore, the city gate price is a good approximation of the marginal cost of delivering an additional unit of natural gas. In the empirical analysis we inflate city gate prices by 0.5% to account for these pipeline and storage uses.

[4]U.S. Department of Energy (2010a).

[5]For more information about the organization and regulatory history of the U.S. natural gas market see Viscusi, Hamilton, and Vernon (2005) and U.S. Department of Energy (2010b).

is that efficiency requires that marginal prices be set equal to marginal costs. The availability of two-part tariffs facilitates pricing at marginal cost because the volumetric charge can be set equal to marginal cost and the fixed monthly fee set to cover fixed costs. In natural gas with declining average costs and constant marginal costs, this would imply setting the fixed monthly fee equal to each customer's share of the LDC's fixed costs.[6]

In practice, natural gas rate schedules differ substantially from this theoretical ideal. Typically the volumetric component includes not only a commodity charge, but also an additional per unit charge for transportation infrastructure, maintenance, billing and other non-volumetric costs, thus increasing the retail price per unit well above marginal cost. To better understand rate schedules in the United States we examined the residential rate schedules for the fifty largest natural gas LDCs. As of summer 2010, 48 of 50 had some fixed monthly fee in their tariffs, generally ranging from \$5 to \$15 per month, but as high as \$26, and two LDCs had no fixed monthly fee. The volumetric charge for natural gas is constant for 30 of the 50 LDCs, with 13 charging decreasing-block prices (a higher volumetric charge for the first units consumed each month and then a lower volumetric charge for all additional units) and the remaining 7 charging increasing-block prices. In all 50 cases, the volumetric charge was well above the marginal natural gas acquisition cost of the LDC. This pattern of low fixed monthly fees and high volumetric charges has been a well-known feature of natural gas rate schedules in the United States since the emergence of a national natural gas market in the 1930s.

This combination of low fixed monthly fees and high volumetric charges causes LDC net revenues – net of commodity costs – to be highly seasonal, with LDCs collecting a large share of their total annual net revenue during cold, high-demand winter months. LDC net revenues are highly volatile both across months and across years. For example, a warmer than average winter can dramatically reduce an LDCs annual net revenue. This revenue volatility is a major source of concern among natural gas LDCs. Simple time-series forecasting of residential consumption a year in advance has a 95% confidence interval of about plus or minus 20% of sales, so the annual mismatch between net revenues and the non-commodity costs of the LDC can be quite substantial.[7]

[6] Although in theory fixed monthly fees could vary between different types of households, most natural gas LDCs use uniform pricing, in which all households in the utility district face the same price schedule. An important exception is energy assistance for low-income households, an issue to which we return in Section 5.2. Later in the paper we also address the extensive margin (in Section 6.2) and the idea that increasing fixed monthly fees can inefficiently induce customers to stop using natural gas altogether.

[7] To arrive at this figure, we collected sales data on 1084 natural gas utilities in the U.S. from the EIA-176 Query System. We then estimated the regression $ln(Q_t) = \alpha_0 + \alpha_1 ln(Q_{t-1}) + \alpha_2 t + \alpha_3 t^2 + \epsilon$ where Q_t is residential consumption for year t. The mean standard error of these regressions was about 0.1 (median about 0.09). Results are essentially identical using average usage per customer, indicating that this volatility is not driven by changes in the number of customers.

Many utilities have adopted a variety of innovative rate designs that "decouple" net revenues from consumption levels. The simplest and most efficient approach to reducing this volatility would be to increase the fixed monthly fee and reduce the volumetric charge to more closely reflect the marginal acquisition costs for natural gas. Nonetheless, with few exceptions natural gas utilities have not gone in that direction. Instead, "decoupling" typically involves mechanisms by which the volumetric component of the bill is automatically adjusted in response to weather and other factors.[8]

Distributional considerations are frequently cited as an explanation for this preference for volumetric charges.[9] When LDCs revenues are overwhelmingly derived from the volumetric charge, high-demand customers are responsible for a larger share of total revenues than they would be if gas were priced at marginal cost. When the fixed monthly fee is zero, for example, a customer consuming 100,000 cubic feet annually pays twice as much as a customer consuming 50,000 cubic feet despite the fact that the cost of providing distribution service to these customers is nearly the same. This can have positive distributional consequences to the extent that natural gas consumption is correlated with household income or other measure of need.

This distributional argument features prominently in rate hearings. For example, the Attorney General of Arkansas has argued against proposed increases in the fixed monthly fee, "While consumption by individual customers varies, on the average, lower income people use less natural gas than higher income people." (Docket 04-121-U) Comparing natural gas consumption with average household income at the zip code level, this testimony finds a "mild but statistically significant relationship to income", and argues that increases in the fixed monthly fee are, "likely to harm low income people" (Docket 06-161-U).[10]

Concerns about the distributional implications of rate reform persist even though several state and federal programs provide energy assistance for low-income households. Nonetheless, how effectively these income-based programs would mitigate the distributional consequences of rate reform is an empirical question. As we discuss later in the paper, the effectiveness of energy assistance

[8] For details see American Gas Association, "Decoupling and Natural Gas Utilities: Fact Sheet," released February 2010. As of 2010, 26 utilities in 13 states have adopted mechanisms that adjust volumetric charges in response to weather and other factors.

[9] An alternative explanation for this preference for volumetric charges is offered by Sherman and Visscher (1982) who argue that rate schedules in electricity and natural gas are a manifestation of the Averch-Johnson effect (Averch and Johnson, 1962). The argument is that a low fixed monthly fee and high volumetric charge increase the total number of customers because even customers with a low level of demand for natural gas decide to connect. This increases the total level of capital expenditures and, if allowed rate of return is above the cost of capital, also profits.

[10] See also JBS Energy, Inc. "Economic and Demographic Factors Affecting California Residential Energy Use" September 2002 and NERA Economic Consulting, "Economic and Demographic Factors Affecting Arkansas Residential Energy Use" April 2007. The 2002 study finds that lower-income households are more likely to live in multi-unit buildings, which tend to use less energy for heating than single-family units of the same size.

programs depends not only on the overall budget allocated for energy assistance, but also on the particular income-eligibility rules, as well as the take-up rate among eligible populations.

3 Data

3.1 The Residential Energy Consumption Survey

The central dataset used in this analysis is the 2005 Residential Energy Consumption Survey (RECS), a nationally-representative in-home survey of households in the United States conducted every five years by the Department of Energy.[11] The RECS provides detailed information about the demographic characteristics of the household including household income, number of children, and the age of all household members. In addition, RECS includes highly-detailed information about the housing unit itself as well as about the appliances owned by the household.

The 2005 RECS includes 4,382 total households. From the complete sample we exclude households who do not use natural gas. This eliminates 1,690 households, or 39% of the sample. In addition, we exclude an additional 137 households who do not directly pay for natural gas. Most of these households live in rental housing units in large multi-unit buildings where household-level metering is not available. It makes sense to drop both of these groups of households because neither would be directly affected by changes in natural gas rate schedules. After these exclusions we are left with a sample that includes 2,555 households, or about 500 per group when we examine households by quintile.

An important feature of the RECS is that, in addition to these household and housing characteristics, it provides high-quality information about natural gas consumption and expenditure. This information is obtained directly from the LDC that provides natural gas to the home. The data collection proceeds as follows. First, during the in-home survey the household is asked which company supplies natural gas to the home. If available, the surveyor also makes copies of the household's recent bills to make it easier to match households with their billing records. Second, the staff at RECS follows up with the LDC, requesting the previous 12 months of bills for the household. Third, the RECS staff use this information to construct an annual measure of natural gas consumption and expenditure for each household.[12] RECS is the only nationally-representative

[11] Interviews for the 2009 RECS started in February 2010, but microdata will not be available for several years.

[12] In requesting bill information from the LDCs, the Department of Energy makes it clear that the reported dollar amounts for expenditures should include all charges including the fixed monthly fee. The survey instrument is also clear about how households on LIHEAP and other energy-assistance program should be treated. In particular, the LDCs are clearly instructed not to report the discounted bill, but instead to report the dollar amount of how much the household would have paid had they been on the regular rate schedule without energy-assistance.

household-level survey that provides both demographic information and utility-provided energy billing data.

The measure of income in the RECS is total household income from all sources (employment income, retirement income, cash benefits from public assistance, and non-cash benefits) before taxes and deductions. Income is reported in 24 different categories ranging from the annual equivalent of "less than $2,500" to "more than $120,000". In the analysis that follows we use a continuous measure of household income constructed using the midpoint of the range.[13] For each household we calculate their Federal income tax liability using TAXSIM Version 9.0.[14] We calculated tax liability for 2005 using household income, marital status, number of children, and the age of the household head. We then subtracted tax liability from household income to calculate after-tax annual household income for each household.

3.2 Federal Poverty Thresholds

To gauge the financial stress on a household, many researchers have argued that income should be adjusted for household composition. To do so, we also examine household income as a percentage of the federal poverty threshold for the specific household's demographics. We use the federal poverty thresholds for 2005 which are based on the total number of household members, the number of children, and whether or not the household head is age 65 and over.[15] Poverty thresholds vary considerably depending on household composition, ranging from $9,367 for a single individual 65 years and over to $37,757 for a household with eight or more children. We prefer this measure of needs-adjusted household income to household income per capita because the former measure takes into account that there are differences in needs across household members of different ages and that there are economies of scale within the household.[16]

[13]For the top category we use $200,000 based on the conditional mean from more detailed household annual income data for 2005 from U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplement for 2006. Table HINC-06. "Income Distribution to $250,000 or More for Households: 2005". Our results are not sensitive to this assumption, however, because we perform the distributional analysis by quintiles and even after adjusting for differences in the composition of households these households in this top income category are always assigned to the top quintile.

[14]For more information about TAXSIM see Feenberg and Coutts (1993). Created and maintained by the National Bureau of Economic Research, TAXSIM is a tax calculator designed for use with survey data. Based on a database of hundreds of thousands of actual tax returns, the program has been used in hundreds of studies and has been shown to calculate Federal income tax liability to a high degree of accuracy.

[15]U.S. Census Bureau, Housing and Household Economic Statistics Division, "Poverty Thresholds for 2005 by Size of Family and Number of Related Children Under 19 Years". Except for somewhat higher poverty thresholds established for Alaska and Hawaii, neither the poverty thresholds from the U.S. Census Bureau nor similar "poverty guidelines" from the U.S. Department of Health and Human Services distinguish by state. We discuss in Section 3.3 that the RECS data do not identify state of residence for most households, so even if state-level thresholds were available they would be difficult to incorporate.

[16]Deaton and Muellbauer (1980, Chapter 8) provides a primer on using equivalence scales for comparing welfare across households with different characteristics.

Table 1 reports covariate means and standard deviations by needs-adjusted household income quintile. The first quintile, for example, includes households between 0 and 148% of the federal poverty line. Annual household income increases from an average of $16,500 in the first quintile to $129,800 in the fifth quintile. All dollar values in the paper have been inflation-adjusted to reflect year 2010 prices. The large standard deviations for household income reflect the fact that the poverty thresholds vary across households depending on household composition. For example, households with several children can have a relatively high level of household income yet appear in one of the bottom quintiles for needs-adjusted household income.

Household economic and demographic characteristics differ substantially across quintiles. The average number of children decreases from 0.94 in the poorest quintile to 0.52 in the wealthiest quintile and the proportion of households who own a home increases steadily across quintiles from 0.49 to 0.91. The proportion of households who receive energy assistance declines across the quintiles as one would expect. Whereas 18% and 6% of households in the two lowest quintiles received some form of energy assistance in 2005, no households in the highest three quintiles received energy assistance.

Natural gas consumption and expenditure in panel (B) increase across quintiles. Mean annual expenditure on natural gas increases from $743 to $993, and the fraction of income dedicated to natural gas expenditures decreases from 6% to less than 1%. In our sample the simple correlation between natural gas consumption and household income is .19 and the correlation between natural gas consumption and needs-adjusted household income is .13.

Figure 1 is a scatterplot of natural gas consumption against household income. Each observation is a household and the figure includes a fitted least squares regression line.[17] The figure illustrates that whereas the correlation is positive, little of the variation in natural gas consumption is explained using the variation in household income. Part of this lack of correlation between natural gas consumption and household income can be explained by systematic differences in natural gas consumption across climate zones. However, even within geographic divisions household income explains only a small fraction of the variation in natural gas consumption. Figure 2 plots residuals from a regression of natural gas consumption on indicator variables for each of the nine census divisions against household income. Again the correlation is positive, but weak. Across census divisions the average R^2 from a regression of natural gas consumption on household income is .09.[18] This weak correlation between income and natural gas consumption illustrates the chal-

[17]For presentation purposes we have excluded from this figure households whose annual after-tax household income exceed $120,000 or whose annual natural gas consumption exceeds 250,000 cubic feet. These households are included in all statistical analyses.

[18]Ideally it would be preferable to examine the *within-utility* correlation between natural gas consumption and

lenge of using natural gas price schedules for redistribution, highlighting the fact that only very large changes in the price schedule will be have substantial distributional effects, and that any price reform will impact different types of households differently.

Finally, panel (C) describes three measures of residential energy efficiency. The proportion of households that report having a heating system that is less than 10 years old increases across quintiles from 34% to 50%. Likewise, the proportion of the houses that are well insulated and the proportion that have double pane windows both also exhibit a strong positive correlation with needs-adjusted household income. This positive relationship between energy efficiency and needs-adjusted household income remains after controlling for geographic division. In alternative results (not reported) we regressed energy efficiency on needs-adjusted household income and indicator variables for each census division. For all three measures of energy efficiency the coefficient on needs-adjusted household income is positive and statistically significant with t-statistics ranging from 5.4 to 9.9.

One potential explanation for this pattern is the landlord-tenant problem. Many studies have pointed out that landlords may underinvest in energy efficiency when their tenants pay the utility bill.[19] Although investments in energy-efficiency could, in theory, be passed on in the form of higher rents, it may be difficult for landlords to credibly convey information about energy efficiency. In the higher quintiles, households are considerably more likely to be homeowners, and so the landlord-tenant problem is less important. When we restrict the sample to exclude renters the correlation between energy efficiency and needs-adjusted household income is positive but weaker. In additional alternative results (also not reported) we used this smaller sample to perform the same regressions as before. For all three measures of energy efficiency the coefficient on needs-adjusted household income is again positive and statistically significant. However, the magnitude of the coefficient estimates is 23.8%, 25.2% and 15.1% smaller in magnitude, respectively, consistent with the landlord-tenant problem providing some but not all of the explanation for the observed correlation. Other potential explanations include capital constraints, a negative correlation between income and discount rates (see, e.g. Hausman, 1979 and Dubin and McFadden, 1984), or the idea that the comfort provided by energy efficiency is a normal good.

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income. Although this is not possible with the RECS data, in additional results described in Appendix A we have used an alternative dataset to examine the within-utility correlation for California utilities. Across the three major natural gas LDCs in California the average R^2 from a regression of natural gas consumption on household income is .04.

[19]For a recent investigation of this relationship, see Davis (forthcoming).

3.3 Wholesale Natural Gas Prices

In order to be able to evaluate the impact of price reform, we augment the household-level data from RECS with natural gas city gate prices from the Platts' GASdat database. Our measure of wholesale prices is the "city gate" price, the price paid by LDCs at the entrance to the distribution network. The Platts data describe daily natural gas spot prices from 131 locations throughout the continental United States, obtained by Platts via surveys of trades made at each location. We aggregate daily city gate prices to the monthly level and then calculate state averages across all locations in a given state. For states without Platts survey locations, prices from the closest available location are used.

Next we aggregate these data to the annual level by taking consumption-weighted averages over the year. Total residential consumption by state and month comes from the U.S. Department of Energy (2010a). The Department of Energy constructs these data using a monthly survey (EIA Form-857) of natural gas distribution companies. This accounts for the fact that city gate prices tend to be somewhat higher during winter months when consumption is higher, though seasonal variation in natural gas prices is mitigated by the ability of natural gas suppliers to store natural gas.[20]

For the main analysis we use city gate prices for the period 2003 to 2005. Although LDCs procure natural gas both on the spot market and in forward markets, LDCs always have the option to buy or sell natural gas on the spot market. Consequently, the city gate price in a given year is a good measure of the true marginal cost of natural gas in that year.[21] The RECS data report residential consumption for 12-month periods ending at different times during 2005, so the relevant wholesale prices would be from 2004 and 2005 if residential tariffs adjusted immediately to wholesale price changes. To account for the fact that there is frequently a lag in adjustment, we include 2003 prices as well. Results are qualitatively similar when we use only 2005 data, though they differ somewhat because there was an unusually sharp increase in natural gas prices during that year. Many utilities do not have mechanisms that allow them to immediately pass on price increases to consumers, so LDC net revenue for 2005 was substantially below average. Using average city gate prices for the period 2003 to 2005 provides a more reasonable representation of typical LDC net revenues.

The RECS identifies the census division of residence for all households. In addition, the RECS identifies the state of residence for households living in Texas, California, New York, and Florida.

[20] U.S. Department of Energy (2010b), Table 14 reports that as of December 2008 working natural gas storage in the lower 48 states is 4.2 trillion cubic feet, enough to meet total consumption for about two months.

[21] See Borenstein, Busse, and Kellogg (2009) for a detailed description of natural gas procurement.

We assign wholesale prices to households using the most highly-disaggregated geographic unit available, separating households in Texas, California, and New York from their respective census divisions. Because there are few households in Florida with natural gas connections, we do not attempt to separate these households from their census division (South Atlantic). Also, we drop the Pacific census division (Alaska, Hawaii, Oregon and Washington) because Platts city gate prices are not available for Alaska and Hawaii and because even if some city gate price could be constructed for these states this census division is extremely heterogeneous with regard to proximity to natural gas producers, weather, and other factors. Thus, the resulting set of geographic units includes eight census divisions and three individual states.[22] For brevity, in the rest of the paper, these geographic units are referred to simply as divisions. In calculating city gate prices by division, we use consumption weights across states.

We focus on city gate prices, because those represent most accurately the true marginal cost of the LDC acquiring additional supplies. Most LDCs purchase some natural gas on short-term fixed-price, fixed-quantity contracts 30-120 days in advance. Some LDCs also purchase on longer-term contracts. Because these contracts are for fixed quantities at fixed prices, and because there are active daily spot markets, the contracts do not change the LDC's marginal opportunity cost of providing additional natural gas. They do, however, create capital gains and losses that the LDC must recover through its rates.

4 Current Natural Gas Rate Schedules

4.1 Graphical Evidence

In this section we use household-level natural gas consumption and expenditure to describe the natural gas rate schedules faced by residential customers in the United States. Figure 3 plots annual consumption and expenditure by division. Each observation is a household and the figures include a fitted least squares regression line (the dashed grey line).[23] Within divisions there is large variation across households in annual natural gas consumption. As expected, the figures

[22]Thus, in addition to the three individual states (California, New York, and Texas), our modified divisions include New England (Connecticut, Maine, Massachusetts, New Hampshire, and Rhode Island), Middle Atlantic (New Jersey and Pennsylvania), East North Central (Indiana, Illinois, Michigan, Ohio, and Wisconsin), West North Central (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota), South Atlantic (Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia), East South Central (Alabama, Kentucky, Mississippi, and Tennessee), West South Central (Arkansas, Louisiana and Oklahoma), and Mountain (Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, and Wyoming).

[23]For presentation purposes in these figures we dropped households with annual consumption above 250,000 cubic feet or annual expenditure above $2,500. These outliers represent less than 2% of the total sample. All subsequent analyses in the paper includes these observations. We have also tested the sensitivity of our results to excluding these outliers and the results are essentially identical.

demonstrate a strong positive correlation between consumption and expenditure. In fact, in most divisions there are a group of households (and in some cases, more than one group) for whom the relationship is almost exactly linear. This is consistent with these observations all coming from the same utility and linear rate schedule.

There is also, however, a large degree of heterogeneity in expenditure in all divisions. In many cases different households consuming the exact same amount of natural gas in the same division pay considerably different amounts. This heterogeneity in rate schedules is at first surprising. After all, natural gas can be easily transported so wholesale prices do not vary much within division. Instead, these differences are driven by differences in the cost of local distribution and other costs that are recovered in the LDC's volumetric charge. Within each division there are several different LDCs and costs vary across LDC based on the mix of residential, commercial, and industrial customers, average consumption levels, population density, age of the distribution grid, and other factors.[24] In addition, the heterogeneity in rate schedules reflects the fact that households differ in the timing of their consumption. Many utilities charge rates that vary seasonally so a household that consumes proportionately more during winter months pays more on average per unit. A limitation of the RECS data is that they do not provide monthly consumption, making it impossible to distinguish these seasonal differences in consumption from differences in price schedules across households.

Another factor that creates differences in rate schedules within divisions is retail choice. Several states including Georgia, Maryland, New York, Ohio, Pennsylvania, and Virginia have active retail choice programs for residential natural gas customers. In these states customers have a choice between buying natural gas from their LDC and buying natural gas from independent natural gas marketers who set their own rate schedules. If the customer buys from an independent marketer, the LDC provides and is reimbursed for transportation services – for the most part on a volumetric basis – but marketers set the rate schedules, procure natural gas in the wholesale market, and bill customers directly.[25] Despite the fact that most of the LDC's costs of providing the services to retail choice customers do not vary with volume, most of the LDC's revenues from these customers are collected on a volumetric basis.

In the calculations that follow we compare households actual expenditure on natural gas with how much they would have spent under marginal cost pricing. Because rate schedules vary within division, however, and because we do not observe the exact rate schedules that each household faces,

[24]LDCs also differ in the longer term natural gas contracts that they sign and the gains and losses these contracts yield relative to the city gate prices. Those gains and losses are part of why rates differ across LDCs in the same division.

[25]In December 2005, 3.9 out of 62.5 million residential natural gas customers in the United States purchased natural gas from a marketer rather than their LDC. See U.S. Department of Energy (2005) for details.

our counterfactual also implicitly imposes a uniform retail tariff for all customers within a division. Under these counterfactual tariffs, all customers within a division pay the same fixed monthly fee and the same volumetric charge. An alternative approach is to perform this harmonization for both the current tariffs and the counterfactual tariffs. This is done by using the fitted values from equation (1) below to predict each household's expenditure under the average rate schedule for that division. These predictions can then be compared to expenditure under the marginal-cost-based alternative tariff. We prefer the former approach because it does not require any assumptions about the structure of current rate schedules. Nonetheless, it is reassuring that when we instead use this alternative approach results are quite similar.

Moreover, results are also similar when we repeat the analysis with a completely different dataset, the Residential Appliance Saturation Survey (RASS). A household-level survey conducted in 2003 by the California Energy Commission, the RASS identifies the exact utility that serves each household, allowing us to perform the counterfactual bill analysis separately by utility. As described in detail in Appendix A, the general pattern of results is very similar with these alternative data. Together with the results from the alternative "harmonization for both actual and counterfactual" approach above, this analysis suggests that our results are not driven by that fact that we create the counterfactual at the geographic division, rather than utility, level. In retrospect this is not surprising because there is no reason *ex ante* for there to be substantial correlation between within-division departures from average rate schedules and our measures of household well-being.

4.2 Volumetric Charges

Table 2 describes natural gas rate schedules by region. For clarity, we present results for the four geographic census regions in the continental United States (North, Midwest, South, and West) that aggregate the areas reported in the RECS data.[26] Columns (1) and (2) describe average features of natural gas rate schedules. These estimates are derived from the following regression,

$$Expenditure_{ij} = \alpha_{0j} + \alpha_{1j} Consumption_{ij} + \epsilon_{ij}, \tag{1}$$

where $Expenditure_{ij}$ is annual expenditure for household i in division j, $Consumption_{ij}$ is annual natural gas consumption, and ϵ_{ij} is an error term which captures unmodeled differences in the rate

[26] West includes California and the Mountain division; South includes Texas and the West South Central, East South Central, and South Atlantic divisions; North includes the West North Central and East North Central divisions; Northeast includes New York and the Middle Atlantic and New England divisions.

structure across households. We estimate equation (1) separately for the 11 different divisions.[27] The parameters in this regression have a direct economic interpretation. The intercept, α_{0j}, is the mean amount paid annually in fixed monthly fees, or equivalently, the level of expenditure implied by the regression equation for a household that consumes zero. The slope, α_{1j} is the mean volumetric charge for natural gas.

Table 2 reports average parameter estimates (weighted by households) for North, Midwest, South, and West regions. Column (1) reports the average estimate of α_{1j}, the volumetric charge and column (2) report the average estimate of α_{0j}, the fixed monthly fee. Column (3) reports the wholesale price of natural gas. Wholesale prices were somewhat higher on average in the Northeast and somewhat lower in the West during this period. These differences reflect differences in transportation costs across regions. Most natural gas in the United States is produced in gas fields concentrated in the South Central United States and wholesale prices tend to increase as one moves farther away from these producing areas. On average across all regions households faced a volumetric charge of \$11.34 compared to a city gate price of \$8.63 for an average markup of 32.1%. Markups vary somewhat across regions but in all regions the volumetric charge is marked up considerably above marginal cost.

Our approach uses within-division, across-household variation to infer the average rate schedule in each geographic division. An alternative to this regression-based approach would be to match households with their exact rate schedules. With the RECS this is not feasible, however, because RECS does not identify exactly where households live or from which utility they obtain natural gas. Given this indirect method for inferring average rate schedules, it is important to cross-check our estimates with measures of rate schedules from other sources. Davis and Muehlegger (forthcoming) use aggregate data and a different empirical approach to estimate residential natural gas schedules in the United States during the period 2002-2007. They find an average markup of \$3.38 per thousand cubic feet compared to our average markup of \$2.71. Although we continue to recognize that our estimates are only an approximation, it is reassuring that this important feature of the rate schedules is similar to this existing estimate in the literature.[28]

[27] We have also tried a more flexible specification that allows α_0 and α_1 to vary both across division and across (i) urban, (ii) suburban, (iii) town, and (iv) rural locations. Although utilities typically do not use different rate schedules for these different groups, such a specification would make sense to the extent that different utilities in each census division tend to serve predominantly households in one particular group. The results with this more flexible specification are essentially unchanged and for parsimony we prefer the baseline specification.

[28] In related work, Naughton (1986) evaluates the efficiency and equity of electricity price schedules for a sample of U.S. electric utilities in 1980. Estimating costs using a translog function, he finds that per-unit prices exceed marginal cost by approximately 50% for residential, commercial, and industrial customers. The study then examines the equity of electricity prices across customer classes, finding no evidence of cross-subsidization.

4.3 Fixed Monthly Fees

The other key feature of natural gas rate schedules is the fixed monthly fee. Column (2) of Table 2 reports the average fixed monthly fee, α_{0j}. We estimate that, under current rate schedules, households in the United States face an average fixed monthly fee of \$6.20. The estimates vary somewhat across regions from \$4.22 in the South to \$10.90 in the Midwest. Under the assumption of zero demand elasticity and revenue neutrality, column (4) shows how the fixed monthly fee would increase if the volumetric charge were set equal to marginal cost. The fixed monthly fee would need to increase substantially to offset the decrease in revenue that would be caused from setting the volumetric charge equal to marginal cost. Across regions, the increase in the fixed monthly fee ranges from \$17.92 to \$24.20. These fixed monthly fees assure that total LDC revenue from residential customers would not change under the counterfactual. This assumes no change in any cross-subsidization across customer classes (residential, commercial, and industrial) or across energy products for utilities that sell both electricity and natural gas.[29]

The transition to marginal cost pricing is illustrated graphically in Figure 3. The black line in these figures is the marginal cost price schedule. The slope of the line is the estimated mean city gate price for each division and the vertical intercept is the mean fixed monthly fee under marginal cost pricing. Notice that the line is considerably flatter than current rate schedules. With the marginal cost schedule, the LDC pays all operating and capital expenses using revenue from the fixed monthly fee. Comparing each observation to the marginal cost schedule illustrates how total expenditure would change under marginal cost pricing. Households with low levels of annual consumption would tend to pay more, and households with high levels of annual consumption would tend to pay less. With our sample, 46% of households would pay less under marginal cost pricing and 54% would pay more. In the following section we examine these distributional consequences in detail, comparing the characteristics of households with different levels of natural gas consumption and determining how particular types of households would fare under a change to marginal cost pricing.

[29]In related research, Knittel (2003) compares prices of single- and dual-product electricity and natural gas utilities, finding evidence that the price markups of residential and commercial electricity consumers are used to subsidize industrial natural gas consumers.

5 A Transition to Marginal Cost Pricing

5.1 Counterfactual Bills

Table 3 describes the distributional impact of a change to marginal cost pricing and the associated increase in the fixed monthly fee, assuming zero demand elasticity. Panel (A) reports results by household income quintile. Households in the first quintile would pay on average $44 more annually under marginal cost pricing and 67% of the households in this quintile would experience some increase in their annual bill. This reflects the fact that these households consume less natural gas than households in other quintiles so the savings experienced from the lower volumetric charge is too small to offset the increased fixed monthly fee. Households in the fourth and fifth income quintiles would pay less under marginal cost pricing because they have relatively high consumption levels and thus benefit more from the decrease in the volumetric charge. A majority of the households in the top two quintiles would experience a decline in expenditures on natural gas.

Results in panel (B) by needs-adjusted household income quintile are similar but somewhat attenuated compared to the results in the first panel. Households in the first quintile would pay on average $30 more annually under marginal cost pricing, whereas households in the fifth quintile would pay on average $55 less. The smaller dollar changes for the first quintile reflect the fact that the needs-adjusted measure accounts for differences in household composition and is less correlated with natural gas consumption than household income. In particular, households with children have higher poverty thresholds and also tend to consume more natural gas.

Households with children are examined specifically in panel (C). On average, households with children would experience decreases in natural gas expenditure under marginal cost pricing. The effect is greater for large households; customers with two or more children would pay on average $34 less annually on natural gas. Panel (D) focuses only on low-income households with children, where low-income is defined as households in the lowest quintile by needs-adjusted household income. On average, these households would experience essentially no change in bills under marginal cost pricing. Low-income households with only one child would see their bills increase on average while larger low-income households with two or more children would see their bills decline on average.

To put these results into perspective, Table 4 reports natural gas expenditure as a share of household income. Columns (1) and (2) report expenditure shares under current price schedules and marginal cost pricing, respectively, and column (3) reports p-values from tests that the means are equal in columns (1) and (2). In panel (A), natural gas expenditure as a share of income decreases from about seven percent for the lowest income quintile to less than one percent for the highest quintile. Under marginal cost pricing low-income households would pay more and higher income households would pay less. These differences, however, are incremental compared to the existing differences across quintiles. Panel (B) shows expenditure shares by needs-adjusted household income quintile. Compared to the upper panel, households in the first quintile have somewhat higher average household income levels, but also somewhat higher average natural gas consumption levels. These two effects are roughly offsetting so that natural gas expenditure as a share of income is similar across quintiles to the shares in the first panel. A transition to marginal cost pricing causes shares to change in the same direction and with roughly the same magnitude as in the first panel.

Of course, it has been widely recognized that household income may not be a very good indicator of the sorts of vulnerable populations or financial need that are of more direct interest to policy makers, who are likely more concerned with financial stress on the family, permanent income, or total wealth. See, e.g., Poterba (1989), Poterba (1991) and Cutler and Katz (1992). Ideally, we would like to compare the results in Tables 3 and 4 to alternative results constructed using a measure of permanent income or household wealth. Although the RECS data does not provide multiple years of household income or any measure of financial wealth, it does include highly-detailed information about the appliances owned by the household. In Appendix B we explain how we used this information together with twenty years of articles from Consumer Reports magazine to construct a measure of "appliance wealth" for each household based on the number, age, characteristics, and original cost of the major appliances used by the household. As we discuss in the appendix, this approach is not a panacea and there are important limitations to "appliance wealth" as a more long-run measure of household well-being. Nevertheless, we find it reassuring that with this alternative measure we find results that are generally similar to the results above.

5.2 Energy Assistance Programs

The estimated bill impacts in Section 5.1 are consistent with conventional wisdom about two-part tariffs, indicating that marginal cost pricing would tend to increase bills on average for low-income households while decreasing bills on average for high-income households. These estimated impacts assume that no energy assistance is available for low-income households. In practice, means-tested energy assistance programs are widely available. LIHEAP, for example, distributes funds to all fifty states. Many states and local governments offer additional energy assistance, and at least a few LDCs offer alternative rate schedules to low-income households. It is important to consider how these programs could mitigate the distributional impact of a change to marginal cost pricing. Suppose, for example, that marginal cost pricing was implemented simultaneously with increased funding for an energy assistance program. This funding could come from public programs like LIHEAP or could be funded with a surcharge on natural gas customers with income (or needs-adjusted income) levels above a particular level.

Table 5 reports the baseline results along with results from five different alternative scenarios. For each scenario the table reports the impact of a change to marginal cost pricing on households in the first quintile by needs-adjusted household income (approximately 150% of poverty line). Row (1) reports that, with no energy assistance whatsoever, households in the first quintile experience about a \$30 annual increase in natural gas bills. This corresponds exactly to the first quintile results in Table 3, panel (B). Row (2) incorporates an energy assistance program that waives the fixed monthly fee for all households below 150% of the poverty line. The advantage of this lump sum approach is that it leaves the volumetric charge equal to marginal cost for households receiving assistance. Under this scenario, the mean impact for the quintile becomes large and negative, a \$210 average annual bill decrease for households below 150% of the poverty. If the program were internally funded, the other 80% of households would experience annual bill increases of \$60 in order to pay for the program. Row (3) shows that under a less generous program the mean impact for households below 150% of the poverty line is still negative. In this scenario, the 20% of households that are below 150% of the poverty line receive a \$10 per month lump sum transfer. A program of this size could be self-financed by increasing the fixed monthly fee for the other 80% of households by \$30 annually.

These results suggest that it may be possible for energy assistance programs to substantially offset the distributional impacts of marginal cost pricing for low-income households. Still, it is important to point out that energy assistance programs have limitations. For example, it has been shown to be difficult to identify and enroll eligible households. Casual evidence of this comes from Table 1 which reports for each quintile the percentage of households who report having received energy assistance in the previous year. Even though most households in the first quintile would typically be eligible for LIHEAP or state-level energy assistance programs, only 18% report receiving energy assistance in the previous year. This is a self-reported measure and one might be concerned that stigma or some other factor might lead this measure to underestimate true participation levels. Still, it seems clear that not all eligible households participate in energy assistance programs, and non-eligible households may attempt to participate fraudulently. Effective screening of program applicants is expensive and imperfect.[30] Rows (4) and (5) in Table 5 examine how incomplete

[30]Borenstein (2010) discusses this problem in administering means-tested low-income electricity rates for three California electric utilities.

takeup affects mean annual bill impacts for the first quintile. With 50% takeup, households below 150% of the poverty line experience on average a $30 decrease in bills. With 20% takeup the lump sum payments are similar in size to bill increases so the net impact is positive but small. The annual cost per non-recipient is lower for these programs because of the lower participation rate.

It is also worth highlighting that these mean impacts for the first quintile obscure substantial heterogeneity across households. Because households differ substantially in their level of natural gas consumption, the $10 monthly lump sum transfer is not enough to ensure net bill decreases for all households in this group. Most at risk of bill increases are households that consume very low levels of natural gas. Increasing the fixed monthly fee makes these households considerably worse off, because they enjoy relatively little benefit from the decreased volumetric charge. More generous energy assistance could prevent bill increases for these households. For example, one could waive the entire fixed monthly fee for households below 150% of the poverty line as in row (2). The tension here is that there are real economic costs of maintaining natural gas connections and eliminating the fixed monthly fee entirely for these households would induce an inefficiently large number of these households to consume natural gas.

Finally, row (6) considers the impact of an energy assistance program based on an important characteristic, not of the household but of the housing unit itself. In particular, this row examines a policy that would provide a $10 lump sum transfer to households living in multi-unit buildings. In our sample 45% of households below 150% of the poverty line live in multi-unit buildings, compared to 28% of households overall. Consequently, the policy is reasonably effective at targeting low-income households and the program has about the same mean impact as a conventional program with 50% takeup. This type of program is expensive because a large number of households above 150% of the poverty line receive the credit. In addition, one would expect multi-unit discounts to be at least partially capitalized into rents, meaning that some of the transfer would be received by landlords rather than tenants. Nonetheless, such a program would also offer a number of potential advantages. First, whereas traditional programs suffer from low enrollment, households in multi-unit buildings could be automatically enrolled. Second, screening for the multi-unit discount is low-cost and highly-accurate, making it very difficult for non-eligible households to participate fraudulently.

Energy assistance programs based on multi-unit discounts would be most effective in utility districts where housing type is highly correlated with income. In high-density utility districts where all households live in multi-unit buildings or in low-density utility districts where no households live in multi-unit buildings there is little scope for redistribution. Alternatively, discounts could be based on a richer set of housing characteristics such as square footage or number of rooms, or even on neighborhood characteristics such as mean household income by zip code. There is little precedent for natural gas LDCs using this kind of differentiation and these policies would likely face political challenges, but these more flexible approaches would also allow better targeting of needy households.

6 Efficiency Effects of Changing Retail Prices

While the distributional impact of changing marginal retail prices of natural gas to reflect marginal cost appears to be fairly modest, the direction of the impact is still contrary to the general goal of helping lower income households. The argument in favor of such a change rests on improving economic efficiency, which requires that consumers change their behavior in response to the price changes. The efficiency impact, however, is complex, for two distinct reasons. First, because natural gas is priced in a two-part tariff and the fixed monthly fee would have to be adjusted as well as the volumetric charge, the change has the potential to cause some consumers to make non-marginal adjustments: some current consumers of natural gas may decide to exit the market and some who have not previously been in the market might choose to enter. Second, the current distortions in the residential market for natural gas are part of a larger set of distortions in energy pricing. Therefore, a broader analysis of the welfare impact is relevant, one that accounts for distortions in closely related markets, such as for other energy products.

In the simplest setting, we could focus only on the deadweight loss from non-marginal-cost pricing of marginal gas consumption, which is a straightforward exercise for any given assumed demand elasticity. We begin with this calculation and then expand the analysis to consider potential welfare changes from changes at the extensive margin: customers entering and leaving the natural gas market. We are not able to make credible point estimates of these impacts, but we attempt to infer the potential magnitude of these effects. We then discuss further impacts of the natural gas tariff change due to the fact that related products are not priced efficiently. We first consider other energy sources. We then consider one of the most pressing distortions in energy, the failure to price greenhouse gases. In the analysis thus far, we have assumed that emission of greenhouse gases is not socially costly and is not priced. We consider two alternative scenarios, one in which carbon dioxide emissions are socially costly, but still not priced and one in which carbon dioxide emissions are socially costly and emitters must pay a price that reflects that cost. Finally, we consider recent research that suggests consumers may not carry out the somewhat sophisticated optimization that would lead them to respond to marginal price. Instead, consumers might focus on total bill in relation to consumption, that is, average price. If consumers engage in this sort of sub-optimizing behavior, we show that the efficiency analysis changes substantially.

6.1 Efficiency Effects of Marginal Quantity Changes

The counterfactuals we have considered thus far show how household expenditure on natural gas would change under marginal cost pricing if demand elasticity were zero, which implies no efficiency consequences of the change. With non-zero elasticity, volumetric charges above marginal cost impose deadweight loss, as customers consume too little natural gas. We first address this issue under the assumption that the tariff change doesn't cause any consumers to enter or exit the market.

Table 6 reports estimates by needs-adjusted household income quintile of the average annual change in consumer surplus resulting from a switch to marginal cost pricing. The table reports consumer surplus change estimates under a range of different plausible price elasticities of demand, ranging from 0.0 to -0.6.[31] The relevant elasticity for these calculations is the long-run demand elasticity for which empirical estimates in the literature are rare and not very convincing.[32] Rather than take a strong stand on the magnitude, we report estimates for this relatively broad range.

To calculate the consumer surplus gain for each household, we assume a constant elasticity form of demand, $D(p) = A_i p^{\epsilon}$ where all households have identical demand up to a scale parameter A_i. On average in our sample lowering the volumetric charge to equal marginal cost implies a 32% decrease. With a -0.2 price elasticity, for example, this yields an average increase in natural gas consumption of 3.5 units (thousand cubic feet) annually compared to a baseline level of 68.7 units. We calculate the change in consumer surplus as the area to the left of the demand curve from the original volumetric charge to the price that reflects marginal cost, and then we subtract off the difference between the fixed monthly fees shown in Table 3.[33]

The magnitude of the efficiency impact varies predictably with the assumed elasticity, with

[31] As a point of comparison, the U.S. Department of Energy (2003) adopts for natural gas a -0.41 long-run price elasticity of demand for residential customers.

[32] Long-run elasticities are difficult to estimate credibly because it may take several years for agents to fully respond to price changes. For example, in the long run, consumers may respond to a decrease in natural gas prices by purchasing a less-efficient furnace than they would have otherwise. Because the stock of equipment turns over slowly, the full long-run impact of a price change may not be realized for many years and estimating such long-run effects using historical data is extremely challenging.

[33] We ignore income effects and calculate surplus changes along the constant-elasticity Marshallian demand curve. The wealth change for the vast majority of households is an extremely small share of annual income as shown in Table 4. Combined with the fact that the income elasticity of demand for natural gas is generally estimated to be well below one, this implies that the cost of omitting income effects is not material.

larger increases in consumer surplus for larger elasticities. The first column reports estimates for $\epsilon = 0$. These results correspond exactly to the results in panel (B) of Table 3 which assumed zero elasticity. For a price elasticity of -0.2, households are better off across quintiles by on average about \$5 per year. Consumer surplus continues to increase with larger price elasticities. Changing the assumed elasticity from zero to -0.6 raises the average consumer surplus of customers in the population by about \$16 per year.

These estimates assume that the price elasticity is the same across income classes. Natural gas expenditure represents a smaller share of total household expenditure for higher income households, so one might expect the price elasticity to be smaller for these households. Although we are not aware of any direct evidence from the natural gas market, this is consistent with evidence from Reiss and White (2005) and Ito (2010) who find that the price elasticity of demand for electricity is smaller for high income households.[34] Redoing the exercise with heterogeneous price elasticities would increase the welfare gains for households in the lower quintiles and decrease the welfare gains for households in the upper quintiles, but would not change the qualitative pattern. In particular, even with a considerably larger price elasticity for low-income households the efficiency gains would still be too small to offset the direct bill impact.

Because these calculations hold the LDC's profits constant, by construction, the sum of the changes in consumer surplus reflects the entire welfare change. Table 6 also reports the overall average change in consumer surplus across all households in the dataset. Multiplying this number by the 65 million households[35] that consume natural gas in the United States implies that the total inefficiency from non-marginal-cost pricing of natural gas to residential customers is \$314 million per year with an elasticity of -0.2 and \$989 million per year with an elasticity of -0.6.

Using a different dataset and empirical methodology, Davis and Muehlegger (forthcoming) find that with a -0.2 elasticity the annual deadweight loss borne by residential natural gas customers between 2001 and 2007 from non-marginal cost pricing was \$968 million. Our considerably lower estimate (\$314 million) reflects the fact that in 2005 natural gas prices were unusually high and retail prices did not fully adjust to reflect this increased commodity cost, resulting in a lower markup. Moreover, because the *level* of prices was much higher in 2005, we estimate a considerably lower *percentage* markup which (with a constant elasticity demand function) implies a smaller change in

[34] Ito (2010), for example, finds a (short-run) price elasticity of -0.13 for households with household income below the median, compared to -0.09 for households with household income above, a difference which is statistically significant but small in magnitude.

[35] The RECS sampling weights imply that in 2005 there were 65.1 million households in the United States with natural gas connections. As a point of comparison, U.S. Department of Energy (2010a) reports 63.6 million residential customers in 2005 using aggregate data reported by utilities.

quantity consumed.

These results help clarify the overall tradeoff between efficiency and redistribution. For the long run elasticity of -0.4, the efficiency cost of non-marginal-cost pricing is $644 million per year and the redistribution impact is to transfer about $520 million per year to households in the two lowest needs-adjusted household income quintiles. Thus, for this price elasticity of demand the deadweight loss from transferring these funds is estimated to be more than 100% of the transfer. This is higher than the cost of public funds ratios generally referenced for tax-funded expenditures, which are generally less than 50%.[36]

This apparently strong case against non-marginal-cost pricing of natural gas, however, seems less strong when we consider other potential distortions in the following subsections.

6.2 Efficiency Effects of Changes on the Extensive Margin

Balancing the revenue lost from lower volumetric charges by raising fixed monthly fees will also have an efficiency effect. Theoretically, it could have two types of efficiency effects: current customers might leave the market ("leavers") and current non-customers might choose to enter ("arrivers"). The degree of efficiency change resulting from these changes on the extensive margin depends in part on the degree to which the fixed monthly fee departs from the monthly customer-level fixed costs – the marginal cost of adding an additional customer to the system – beyond the direct commodity cost. With the volumetric charge set to reflect only the commodity cost, all other utility costs must be captured through the fixed monthly fee. Some of those costs vary with the number of residential customers served and some are system fixed costs that are mostly unchanged by the addition of one more residential customer. The distinction between these costs is not always completely clear, particularly in the long run, but the former category would probably include monthly paperwork and billing of the customer, meter and other household-level maintenance and call center staffing. The latter category would include maintenance of the main gas pipelines in the service territory, recovery of past investments in building the pipeline infrastructure, and some portion of the management budget if there are any scale economies in managing the LDC, which seems likely.

If the customer-level fixed costs were equal to the LDC's full non-commodity expenses divided by the number of customers, then the move to marginal cost pricing of natural gas would also reset the fixed monthly fee to the efficient level, and all in- and out-migration of customers would be efficient. Unfortunately, that is not the case; in fact, the monthly incremental cost to the LDC of

[36]See Ballard and Fullerton (1992) and Snow and Warren (1996).

managing an additional customer is likely much lower than the fixed monthly fees under marginal cost pricing that are shown in column 5 of Table 2. Data shared with us by one California utility indicate that somewhat less than half of non-commodity costs vary significantly with number of subscribing customers within the service territory, though that probably overstates the marginal cost per customer, because the customer-specific fixed costs probably exhibit some economies of scale. As a result, some customers might leave the market even though they receive net surplus in excess of the monthly incremental (non-commodity) cost they impose on the system.[37]

A complete empirical investigation of changes on the extensive margin is beyond the scope of this paper. Still, it could be an important input in the analysis of a switch to marginal cost pricing. And incorporation of changes on the extensive margin could reduce the estimated efficiency gains from a switch to marginal cost pricing.

To investigate the potential impact of incorporating the extensive margin, we focus first on leavers, customers who use natural gas under the current tariff, but would leave the market under a rebalancing that substantially increased the fixed monthly fee. Low-consumption customers are the ones who lose surplus under the rebalanced tariff. For them, the alternative energy source for all current natural gas services would almost certainly be electricity, which is generally sold with little or no fixed monthly fee.

To evaluate the impact of leavers on the welfare analysis, we consider first the customer's energy cost if she switched to electricity to provide the energy services received from natural gas under the current tariff. This ignores the fact that cooking, space heating, water heating and clothes drying are not exactly the same services when provided with natural gas as when provided with electricity. That product differentiation will almost surely reduce the level of switching in comparison to a strict cost comparison. This explains why we observe households consuming very small, but positive quantities of natural gas.

The customers who would leave the natural gas market under the rebalanced tariff are those who received positive consumer surplus from the current tariff, but negative consumer surplus under the rebalanced tariff. To analyze who these customers would be, we constructed a simple model of demand for natural gas that assumes a customer consumes gas along a demand curve of a given constant elasticity until the price per unit of heat (adjusting for combustion efficiency) with natural gas exceeds the cost of using electricity, at which price the household's demand drops discontinuously to zero. Energy services cost includes the volumetric charge, the fixed monthly fee, and any differences in the cost of appliances that use the energy. The most important difference

[37] Coase (1946) first recognized this tension between the efficiency costs of raising the fixed monthly fee versus raising the volumetric charge. Baumol and Bradford (1970) present a technical analysis of the problem.

in appliance cost is that a natural gas furnace is substantially more expensive than electrical space heaters. The assumptions we make are shown in Table 7. We show two scenarios, one in which the household does space heating with natural gas and another in which they do not. Because natural gas furnaces are more expensive than electrical space heaters, there are many households in mild climates that choose not to use natural gas heating even though they either face a very low fixed monthly fee or already pay the fixed monthly fee to use natural gas for other purposes.[38] The range of natural gas usage for which the tariff switch would make natural gas consumption cost-inefficient is fairly small, so many affected households will be ones that already do not do space heating with natural gas and will not save on capital cost of a furnace versus electrical space heating. Table 7 indicates that for such houses, consumer surplus increases from dropping natural gas completely if the household was consuming between and 6 and 17 units (thousand cubic feet) of natural gas per year. If the household was below 6 units per year it should have already dropped natural gas under the current tariff, while if it is above 17 units per year, natural gas is still cost effective. If the household is space heating with natural gas, presumably in a very mild climate, it would also save on the capital cost of the furnace, as shown. In that case, the range for dropping natural gas moves to 14-22 thousand cubic feet per year.

These calculations are obviously rough, but they give an idea of the range of consumption that might lead a household to consider dropping natural gas in response to the tariff change. The bottom row of the table shows the proportion of households in the RECS data in each range among households that do and do not use natural gas to for space heating. To infer the potential deadweight loss from changes on the extensive margin, one would need to know the share of these customers who would actually choose to drop natural gas – presumably some would not because of a preference for using natural gas in cooking or other activities. The deadweight loss would also depend on the share of fixed costs that are customer-specific as opposed to system level.

We do not attempt to analyze these parameters further, but it is clear from Table 7 that the impact of changes on the extensive margin could be important. If half of the 4.1 million customers in the "switch range" did actually switch and if the customer-specific fixed costs were a small share of the fixed monthly fee that covers all non-commodity costs, then these switches would result in deadweight loss that is well over $100 million per year.[39] It is not clear that it would reverse the

[38]In addition, some households do not have access to natural gas either because they live in rural or other areas with no natural gas distribution pipeline system. From RECS data, it appears that 72% of U.S. households have access to natural gas and 85% of those with access to natural gas consume positive quantities.

[39]As an example, assume that customer-specific fixed costs are equal to the current fixed annual fee of $72. Also assume that there are no distortions in other markets. Since all leavers are choosing to consume gas under the current tariff, and since the higher fixed annual fee under marginal cost pricing does not reflect costs that actually change if the customer leaves, then all leavers are doing so inefficiently. The deadweight loss of one leaver's departure is

result of the analysis that ignored the extensive margin, but it could reduce the gains substantially.

The other side of the extensive margin is "arrivers", customers who would choose to enter the market if the tariff changed. We consider, in turn, households substituting away from electric and heating oil heating systems. A straightforward analysis suggests that the number of households switching from electricity to natural gas is likely to be extremely small. Such a household must have chosen not to enter the natural gas market under the current tariff, so it receives negative consumer surplus under the current tariff. Yet, the lower volumetric charge creates so much more consumer surplus that it more than offsets the higher fixed monthly fee. In the example in Table 7, fixed fees increase by \$168 per year and the volumetric charge declines \$3 per thousand cubic feet. Thus, a household switching from electricity to natural gas would have to receive at least an additional \$168 per year in consumer surplus due to the price drop. It is possible to derive a demand curve that satisfies both of these conditions – not entering under the current tariff, but entering under the alternative tariff – but it would have to demonstrate very high elasticity around the current volumetric charge. For instance, a linear demand curve that exactly satisfies this condition would have a price elasticity of nearly -3 at the current marginal tariff price, far larger than any estimates of the price elasticities of residential demand for natural gas. While there is probably a non-zero set of customers who meet these criteria, it seems likely to a very small set.

In contrast, there may be scope for substitution from heating oil to natural gas. Although only 7% of the households in our data use heating oil as the primary source of home heating, the fraction among households in the Northeast region is 30%. Heating oil and natural gas heating systems are similar in that both use a central furnace that is connected to the rest of the house with air ducts. The capital cost and installation costs are substantial so these systems are favored by households with relatively high demand for heat. In most locations and time periods the price per BTU of heating oil exceeds the price per BTU of natural gas. This lower price, combined with cleanliness and convenience of natural gas, has made it the popular choice for most households. The one exception is the Northeast, where natural gas prices are the highest in the continental United States and during some years the price per BTU of natural gas has exceeded the price per BTU of heating oil. Price reform would decrease volumetric charges enough that it would be very unusual to observe this inversion in prices. Because the market for heating oil is essentially perfectly

the consumer surplus that she would have received had the volumetric charge been \$7 and the fixed annual charge been \$72. For a leaver who had been consuming nearly zero gas, that lost consumer surplus is bounded between zero and \$168, because they would not leave under the new tariff if they would receive more than \$168 in surplus. For a leaver with natural gas demand $Q(P)$, that lost consumer surplus is bounded between $\$3 \cdot Q(10)$ (below which he would have already left under the current tariff) and approximately $\$168 - \$3 \cdot Q(10) + \frac{1}{2} \cdot \$3 \cdot \, (Q(7) - Q(10))$. This is essentially a narrower range centered between zero and \$168. Taking the midpoint of \$84 per year and multiplying by $\frac{4.1}{2}$ million leavers yields approximately \$170 million per year in deadweight loss.

competitive, substitutions away from heating oil toward natural gas would represent efficiency gains.

6.3 The Impact of Distortions in Related Markets

The analysis thus far rests on the assumption that prices in the rest of the economy are set efficiently. This is of particular concern if the prices of complementary and substitute products are also distorted. The three markets that are of greatest potential concern are heating oil and electricity, both of which are substitutes, and greenhouse gases, which is a complement in consumption of natural gas. We consider the first two in the absence of considering greenhouse gas externalities, and then turn specifically to greenhouse gases at the end of the section.

While 7% of all households use heating oil as their primary home heating fuel, this is a reasonably competitive market in which price reflects marginal cost quite closely.[40] Thus, substitution to or from heating oil in response to a rebalancing of natural gas rates is unlikely to impose additional distortions. Electricity is a more complex issue as prices around the country differ from marginal cost, in some cases substantially. Residential prices for electricity are generally established through a regulatory process that sets rates in order to allow the utility to recover its historical costs, thus prices reflect an historical average cost.[41] In some areas of the country price is below marginal cost as the utilities are able to average in cheap sources that would be a small share of marginal expansion – such as large hydroelectric projects – or older fossil fuel sources that have been depreciated in the accounting sense, so they are assigned a very low cost in the ratemaking process – such as older coal and natural gas plants. In other parts of the country, prices are well above marginal cost as the rates are being set to cover mistakes of the past, such as cost overruns on nuclear (and other) power plants, and costs incurred from unsuccessful deregulation plans or poorly-designed attempts at competitive procurement. In addition, throughout the country, residential rates are set to cover costs of transmission and distribution systems, much of which are do not vary with marginal consumption. A complete analysis of the distortion from substitution between electricity and natural gas, on both the intensive and extensive margin, is beyond the scope of this paper. Still, it seems likely that prices are generally above marginal cost of electricity, so to the extent that rebalancing natural gas rates causes substitution from electricity to natural gas, our estimates

[40]One might argue that OPEC or, more exactly, Saudi Arabia, exercises market power and raises oil prices above competitive levels. Nonetheless, if the goal is to maximize US surplus, then it probably makes sense to treat these as exogenous quantity constraints, with all other producers acting as price takers in the oil market. Downstream from oil, in the refining and distribution sectors, sellers are generally thought to be quite competitive.

[41]This description is not entirely accurate in areas where there is competition among retail providers, but even in those areas transmission and distribution costs are still recovered through regulated charges that are set to cover average cost, and adjustments to retail prices are made to allow recovery of revenues that are necessary to cover other historical costs.

of efficiency gains would need to be adjusted downwards.

Perhaps the most significant related distortion is the fact the greenhouse gas emissions are currently free. Rates for natural gas do not reflect the negative externality that burning the gas creates. It is interesting to compare the average markup on natural gas that we have calculated with the price increase that would be implied by a carbon tax. Table 2 reports an average markup in the United States in 2005 of \$2.71 per thousand cubic feet. There are .0543 metric tons of carbon dioxide per thousand cubic feet of natural gas, so this average markup is equivalent to a tax of about \$50 per ton of carbon dioxide. This is higher than the level of a carbon tax envisioned by most economists and policy makers. As a point of comparison, Federal Interagency Working Group (2010) adopts a central social cost of carbon dioxide of \$22 for 2015.[42] Compared to this measure, current markups exceed the external cost of natural gas consumption, so residential customers may already face a volumetric charge that exceeds social marginal cost.

Table 8 reports efficiency gains under alternative assumptions about greenhouse gas emissions and policy. The results in the paper up until this point implicitly assume that there are no externalities from the production or consumption of natural gas, and that there is no policy in place such as a carbon tax or cap-and-trade program that places an implicit price on these emissions. Row (1) reports mean annual efficiency gains by needs-adjusted household income quintile under this baseline scenario for a price elasticity of demand of -0.4. These efficiency gains are identical to the implied gains comparing the $\epsilon = 0$ and $\epsilon = -0.4$ columns in Table 6.

Row (2) shows that, assuming that carbon dioxide emissions remain unpriced, but are truly costly to society, then the potential efficiency gains from marginal cost pricing are reduced by about 60%. In this scenario, volumetric charges are set equal to social marginal cost, equal to private marginal cost plus external damages which we assume are equal to \$22 per ton of carbon dioxide. Here the welfare gains from price reform, or equivalently, the inefficiency of current price schedules is considerably smaller because incorporating marginal damages reduces the wedge between current volumetric charges and the proper measure of marginal cost. Of course, if the true social cost of carbon dioxide is more than \$50 per ton, then even the current rate structure places a marginal price on natural gas consumption that is too low.

[42] Federal Interagency Working Group (2010) presents a range of values for the social cost of carbon dioxide according to different discount rates and for different time periods that is intended to capture changes in net agricultural productivity, human health, property damages from increased flood risk, and other factors. In Table 15A.1.1 with a 3% discount rate (their "central value") for 2010 they find a social cost of carbon dioxide of \$21.40 (in 2007 dollars) per metric ton of carbon dioxide. In 2010 dollars this is approximately \$22. To avoid confusion we use carbon dioxide, rather than carbon, throughout. Because the atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44, one ton of carbon equals 44/12 tons of carbon dioxide. The average markup of \$2.71 is equivalent to a tax of \$50 per ton of carbon dioxide or \$183 per ton of carbon.

Row (3) considers the scenario in which again carbon dioxide emissions are assumed to impose external damages of $22 per ton of carbon dioxide, but there is also assumed to be a carbon tax or cap-and-trade program in place that puts a price of $22 per ton of carbon dioxide emissions. We assume that this policy increases the volumetric charge faced by residential customers by the equivalent of $22 per ton of carbon dioxide. Here the efficiency gains from marginal cost pricing are very similar in magnitude to the gains observed in row (1). This scenario illustrates that the distortion we have addressed in this paper would still be present if carbon dioxide emissions were priced to reflect the negative externality. The fixed costs of operating a natural gas distribution system would still have to be recovered and the policy argument over whether to recover them through fixed or volumetric charges would be essentially the same as if there were no negative externality.

6.4 To Which Price Do Customers Respond?

The discussion and analysis thus far in Section 6 maintains the implicit assumption that households have perfect information and respond optimally in response to two-part tariffs. These may not be reasonable assumptions. Although natural gas bills typically are reasonably clear about the distinction between the fixed monthly fee and the volumetric charge, many customers have not thought much about the distinction.

Customers who are not aware of, or do not understand the two-part tariff might instead respond to the total bill, rather than the volumetric charge. Recent empirical evidence from the electricity market provides some evidence for this alternative hypothesis. Focusing on the California electricity market, Ito (2010) finds evidence consistent with households responding to average, rather than marginal prices. Although these results are compelling, it is important to point out that in the market examined in Ito (2010) households face four- and five-part increasing block tariffs. In comparison, the typical natural gas schedule is substantially less complex with most natural gas LDCs using only a fixed monthly fee and a single, constant, volumetric charge. Given this considerably simpler structure it seems likely that households would be better able to distinguish between average price and marginal price. This lends some support to our baseline estimates which assume households respond to marginal price.

Nonetheless, it is interesting to consider how the welfare implications would change under the alternative hypothesis that households respond to average prices. Under a transition to marginal cost pricing households with high consumption levels would experience decreases in both average and marginal price, implying welfare gains regardless of how well the customer understands the tariff. In contrast, households with low consumption levels would see decreases in marginal price but *increases* in average price, potentially moving consumption in the wrong direction. The total change in welfare could, in theory, be positive or negative.

Repeating the analysis in Section 6.1 under the assumption that households respond to average price rather than marginal price, we find that the overall change in welfare from a transition to marginal cost pricing is still positive, but considerably smaller in magnitude. With a -0.4 price elasticity of demand, we find an increase in total welfare nationally of $223 million annually, compared to $644 million annually in the original analysis. About half of all households experience a decrease in average price under a transition to marginal cost pricing, but the net welfare change is positive because we find that the increases in welfare for households experiencing average price decreases (high-consumption households) tend to be larger than the decreases in welfare for households experiencing average price increases (low-consumption households).

Overall, it seems clear that if customers indeed respond to average price rather than marginal price, then the welfare gain from rebalancing natural gas rates could be substantially smaller than the baseline estimates in Section 6.1. This raises the question of customer education, and whether changes in the way that bills are designed could have impacts on household welfare. In particular, after a transition to marginal cost pricing it would be important for natural gas LDCs to make every effort to describe the reform to the public as clearly as possible, and to strive to make bills as transparent as possible, distinguishing between marginal and average prices using easy-to-understand language, figures and examples.

7 Conclusion

In this paper we used nationally-representative microdata to characterize the effect of a transition to marginal cost pricing in the U.S. natural gas market. The results confirm a widespread perception in the industry and among regulators and consumer protection groups that price reform would have negative distributional consequences. However, our results indicate that the magnitude of these effects is relatively small. What matters for distributional consequences is the correlation between household income and natural gas consumption. We show that this relationship is positive, but weak, so that current price schedules deliver a modest amount of redistribution. Needs-based programs, such as LIHEAP, could likely reduce the negative impacts to vulnerable subgroups substantially.

Our analysis highlights a number of confounding factors that weaken the relationship between energy consumption and income, complicating attempts to accomplish distributional goals through price schedules. For example, we show that household income is positively correlated with energy efficiency. Part of this is likely driven by the landlord-tenant problem, which leads to suboptimal energy efficiency investment in rental properties, though the correlation holds within owner-occupied housing units as well. In addition, households in the bottom quintiles of income or needs-adjusted income tend to have more children and we show that, in particular, low-income households with multiple children tend to have high levels of natural gas consumption and thus would tend to benefit from marginal cost pricing.

The broader conclusion of our paper is that it is important for policymakers to keep in mind this tradeoff between efficiency and equity when implementing rate structures. The reality is that whenever policymakers can influence prices there is a temptation to use these prices to accomplish distributional goals. This is despite the fact that economists generally view optimal tariff design as separate from redistribution, particularly when there are broader redistributive tools in place such as the income tax. Striking a balance between these two objectives is perhaps the biggest challenge faced by utility regulators, and it is surprising that there is so little empirical evidence on the topic. Studies like this one are important because they move us closer to understanding the sometimes complex distribution and efficiency implications of price schedules and because they demonstrate that analyses using real-world data can reveal important evidence about the magnitude of these effects.

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Figure 1: Natural Gas Consumption and Household Income

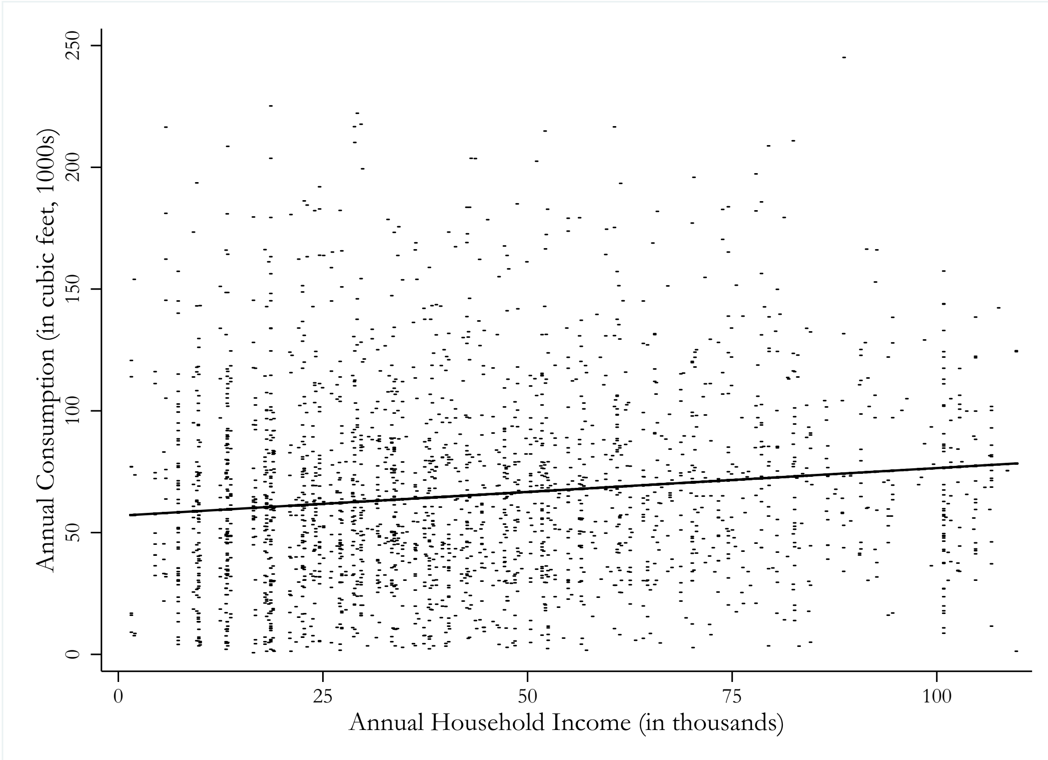

Figure 2: Natural Gas Consumption and Household Income, Controlling for Census Division

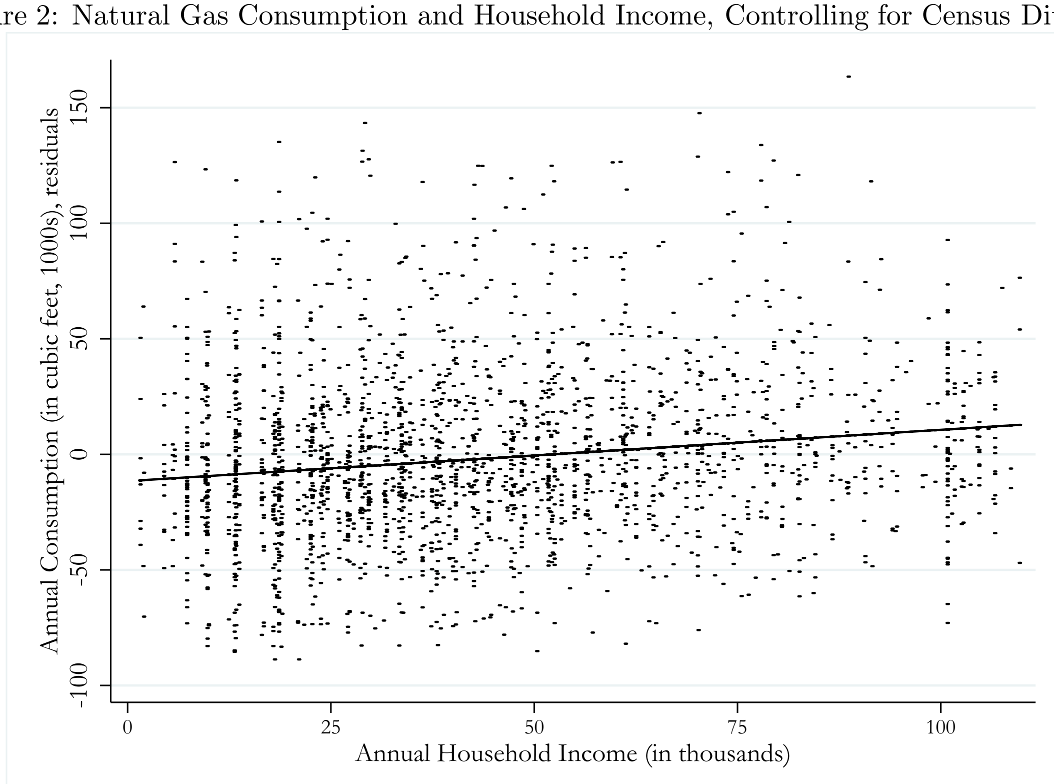

Figure 3: Residential Natural Gas Rate Schedules for 2005, By Geographic Division

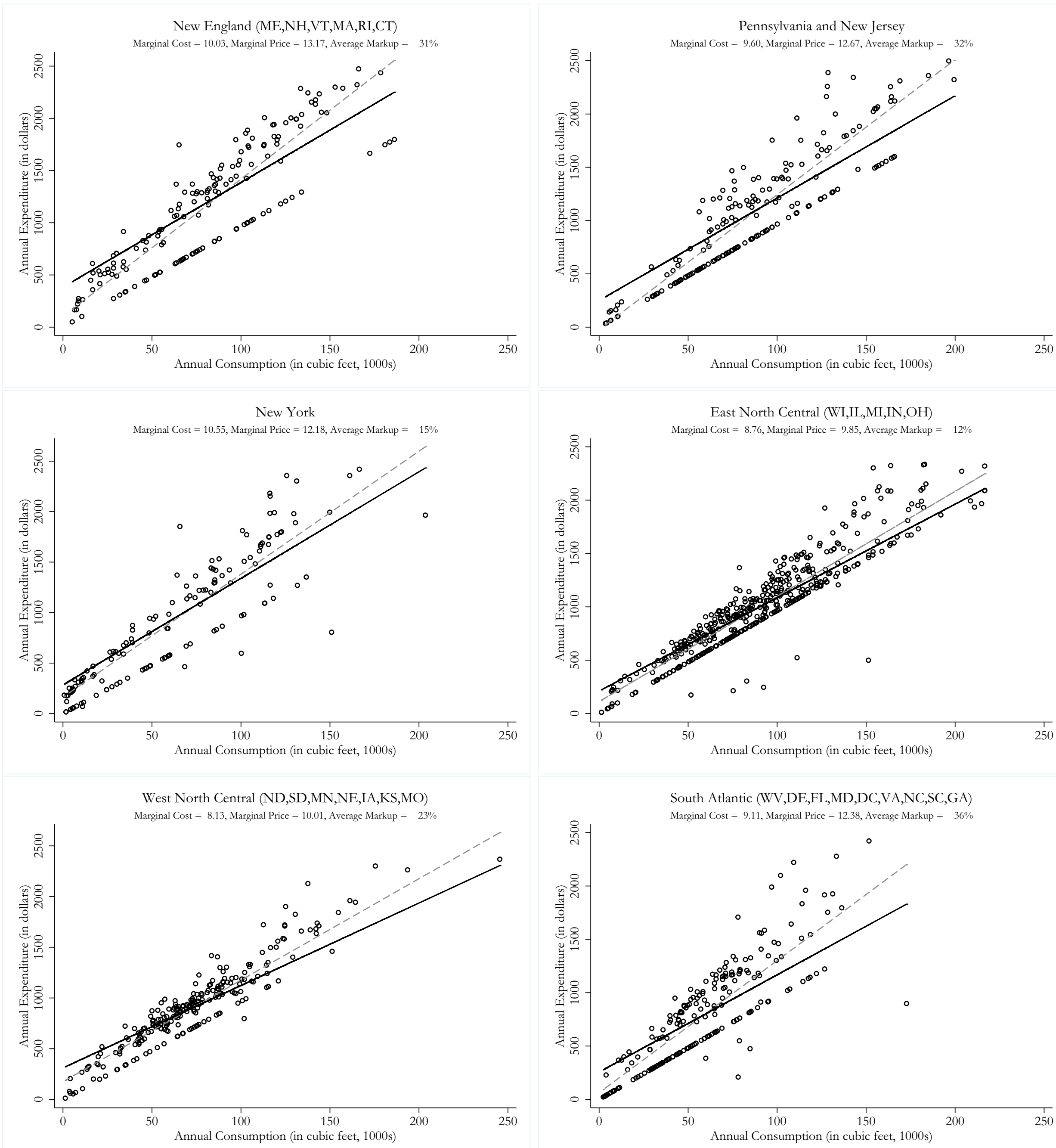

Figure 3: Residential Natural Gas Rate Schedules for 2005, By Geographic Division

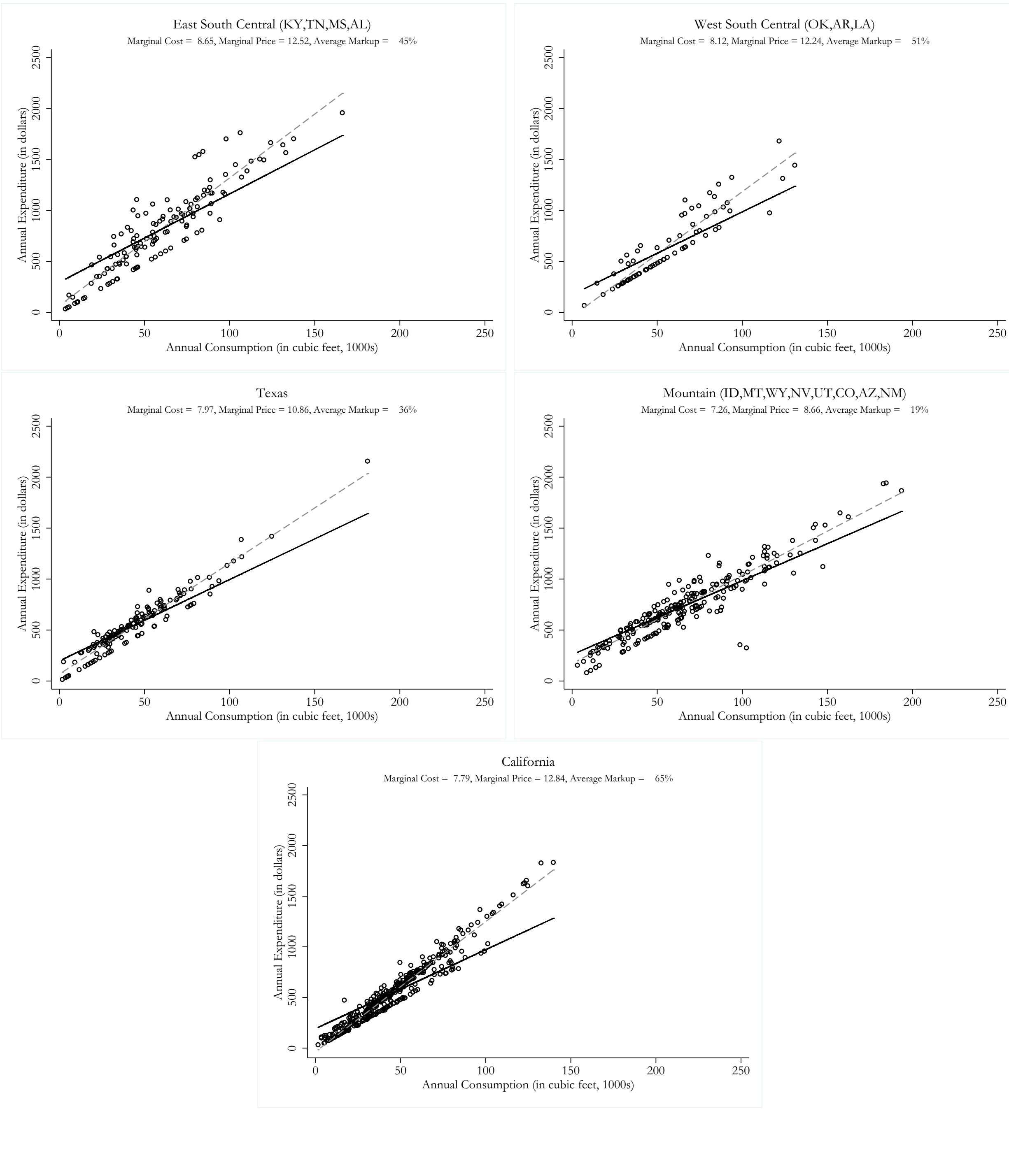

Table 1: Descriptive Statistics by Needs-Adjusted Household Income Quintiles

	1st Quintile	2nd Quintile	3rd Quintile	4th Quintile	5th Quintile
A. Household Economic and Demographic Characteristics					
Percent of Poverty Line	<148%	148-235%	235-334%	334-514%	>514%
Mean Annual Household Income (1000s)	$16.5	$32.3	$46.7	$65.3	$129.8
	(8.9)	(12.0)	(15.8)	(20.8)	(44.1)
Number of Household Members	2.75	2.86	2.71	2.50	2.47
	(1.92)	(1.61)	(1.51)	(1.32)	(1.17)
Number of Children	0.94	0.85	0.78	0.61	0.52
	(1.38)	(1.14)	(1.08)	(0.97)	(0.92)
Proportion Homeowner	0.49	0.66	0.77	0.85	0.91
	(0.50)	(0.47)	(0.42)	(0.36)	(0.29)
Proportion Receives Energy Assistance	0.18	0.06	0.0	0.0	0.0
	(0.38)	(0.24)	(0)	(0)	(0)
B. Natural Gas Consumption and Expenditure					
Mean Annual Consumption (cubic feet, 1000s)	61.1	68.2	66.7	67.9	80.9
	(47.8)	(44.1)	(40.7)	(41.6)	(47.9)
Mean Annual Expenditure	$743	$823	$807	$854	$993
	(588)	(533)	(476)	(550)	(586)
Expenditure as a Fraction of Income	0.06	0.03	0.02	0.01	0.01
	(0.09)	(0.02)	(0.01)	(0.01)	(0.01)
C. Energy Efficiency					
Main Heating System is Less than 10 Years Old	0.34	0.38	0.41	0.48	0.50
	(0.47)	(0.49)	(0.49)	(0.50)	(0.50)
Home is Well Insulated	0.30	0.39	0.38	0.37	0.45
	(0.46)	(0.49)	(0.49)	(0.48)	(0.50)
Double-Pane Windows	0.38	0.51	0.62	0.60	0.70
	(0.49)	(0.50)	(0.49)	(0.49)	(0.46)

Note: These data come from the 2005 Residential Energy Consumption Survey (RECS). The sample includes all households with a natural gas connection excluding renters living in housing units where utilities are included in the rent. The resulting sample includes 2,555 households, or approximately 500 households per quintile. Means and standard deviations (in parentheses) are calculated using RECS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table 2: Natural Gas Rate Schedules By Region

	Current Rate Schedule		Rate Schedule After Rebalancing	
	Volumetric Charge	Fixed Monthly Fee	Volumetric Charge (Marginal Cost)	Fixed Monthly Fee
	(1)	(2)	(3)	(4)
Northeast	\$12.60	\$5.82	\$10.04	\$24.20
	(0.38)	(2.10)		(1.37)
Midwest	\$9.90	\$10.90	\$8.57	\$20.03
	(0.44)	(2.75)		(0.68)
South	\$11.97	\$4.22	\$8.58	\$19.67
	(0.46)	(1.90)		(0.93)
West	\$11.47	\$2.69	\$7.61	\$17.92
	(0.26)	(0.96)		(0.58)
Average	\$11.34	\$6.20	\$8.63	\$20.24
	(0.20)	(1.05)		(0.44)

Note: Column (1) is the mean volumetric charge for current rate schedules in the RECS data per 1000 cubic feet. Column (2) is the mean fixed monthly fee for current rate schedules in the RECS data. Column (3) is the mean city gate price from Platts per 1000 cubic feet. Finally, column (4) calculates the fixed monthly fee that would be required to maintain the same level of revenue if the volumetric charge were decreased to marginal cost. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RECS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table 3: The Distributional Impact of a Change to Marginal Cost Pricing

	Mean Annual Change in Dollars		Percent Experiencing Bill Increase		Mean Bill Change in Percent	
A. By Household Income Quintile						
1st Quintile	$44.39	(9.79)	66.7%	(2.3)	6.1%	(1.5)
2nd Quintile	$23.26	(9.69)	60.2%	(2.5)	2.9%	(1.3)
3rd Quintile	$8.20	(10.19)	53.7%	(2.4)	1.0%	(1.3)
4th Quintile	-$19.04	(11.37)	49.2%	(2.6)	-2.1%	(1.2)
5th Quintile	-$58.45	(10.93)	39.0%	(2.4)	-5.9%	(1.0)
B. By Needs-Adjusted Household Income Quintile						
1st Quintile	$29.70	(10.05)	64.7%	(2.3)	4.0%	(1.4)
2nd Quintile	$28.16	(9.73)	59.9%	(2.4)	3.5%	(1.3)
3rd Quintile	$12.44	(9.70)	54.8%	(2.5)	1.5%	(1.2)
4th Quintile	-$16.47	(11.07)	50.4%	(2.6)	-1.9%	(1.3)
5th Quintile	-$54.97	(10.52)	39.2%	(2.4)	-5.6%	(1.0)
C. Households with Children						
All Households with Children	-$21.19	(6.20)	52.1%	(1.5)	-2.3%	(0.7)
Households with One Child	-$1.34	(10.94)	53.9%	(2.7)	-0.2%	(1.3)
Households with Two Children	-$33.63	(12.17)	53.5%	(2.6)	-3.6%	(1.2)
Households with Three or More Children	-$33.72	(16.37)	46.4%	(3.6)	-3.5%	(1.6)
D. Low-Income Households with Children						
Households with Children	$2.80	(18.47)	65.5%	(3.4)	0.3%	(2.2)
Households with One Child	$65.68	(21.68)	73.7%	(6.0)	10.1%	(3.8)
Households with Two Children	-$24.96	(36.58)	64.3%	(5.9)	-2.7%	(3.8)
Households with Three or More Children	-$29.94	(32.31)	58.2%	(6.4)	-3.2%	(3.3)

Note: This table reports how household expenditure on natural gas would change under marginal cost pricing. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RECS sampling weights. Dollar amounts are expressed in year 2010 dollars. In panel (D) low-income is defined as households in the lowest quintile by needs-adjusted household income.

Table 4: Natural Gas Expenditure as a Share of Household Income

	(1) Under Current Price Schedules	(2) Under Marginal Cost Pricing	(3) p-value (1) vs (2)
A. By Household Income Quintile			
1st Quintile	6.7%	7.1%	.00
2nd Quintile	2.8%	2.9%	.02
3rd Quintile	1.8%	1.8%	.46
4th Quintile	1.4%	1.3%	.24
5th Quintile	0.8%	0.7%	.00
B. By Needs-Adjusted Household Income Quintile			
1st Quintile	6.5%	6.8%	.01
2nd Quintile	2.8%	2.9%	.00
3rd Quintile	1.9%	1.9%	.09
4th Quintile	1.4%	1.4%	.34
5th Quintile	0.9%	0.8%	.00

Note: This table reports natural gas expenditure as a share of household income under current price schedules and marginal cost pricing. Column (3) reports p-values from tests that the means in columns (1) and (2) are equal. All calculations are made using RECS sampling weights.

Table 5: The Impact on Households Below 150% of Poverty Line

		Mean Annual Change (in Dollars)	Mean Change (in Percent)	Share Who Receive Benefits	Annual Cost Per Non-Recipient
(1)	No Energy Assistance Program	$29.70	4.0%	0.0%	$0.0
		(10.05)	(1.4)	(0.0)	(0.0)
(2)	Zero Fixed Monthly Fee for Households Below 150% Poverty Line (100% takeup)	-$210.14	-28.0%	20.0%	$60.07
		(11.41)	(1.0)	(0.1)	(1.52)
(3)	$10 Monthly Lump Sum Payment for Households Below 150% Poverty Line (100% takeup)	-$90.30	-12.0%	20.0%	$30.06
		(10.05)	(1.1)	(0.1)	(0.23)
(4)	$10 Monthly Lump Sum Payment for Households Below 150% Poverty Line (50% takeup)	-$30.30	-4.0%	10.0%	$13.36
		(10.05)	(1.2)	(0.1)	(0.09)
(5)	$10 Monthly Lump Sum Payment for Households Below 150% Poverty Line (20% takeup)	$5.70	0.8%	4.0%	$5.01
		(10.05)	(1.4)	(0.0)	(0.03)
(6)	$10 Monthly Lump Sum Payment for Households in Multi-Unit Buildings	-$24.25	-3.2%	27.6%	$45.65
		(10.19)	(1.3)	(1.0)	(2.34)

Note: This table reports how household expenditure on natural gas would change under marginal cost pricing for households below 150% of the poverty line. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RECS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table 6: Consumer Surplus Impact of a Change to Marginal Cost Pricing

	Mean Annual Change in Consumer Surplus			
	ϵ=0	ϵ=-0.2	ϵ=-0.4	ϵ=-0.6
By Needs-Adjusted Household Income Quintile:				
1st Quintile	-\$29.70	-\$25.54	-\$21.17	-\$16.60
	(10.05)	(10.10)	(10.32)	(10.11)
2nd Quintile	-\$28.16	-\$23.66	-\$18.94	-\$14.01
	(9.73)	(9.97)	(10.16)	(9.89)
3rd Quintile	-\$12.44	-\$7.88	-\$3.10	\$1.91
	(9.70)	(9.81)	(9.92)	(9.71)
4th Quintile	\$16.47	\$21.46	\$26.68	\$32.15
	(11.07)	(11.12)	(11.20)	(11.61)
5th Quintile	\$54.97	\$61.72	\$68.82	\$76.28
	(10.52)	(11.24)	(11.75)	(11.90)
Average Across Quintiles	\$0.00	\$4.99	\$10.21	\$15.69
	(0.00)	(0.59)	(1.21)	(1.87)
Percent of Households Better Off	46.2%	47.5%	48.5%	49.6%
	(0.9)	(0.8)	(0.8)	(0.8)
Total National Change in Welfare	\$0	\$314	\$644	\$989
(In Millions, Annually)	(0.0)	(37)	(76)	(118)

Note: This table reports how consumer surplus would change under marginal cost pricing. The table reports results separately by needs-adjusted household income quintile for four alternative assumptions about the price elasticity of demand for natural gas. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RECS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table 7: Evaluating Potential "Leavers" Under Marginal Cost Pricing

	Gas Space Heating	No Gas Space Heating
Assumptions:		
Cost of Electricity ($/kWh)	$0.10	$0.10
kWH per thousand cubic feet	293	293
Efficiency of Natural Gas Appliances	0.80	0.80
Choke-off Price for Gas ($/thousand cubic feet)	$23.44	$23.44
Current Volumetric Charge for Natural Gas	$10.00	$10.00
Volumetric Charge Under Marginal Cost Pricing	$7.00	$7.00
Current Fixed Annual Fee	$72.00	$72.00
Fixed Annual Fee Under Marginal Cost Pricing	$240.00	$240.00
Annual Fixed Cost of Natural Gas Furnace	$100.00	$0.00
Annual Fixed Cost of Electric Heat	$20.00	$0.00
Elasticity of Demand	-0.40	-0.40
Results:		
Breakeven Consumption Under Current Tariff	14	6
Breakeven Consumption Under Marginal Cost Pricing	22	17
Proportion of Households in this Category with Natural Gas Consumption Levels Between Two Breakeven Levels	0.03	0.26
Implied Total Number of Households in U.S. (millions)	1.65	2.41

Note: Consumption is annual consumption of natural gas in thousands of cubic feet. Dollar amounts are expressed in year 2010 dollars.

Table 8: Alternative Assumptions About Greenhouse Gases

		Mean Annual Efficiency Gain By Quintile					
		First Quintile	Second Quintile	Third Quintile	Fourth Quintile	Fifth Quintile	Average Across Quintiles
(1)	No Externalities,	\$8.53	\$9.22	\$9.33	\$10.21	\$13.86	\$10.21
	No Greenhouse Gas Policy	(1.15)	(1.14)	(1.13)	(1.29)	(1.90)	(1.21)
(2)	External Cost of CO_2 Emissions of \$22,	\$3.34	\$3.50	\$3.68	\$4.01	\$5.86	\$4.07
	No Greenhouse Gas Policy	(0.67)	(0.65)	(0.65)	(0.77)	(1.20)	(0.73)
(3)	External Cost of CO_2 Emissions of \$22,	\$7.64	\$8.26	\$8.36	\$9.14	\$12.42	\$9.15
	Tax (or permit) on Carbon Dioxide of \$22	(1.04)	(1.03)	(1.02)	(1.17)	(1.72)	(1.09)

Note: This table reports the mean annual efficiency gain per household under a transition to marginal cost pricing for alternative assumptions about carbon dioxide emissions and policies. The table reports results separately by needs-adjusted household income quintile and for the average across quintiles. External damages of \$22 per ton of carbon dioxide are adopted following Federal Interagency Working Group (2010). All results assume that the price elasticity of demand is -0.4. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RECS sampling weights. Efficiency gains are expressed in year 2010 dollars.

Appendix A
Results For California Using Alternative Data

In this section we present results using an alternative dataset from the Residential Appliance Saturation Survey (RASS), a household-level survey conducted in 2003 by the California Energy Commission. The RASS provides household-level demographics, natural gas consumption, and the exact utility district for a representative sample of households in California. We collected actual utility rate schedules for Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Gas by contacting the utilities directly. These three utilities represent 97% of residential sales of natural gas in California. Table A1 provides descriptive statistics. We then calculated the revenue neutral, marginal-cost price schedule for each utility. Table A2 reports price schedules separately by utility and for the state as a whole. Markups are considerably higher in California than the national average, reflecting relatively low city gate prices in 2003 and the fact that the typical household in California uses less natural gas than the typical household nationwide. The rest of the tables describe the distributional impacts of a change to marginal cost pricing. The general pattern of the results is similar to our main results in Table 3. Under marginal cost pricing low-income households would tend to pay somewhat more and high-income households and households with children would tend to pay somewhat less. This pattern holds for the state as a whole in Table A3, and for each utility separately in Tables A4, A5, and A6.

Figure A1: Natural Gas Consumption and Household Income, All California Households

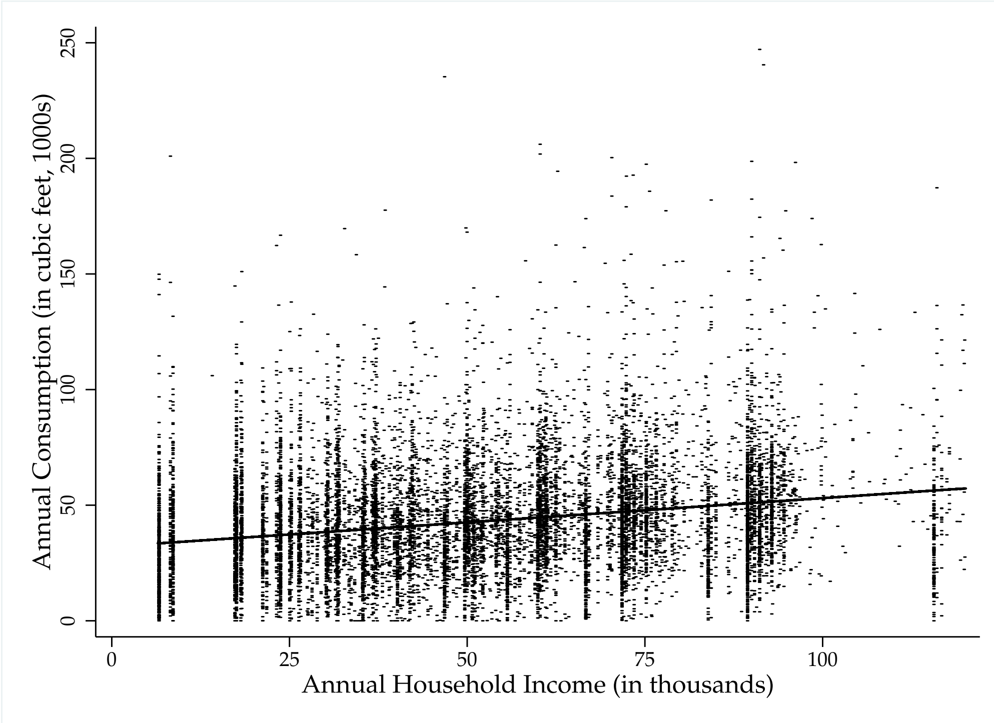

Figure A2: Natural Gas Consumption and Household Income, Separately By Utility

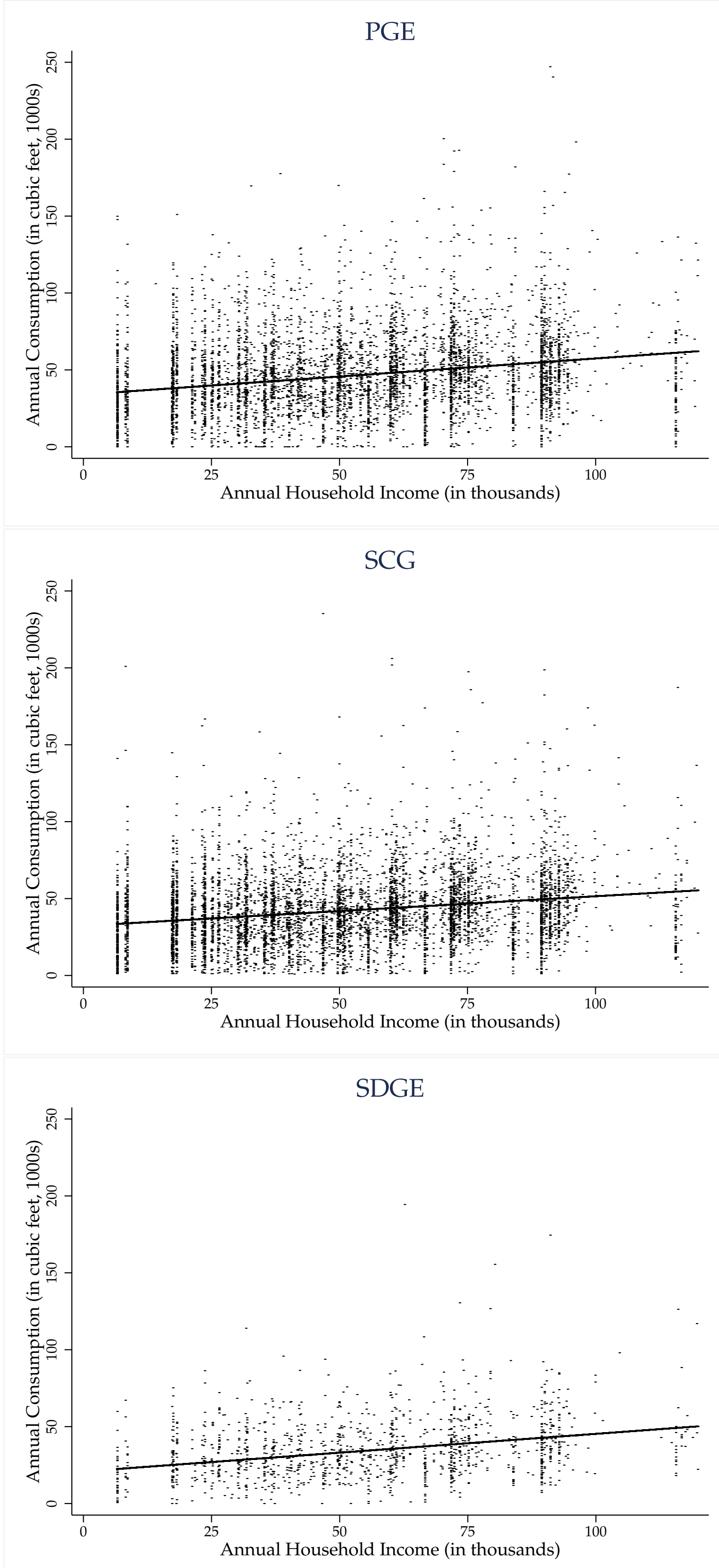

Figure A3: Residential Natural Gas Rate Schedules for 2002, By California Utility

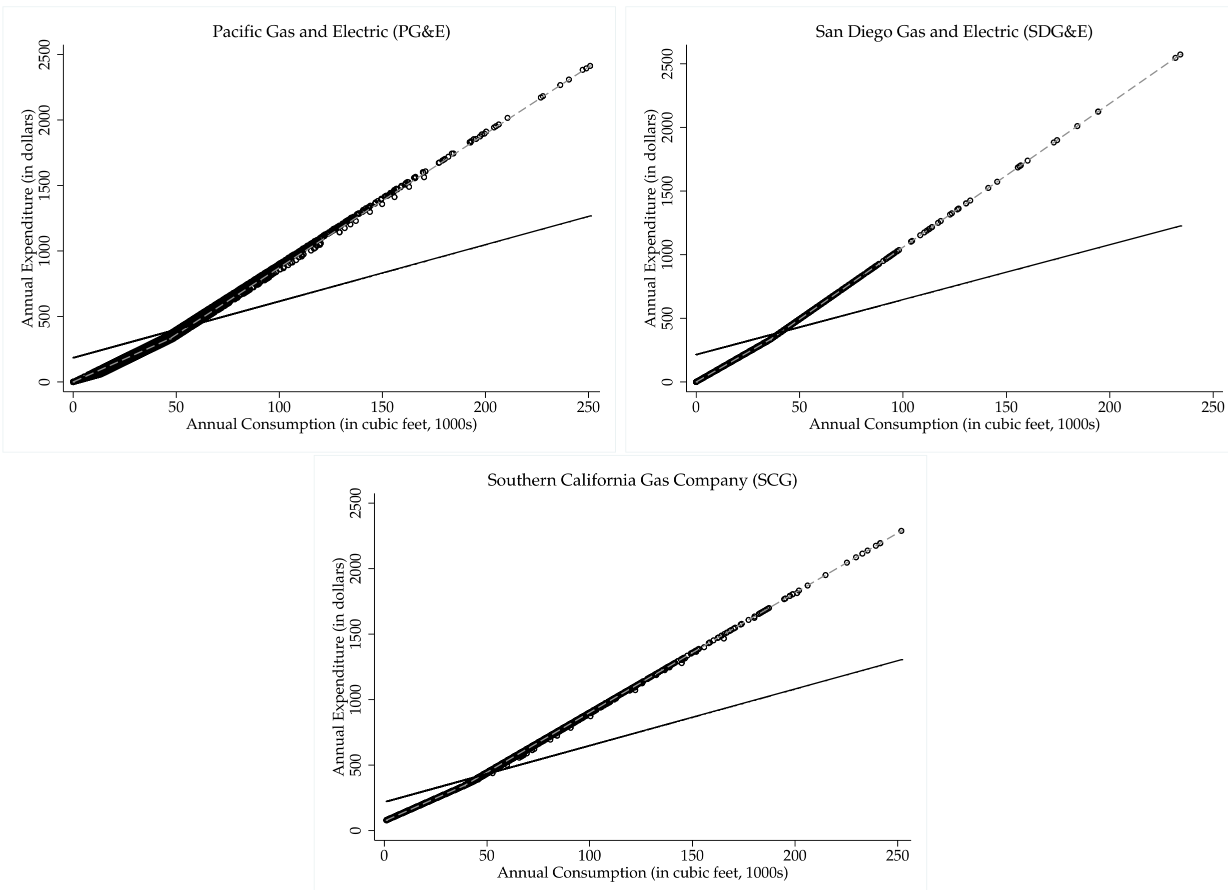

Table A1: Descriptive Statistics from RASS by Percent of Poverty Line Quintiles

	Quintile 1 <190%	Quintile 2 190-307%	Quintile 3 308-426%	Quintile 4 427-612%	Quintile 5 >613%
A. Household Economic and Demographic Characteristics					
Mean Annual Household Income (1000s)	26.88	47.54	66.35	86.47	136.78
	(13.51)	(17.22)	(19.78)	(28.06)	(30.01)
Number of Household Members	3.90	3.24	2.92	2.55	2.45
	(2.33)	(1.65)	(1.33)	(1.34)	(1.01)
Number of Children	1.45	1.03	0.78	0.55	0.44
	(1.61)	(1.26)	(0.98)	(1.01)	(0.79)
Proportion Homeowners	0.46	0.70	0.81	0.90	0.92
	(0.50)	(0.46)	(0.39)	(0.30)	(0.26)
B. Natural Gas Consumption and Expenditure					
Mean Annual Consumption (cubic feet, 1000s)	42.00	46.03	46.96	50.46	61.52
	(29.49)	(23.78)	(26.22)	(30.79)	(40.91)
Mean Annual Expenditure	361.20	397.23	408.31	442.24	544.81
	(267.17)	(215.03)	(240.69)	(297.13)	(394.06)
Expenditure as a Fraction of Income	0.02	0.009	0.006	0.005	0.004
	(0.02)	(0.01)	(0.00)	(0.00)	(0.00)
C. Energy Efficiency					
Main Heating System is Less than 9 Years Old	0.28	0.33	0.35	0.37	0.38
	(0.45)	(0.47)	(0.48)	(0.48)	(0.49)
All Exterior Walls are Insulated	0.43	0.51	0.52	0.61	0.63
	(0.50)	(0.50)	(0.50)	(0.49)	(0.48)
Some or All Exterior Walls are Insulated	0.58	0.69	0.70	0.77	0.80
	(0.49)	(0.46)	(0.46)	(0.42)	(0.40)
Ceiling/Attic is Insulated	0.52	0.70	0.74	0.82	0.83
	(0.50)	(0.46)	(0.44)	(0.38)	(0.37)
All Windows are Double-Pane	0.25	0.32	0.36	0.46	0.48
	(0.43)	(0.47)	(0.48)	(0.50)	(0.50)
Some or All Windows are Double-Pane	0.34	0.42	0.50	0.56	0.60
	(0.47)	(0.49)	(0.50)	(0.50)	(0.49)

Note: Summary statistics are reported only for those households (n=11,722) that answered every question of interest. Data are from the 2003 California Residential Appliance Saturation Study (RASS). Means and standard deviations (in parentheses) are calculated using RASS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table A2: Natural Gas Rate Schedules in California, by Utility

	Current Rate Schedule		Rate Schedule After Rebalancing	
	Volumetric Charge Below and Above Baseline	Fixed Monthly Fee	Volumetric Charge (Marginal Cost)	Fixed Monthly Fee
	(1)	(2)	(3)	(4)
Pacific Gas and Electric (PGE)	\$7.71 \$10.08	\$0.00	\$4.31	\$15.45
San Diego Gas and Electric (SDGE)	\$9.30 \$11.29	\$0.00	\$4.31	\$17.97
Southern California Gas Company (SCG)	\$6.94 \$9.14	\$6.05	\$4.31	\$18.22
Consumption-Weighted Average	\$7.50 \$9.74	\$2.97	\$4.31	\$17.06

Note: Sample size is 6,745 for PGE, 1,670 for SDGE, and 7,582 for SCG. Column (1) is the mean volumetric charge per 1000 cubic feet for current rate schedules both below and above baseline as reported by the LDCs. Column (2) is the monthly fixed fee for the current rate schedules, as reported by the LDCs. Column (3) is the mean city gate price from Platts, calculated as the consumption-weighted mean of monthly California prices. Finally, column (4) calculates the annual fee that would be required to maintain the same level of revenue if volumetric charges were decreased to marginal cost. The calculations in column (4) ignore that PGE currently offers a discount to multi-family homes of approximately 10 cents per day. All calculations are made using RASS sampling weights.

Table A3: The Distributional Impact of Marginal Cost Pricing, All California Utilities

	Mean Annual Change in Dollars		Percent Experiencing Bill Increase		Mean Bill Change in Percent	
A. By Household Income Quintile						
1st Quintile (<$32,000)	$40.46	(4.68)	73.1%	(1.7)	12.3%	(1.8)
2nd Quintile ($32,000-$47,000)	$34.90	(4.42)	73.3%	(1.8)	10.3%	(1.6)
3rd Quintile ($47,000-$68,000)	$15.05	(5.26)	67.6%	(1.9)	4.0%	(1.5)
4th Quintile ($68,000-$92,000)	-$15.42	(4.71)	54.2%	(1.9)	-3.5%	(1.0)
5th Quintile (>$92,000)	-$77.03	(6.43)	43.8%	(2.0)	-14.1%	(0.9)
B. By Percent of Poverty Line Quintile						
1st Quintile (<165%)	$31.68	(5.00)	70.5%	(1.8)	9.1%	(1.7)
2nd Quintile (165%-281%)	$21.77	(4.44)	67.8%	(1.8)	6.0%	(1.4)
3rd Quintile (281%-412%)	$11.60	(4.96)	64.4%	(2.0)	3.0%	(1.4)
4th Quintile (412%-587%)	-$11.31	(5.41)	58.4%	(1.9)	-2.7%	(1.2)
5th Quintile (>587%)	-$61.64	(7.40)	49.3%	(2.1)	-11.9%	(1.1)
C. Households with Children						
All Households with Children	-$10.70	(2.94)	58.1%	(1.2)	-2.5%	(0.7)
Households with One Child	$2.40	(6.04)	64.9%	(2.0)	0.6%	(1.5)
Households with Two Children	-$17.78	(5.69)	53.6%	(2.3)	-4.0%	(1.2)
Households with Three or More Children	-$20.58	(7.45)	54.3%	(2.6)	-4.6%	(1.5)
D. Low-Income Households with Children						
Households with Children	$28.26	(6.17)	68.1%	(2.5)	8.0%	(2.0)
Households with One Child	$49.58	(10.54)	74.4%	(4.5)	15.8%	(4.4)
Households with Two Children	$37.85	(9.98)	70.3%	(4.7)	11.3%	(3.6)
Households with Three or More Children	$8.54	(10.18)	62.8%	(3.9)	2.2%	(2.7)

Note: The sample used for this table includes all households in the 2003 Residential Appliance Saturation Survey who use natural gas. A small number of households were dropped for whom demographic information were not available. This table reports how household expenditure on natural gas would change under marginal cost pricing. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RASS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table A4: The Distributional Impact of Marginal Cost Pricing, Pacific Gas and Electric

	Mean Annual Change in Dollars		Percent Experiencing Bill Increase		Mean Bill Change in Percent	
A. By Household Income Quintile						
1st Quintile (<$32,000)	$57.39	(6.88)	74.1%	(2.6)	19.4%	(3.1)
2nd Quintile ($32,000-$47,000)	$43.02	(6.88)	75.7%	(2.7)	13.2%	(2.6)
3rd Quintile ($47,000-$68,000)	$20.72	(7.77)	64.4%	(2.8)	5.7%	(2.3)
4th Quintile ($68,000-$92,000)	-$28.20	(8.76)	51.8%	(2.8)	-6.2%	(1.7)
5th Quintile (>$92,000)	-$82.24	(9.01)	43.7%	(2.5)	-15.0%	(1.2)
B. By Percent of Poverty Line Quintile						
1st Quintile (<165%)	$55.75	(7.33)	74.0%	(2.9)	18.6%	(3.2)
2nd Quintile (165%-281%)	$21.90	(7.39)	67.9%	(2.9)	6.0%	(2.3)
3rd Quintile (281%-412%)	$10.12	(9.48)	63.4%	(2.9)	2.7%	(2.5)
4th Quintile (412%-587%)	-$16.28	(8.81)	53.7%	(2.9)	-3.8%	(1.9)
5th Quintile (>587%)	-$68.54	(10.65)	49.1%	(2.6)	-13.1%	(1.6)
C. Households with Children						
All Households with Children	-$8.80	(4.70)	56.5%	(1.9)	-2.1%	(1.1)
Households with One Child	$5.34	(10.48)	64.0%	(3.1)	1.4%	(2.8)
Households with Two Children	-$17.51	(7.84)	51.0%	(3.4)	-4.0%	(1.7)
Households with Three or More Children	-$17.91	(11.95)	52.9%	(4.4)	-4.1%	(2.6)
D. Low-Income Households with Children						
Households with Children	$52.95	(9.35)	72.6%	(3.9)	17.2%	(4.0)
Households with One Child	$102.16	(11.77)	87.7%	(4.8)	48.3%	(11.0)
Households with Two Children	$47.86	(16.02)	70.8%	(7.5)	14.8%	(6.5)
Households with Three or More Children	$19.21	(16.44)	62.4%	(7.0)	5.2%	(5.0)

Note: The sample used for this table includes all Pacific Gas and Electric customers in the 2003 Residential Appliance Saturation Survey who use natural gas. A small number of households were dropped for whom demographic information were not available. This table reports how household expenditure on natural gas would change under marginal cost pricing. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RASS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table A5: The Distributional Impact of Marginal Cost Pricing, San Diego Gas and Electric

	Mean Annual Change in Dollars		Percent Experiencing Bill Increase		Mean Bill Change in Percent	
A. By Household Income Quintile						
1st Quintile (<$32,000)	$70.06	(16.81)	79.8%	(6.0)	26.5%	(8.8)
2nd Quintile ($32,000-$47,000)	$59.70	(16.37)	74.6%	(5.8)	21.2%	(7.6)
3rd Quintile ($47,000-$68,000)	$10.37	(33.22)	74.3%	(5.1)	2.8%	(9.1)
4th Quintile ($68,000-$92,000)	$6.81	(14.76)	62.0%	(6.5)	1.8%	(4.0)
5th Quintile (>$92,000)	-$109.22	(24.70)	43.7%	(5.1)	-19.3%	(2.8)
B. By Percent of Poverty Line Quintile						
1st Quintile (<165%)	$66.22	(20.15)	78.2%	(6.4)	24.6%	(10.6)
2nd Quintile (165%-281%)	$44.23	(17.42)	69.5%	(6.1)	14.4%	(6.9)
3rd Quintile (281%-412%)	$41.71	(13.03)	72.1%	(6.6)	13.2%	(4.5)
4th Quintile (412%-587%)	-$5.34	(19.37)	67.8%	(5.1)	-1.4%	(4.6)
5th Quintile (>587%)	-$103.13	(26.83)	44.3%	(5.4)	-18.6%	(3.2)
C. Households with Children						
All Households with Children	-$22.00	(14.85)	62.3%	(3.7)	-5.2%	(3.2)
Households with One Child	$3.05	(31.77)	74.6%	(6.1)	0.8%	(8.4)
Households with Two Children	-$28.32	(21.20)	53.1%	(7.1)	-6.6%	(4.5)
Households with Three or More Children	-$58.92	(56.19)	55.5%	(9.3)	-12.3%	(9.8)
D. Low-Income Households with Children						
Households with Children	$40.34	(33.23)	67.2%	(11.0)	12.9%	(14.0)
Households with One Child	$99.02	(39.50)	83.7%	(11.3)	47.0%	(27.6)
Households with Two Children	$21.44	(49.36)	65.4%	(18.7)	6.2%	(19.9)
Households with Three or More Children	$29.27	(60.85)	59.7%	(18.2)	8.9%	(27.8)

Note: The sample used for this table includes all San Diego Gas and Electric customers in the 2003 Residential Appliance Saturation Survey who use natural gas. A small number of households were dropped for whom demographic information were not available. This table reports how household expenditure on natural gas would change under marginal cost pricing. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RASS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Table A6: The Distributional Impact of Marginal Cost Pricing, Southern California Gas

	Mean Annual Change in Dollars		Percent Experiencing Bill Increase		Mean Bill Change in Percent	
A. By Household Income Quintile						
1st Quintile (<$32,000)	$22.71	(6.47)	71.3%	(2.3)	6.2%	(2.0)
2nd Quintile ($32,000-$47,000)	$23.83	(6.10)	71.1%	(2.6)	6.6%	(1.9)
3rd Quintile ($47,000-$68,000)	$11.83	(6.07)	68.8%	(2.6)	3.0%	(1.6)
4th Quintile ($68,000-$92,000)	-$9.93	(4.93)	54.3%	(2.8)	-2.3%	(1.1)
5th Quintile (>$92,000)	-$62.01	(8.52)	44.0%	(3.3)	-11.5%	(1.2)
B. By Percent of Poverty Line Quintile						
1st Quintile (<165%)	$11.46	(6.80)	67.4%	(2.4)	3.0%	(1.9)
2nd Quintile (165%-281%)	$17.44	(5.52)	67.4%	(2.6)	4.6%	(1.6)
3rd Quintile (281%-412%)	$7.55	(5.43)	63.8%	(2.5)	1.9%	(1.4)
4th Quintile (412%-587%)	-$8.19	(6.35)	60.3%	(2.9)	-1.9%	(1.4)
5th Quintile (>587%)	-$43.05	(8.09)	50.9%	(3.1)	-8.6%	(1.3)
C. Households with Children						
All Households with Children	-$10.17	(3.34)	58.7%	(1.7)	-2.3%	(0.7)
Households with One Child	$0.03	(6.44)	63.8%	(2.8)	0.0%	(1.6)
Households with Two Children	-$15.78	(8.52)	56.0%	(3.1)	-3.6%	(1.8)
Households with Three or More Children	-$17.46	(7.88)	54.9%	(3.3)	-3.9%	(1.6)
D. Low-Income Households with Children						
Households with Children	$11.32	(7.50)	65.4%	(3.2)	2.9%	(2.0)
Households with One Child	$8.96	(13.41)	64.3%	(6.5)	2.3%	(3.6)
Households with Two Children	$32.69	(10.73)	70.8%	(6.0)	9.5%	(3.8)
Households with Three or More Children	$1.51	(12.73)	63.2%	(4.8)	0.4%	(3.1)

Note: The sample used for this table includes all Southern California Gas customers in the 2003 Residential Appliance Saturation Survey. A small number of households were dropped for whom demographic information were not available. This table reports how household expenditure on natural gas would change under marginal cost pricing. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RASS sampling weights. Dollar amounts are expressed in year 2010 dollars.

Appendix B
An Alternative Measure of Household Resources

In this appendix we repeat the counterfactual bill analysis using what we argue is a more permanent measure of household resources. Because income varies over the life-cycle, many studies have pointed out that welfare analyses using annual income may be misleading. See, e.g., Poterba (1989), Poterba (1991), and Cutler and Katz (1992). Annual income is typically low early and late in life but households with access to credit markets or other forms of intertemporal borrowing can smooth their consumption. The goal of redistributive policy is to transfer resources to truly needy households so a program that sends money to, for example, college students with high permanent income and wealthy retirees would not be viewed as socially desirable.

Previous studies have used a variety of approaches to construct more permanent measures of household resources. Some studies have argued that expenditure provides a more accurate measure of household well-being than income. For example, Poterba (1989) and Poterba (1991) examine the distributional impact of gasoline, alcohol, and tobacco taxes, contrasting results using annual income and annual expenditure. The main finding in both studies is that excise taxes appear less regressive when expenditure is used. Where longitudinal data are available, other studies have constructed measures of long-run income such as the present discounted value of lifetime earnings. See, e.g., Haider and Solon (2006) and Rothstein and Wozny (2009).

The RECS data only include a single year of income and no measure of financial wealth. However, the survey does include highly-detailed information about the appliances owned by the household. In this subsection we use this information to construct a measure of "appliance wealth" that may be a reasonable proxy for lifetime income. Because households replace appliances relatively infrequently, our approach is likely to be more accurate than a measure of the total resources of the household than expenditure on appliances in a given year.

We consider four classes of appliances: refrigerators, clothes washers, dryers and dishwashers. The RECS also includes detailed information about heating and cooling equipment, but we exclude these durable goods because they are more a function of climate than household resources. We also wanted to focus on durable goods that were not primary drivers of natural gas consumption in the home. Refrigerators are the best example because the size, age, and characteristics of a refrigerator are correlated with household wealth yet the appliance uses no natural gas. The only appliance we considered that directly uses natural gas is the clothes dryer. In our sample 30% of households own a clothes dryer that runs on natural gas. Clothes washers and dishwashers use natural gas indirectly through consumption of hot water, but this is a relatively small fraction of total natural gas consumption. One might have, in addition, included cars and trucks owned by the household but the RECS focuses on energy consumption within the home and does not include questions about household vehicles.[1]

We predict the price at the time of sale for these appliances using Consumer Reports (CR) magazine from 1986-2005. CR publishes an article on each of these four types of appliances every year or two. For refrigerators, for example, CR included an article approximately every two years during the 1980s, and then every year since 2000. These articles include a detailed description of a representative group of appliance models sold during a given year.

We match appliances to CR prices using the reported age of the appliance and other available characteristics. For example, because the RECS survey was conducted in 2005, for a three year-old appliance we use the CR article from 2002. More specifically, because RECS provides an age range (e.g. 2-4 years old) rather than an exact age, we use the midpoint of the range. Moreover, for appliances that are "20 years or older" we use prices from the 1986 edition of CR, the oldest edition that is available electronically. Finally, in less than 5% of all cases a household reports that they "don't know" the appliance age. For these cases, we assign appliances to the median age category for that appliance type.

For each reviewed model, CR reports purchase price and a number of detailed characteristics. To predict prices we use the most detailed available characteristics that can be matched across CR and RECS. For example, for refrigerators both CR and RECS report the size (in cubic feet), whether or not the refrigerator has side-by-side doors, and whether or not the refrigerator has through-the-door ice and water. For some of the other appliances the characteristics are more limited. For example, for clothes washers RECS elicits information about the age of the clothes washer, and whether or not the clothes washer is top-loading or front-loading, but does not ask about capacity.

Purchase prices are normalized to reflect year 2005 prices. We assume that the value of an appliance depreciates at a constant real annual rate of 5%. This is approximately consistent with U.S. Department of Energy (2010c) which uses an average life expectancy of about 20 years for most residential appliances. We have evaluated the sensitivity of our estimates to alternative depreciation rates (2% and 8%) and results are similar.

Table A7 reports results by durable wealth quintile. Results are similar to the results by income quintile. Changes in natural gas bills range across quintiles from +$57 annually in the first quintile to -$55 annually in the fifth quintile. These fairly modest effects reflect the fact that appliance wealth is no more correlated with natural gas consumption than household income. Whereas the correlation between natural gas consumption and household income is .19, the correlation between

[1] The 2009 RECS includes a new section on "Residential Transportation" that elicits information about vehicles owned by the household by vehicle year, make, and model and it would be interesting to repeat this analysis with these data when they become available.

natural gas consumption and appliance wealth is .15. Overall, Table A7 suggests that our results may not be unduly sensitive to a more long-run measure of household resources.

Still, it is important to point out that there are important limitations to "appliance wealth" as a measure of permanent income. The measure is likely to work best for homeowners who have lived in their home for a long time. In these cases, the appliance portfolio essentially provides a 20+ year history of household expenditure on appliances. The measure works less well for new homeowners and renters because of principal-agent problems and other market failures. Because secondary markets for appliances are near non-existent, a new homeowner may need to continue to use whatever appliances are sold with the home rather than immediately adopting an appliance portfolio consistent with what the household can afford based on permanent income. Similarly, landlords may underinvest in high-quality appliances when informational asymmetries make it difficult to credibly convey information about these investments. The landlord-tenant problem implies that "appliance wealth" is likely to understate permanent income for renters.

Additional References in Appendix B

Haider, Steven and Gary Solon, "Life-Cycle Variation in the Association between Current and Lifetime Earnings," *American Economic Review*, Vol 96, No. 4 (September, 2006), pp. 1308-1320.

Rothstein, Jesse and Nathan Wozny, "Permanent Income and the Black-White Test Score Gap," *working paper*, June 2009.

U.S. Department of Energy, Energy Information Administration, "Assumptions to the Energy Outlook 2010," DOE/EIA-0554, released April 2010 (2010c).

Table A7: The Distributional Impact By Appliance Wealth Quintile

	Mean Annual Change in Dollars		Mean Change in Percent	
1st Quintile	$56.64	(10.10)	7.8%	(1.6)
2nd Quintile	$28.57	(10.51)	3.5%	(1.3)
3rd Quintile	-$2.14	(9.31)	-0.3%	(1.1)
4th Quintile	-$31.12	(10.71)	-3.5%	(1.1)
5th Quintile	-$54.84	(10.41)	-5.7%	(1.0)

Note: This table reports how household expenditure on natural gas would change under marginal cost pricing. Bootstrap standard errors based on 1000 replications are shown in parentheses. All calculations are made using RECS sampling weights. Dollar amounts are expressed in year 2010 dollars.