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ABSTRACT

A direct consequence of imposing a ceiling on the price of a good for which secondary markets do not exist, is that, when there is excess demand, the good will not be allocated to the buyers who value it the most. The resulting allocative cost has been discussed in the literature as a potentially important component of the total welfare loss from price ceilings, but its practical importance has yet to be established empirically. In this paper, we address this question using data for the U.S. residential market for natural gas which was subject to price ceilings during 1954-1989. This market is well suited for such an empirical analysis and natural gas price ceilings affected millions of households. Using a household-level, discrete-continuous model of natural gas demand, we estimate that the allocative cost in the U.S. residential market for natural gas averaged $4.6 billion annually since the 1950s, effectively tripling previous estimates of the net welfare loss to U.S. consumers. We quantify the evolution of this allocative cost and its geographical distribution during the post-war period, and we highlight implications of our analysis for the regulation of other markets.

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1 Introduction

A large literature in economics examines the welfare costs of price ceilings. Among the markets that have received the most attention are rental housing, telecommunications, insurance, energy, and health care.[1] In traditional welfare analysis, price ceilings reduce the quantity transacted below the competitive level, imposing deadweight losses on both buyers and sellers. In this paper we concentrate on an additional component of welfare loss that is often ignored. Notably, when there is excess demand for a good for which secondary markets do not exist, a welfare loss occurs when the good is not allocated to the buyers who value it the most. This allocative cost has been studied, for example, by Glaeser and Luttmer (2003), but its practical importance has yet to be established empirically.[2]

Our analysis focuses on price ceilings in the U.S. residential market for natural gas in the post-war period. This market is a good candidate for an empirical study of allocative costs for several reasons. First, natural gas is a homogeneous good, eliminating the concerns about differences in quality that complicate the estimation of allocative costs in other markets. Second, whereas secondary markets may act to mitigate the costs of misallocation in some markets such as rental housing, there are no resale markets for natural gas. Third, the residential market for natural gas affects millions of consumers suggesting that allocative costs could be very large. Fourth, this market was continuously regulated between 1954 and 1989 before experiencing complete deregulation. This allows us to observe market behavior both under regulation and in the absence of regulation. Fifth, the fact that some states remained unregulated throughout this period allows us to evaluate the out-of-sample fit of our model in settings where markets operate freely. These markets also allow us to assess the evidence for possible structural changes in the model parameters. Sixth, this market lends itself to empirical analysis, given the availability of unusually comprehensive household-level data by state and year as well as the corresponding state-level price data.

We construct estimates of the allocative costs associated with the regulation of natural gas

[1] See, for example, Hayek (1931), Olsen (1972), Smith and Phelps (1978), Raymon (1983), Frech and Lee (1987) and MacAvoy (2000). A closely related literature studies the welfare costs of minimum wage legislation in labor markets (see, e.g., Holzer, Katz and Krueger (1991); Card and Krueger (1994).)

[2] The problem of allocative costs is aptly described in Friedman and Stigler (1946). An early theoretical treatment can be found in Weitzman (1977). The analogous problem of misallocation due to minimum wages has been discussed as early as Welch (1974) and has been studied in Luttmer (2007). Allocative costs should not be confused with *allocated costs*, a legal term used by the Federal Energy Regulatory Commission to describe average cost pricing. We prefer the term "allocative cost" also to the term "allocative inefficiency" as used by Viscusi, Harrington and Vernon (2005) because the latter does not distinguish between physical shortages and the economic costs associated with the misallocation. Likewise, we do not use the term "distributional inefficiency" which is sometimes used to refer to the equalization of the marginal rate of substitution across consumers because it evokes images of income redistribution.

prices based on several alternative thought experiments. Our baseline thought experiment exploits the fact that by the 1990s, the natural gas market had been completely deregulated and, unlike during the period of regulation, all households wanting to adopt natural gas heating systems were able to make that choice. Our empirical strategy is to ask how much natural gas would have been consumed in 1950-2000 based on the household preferences revealed in the 1990s data. Comparing households' actual choices with what they would have liked to choose in an unconstrained world, as implied by an economic model of consumer choice, allows us to calculate physical shortages of natural gas and to measure the allocative cost of price ceilings.

Our paper provides for the first time a detailed picture of the evolution of physical shortages in the U.S. natural gas market during the post-war period. Whereas previous studies have traditionally measured the degree of disequilibrium in the natural gas market using shortfalls in contractually-obligated deliveries to pipelines, our measure of the physical shortage correctly incorporates not only demand from existing delivery contracts, but the unrealized demand from prospective new customers as well.[3] This distinction is particularly important in the residential market because shortages were accommodated by restricting access to potential new customers rather than by rationing existing users. Thus, rationing took place on the extensive rather than the intensive margin. We find that during the period 1950-2000 demand for natural gas exceeded observed sales of natural gas by an average of 20.3%, with the largest shortages during the 1970s and 1980s. Compared to previous studies, we find that the shortages began earlier, lasted longer, and were larger in magnitude.

Physical shortages are important in describing the effect of price ceilings, but in themselves do not provide a measure of economic costs. Using a household-level, discrete-continuous model of natural gas demand following Dubin and McFadden (1984) we estimate that the allocative cost from price ceilings averaged $4.6 billion annually in the U.S. residential market during 1950-2000.[4] While this estimate may appear large, alternative (if less credible) identifying strategies using gas-exporting states yield estimates about twice as large, leading us to interpret the baseline estimate as a conservative lower bound on the allocative cost. Because this allocative cost arises in addition to the conventional deadweight loss, our estimates imply that total welfare losses from natural

[3]For example, Vietor (1984) reports that shortfalls in contractually-obligated deliveries to pipelines increased steadily beginning in 1970, reaching approximately 3 trillion cubic feet in 1976. This is a significant amount considering that total natural gas consumption in the U.S. in that year was 20 trillion. As large as these curtailments were, results from our model suggest that they understate the true level of disequilibrium in the market because they fail to account for demand from prospective new customers.

[4]All dollar amounts are expressed in year 2000 dollars.

gas regulation were considerably larger than previously believed. Moreover, our household-level approach provides insights into the distributional effects of regulation that could not have been obtained using a model based on national or even regional data. In particular, we are able to identify which states were the biggest losers from regulation. We show that the allocative cost of regulation was borne disproportionately by households in the Northeast, Midwest, and South Atlantic states. We compare the geographic distribution of allocative cost to Congressional voting patterns and document that regulation was primarily supported by Senators from states in the Northeast and Midwest whose constituents ended up bearing a disproportionately large share of the allocative cost.[5]

Our analysis has several policy implications. First, regulators need to be aware that price ceilings only benefit consumers that have access to regulated markets. When there is a shortage of a good, not all consumers will have access to the market, and those who have access will not necessarily be the consumers who value the good the most. Second, the adverse effects of price ceilings can last much longer than the regulatory policies themselves. With natural gas, since households change heating systems infrequently, households who are barred from adopting natural gas heating systems because of a price ceiling will continue to use inferior technologies for years to come. This lock-in effect helps explain the persistence and the magnitude of the allocative costs that we find, and highlights the difficulty of predicting the duration of the effects of price regulation. Third, our analysis underscores the difficulty of determining in advance how the allocative cost of price regulation will be distributed geographically.

The format of the paper is as follows. Section 2 provides a description of regulation in the U.S. natural gas industry since the 1930s, emphasizing characteristics of the regulating policies that are relevant to our analysis. Section 3 describes a model of price ceilings. We demonstrate the existence of an allocative cost from price ceilings in addition to the conventional deadweight welfare loss for goods for which there is no secondary market. Sections 4 and 5 introduce our household-level model of demand for natural gas and discuss its empirical implementation. In section 6, we discuss

[5]Our analysis is germane to a substantial literature that examines regulation in the U.S. natural gas industry. Early studies such as MacAvoy (1971), MacAvoy and Pindyck (1973), Breyer and MacAvoy (1973) and MacAvoy and Pindyck (1975) document gas shortages in the early 1970s and use structural dynamic simultaneous equation models to simulate hypothetical paths for prices, production and reserves under alternative regulatory regimes. Subsequent studies by Sanders (1981), MacAvoy (1983), Braeutigam and Hubbard (1986), Kalt (1987), Bradley (1996) and MacAvoy (2000) describe the regulatory policies in the natural gas market since the 1970s and provide further documentation of shortages. Several of these studies present estimates of the deadweight loss from natural gas price ceilings, but only Braeutigam and Hubbard (1986) and Viscusi, Harrington and Vernon (2005) discuss the issue of allocative cost. Our study is the first to quantify the size of this allocative cost and to assess its evolution over time and its geographic distribution across states during the post-war period.

the estimates of physical shortages and allocative cost. We study both the within-state allocation of natural gas and the allocation across states. The allocative cost arising from misallocations across states can be readily computed by comparing the actual allocation with the hypothetical allocation under efficient rationing. An inherent difficulty with modeling the within-state allocation of natural gas during shortages is that the data do not allow us to distinguish between households who chose not to use natural gas and households who were rationed out of the market. Consistent with evidence presented in section 6.2 we assume that the within-state allocation among households interested in acquiring natural gas is random. In section 6.5 we evaluate the out-of-sample fit of the model, and in section 6.6 we examine the sensitivity of the estimates of allocative cost to alternative modeling assumptions. Section 7 contains concluding remarks.

2 History of Natural Gas Regulation in the U.S.

The natural gas market in the United States consists of three main players: gas producers, interstate pipeline companies, and local distributors. Most natural gas in the United States is produced in gas fields concentrated in the Southwest, whereas most consumption takes place in the Midwest and Northeast. Gas producers are responsible for exploring for and producing natural gas. Interstate pipeline companies buy natural gas from producers at the wellhead and deliver it to the consuming areas in exchange for a markup on wellhead prices. Local distributors in turn purchase natural gas from the interstate pipelines at wholesale prices, and distribute it to retail customers subject to an additional mark-up.

Each of the three main players in the natural gas market faced different regulatory constraints in the post-war period. Throughout this period, local gas distributors were regulated at the state level. Pipeline companies that transported gas across state lines were regulated at the federal level by the Natural Gas Act of 1938, following the well-established model of public utilities. Finally, until the early 1950s, producers of natural gas were unregulated. By all accounts natural gas producers were operating in a competitive market. In 1953, the 30 largest gas producers controlled less than half of all proved reserves, and accounted for only one third of sales to interstate pipelines (see Vietor 1984). In the same year, the largest four firms produced 17% of the national output and the largest 44 firms produced 73% (see Lindahl 1956).[6] Neuner (1960) based on an in-depth

[6]Similarly, Cookenboo (1958) finds that around 1954 the twenty largest gas producing firms represent 54% of the volume of total contracts for interstate sales, 54% of total production, and 55% of total undeveloped acreage under lease. Cookenboo (1958, p. 79-80) points out that these figures indicate that, "...about three-fourths of manufacturing industries are more concentrated than is the field market for natural gas... No one firm is several times larger than

study of national as well as regional markets rejects the claim that the Southwestern gas market was not competitive in 1953.

The major problem in the natural gas industry in the 1930s and 1940s had been one of overproduction. This situation changed in the 1950s. As the pipeline system expanded, supply could barely keep up with rising demand for natural gas among urban consumers in the Midwest and Northeast. Supply of natural gas was concentrated in four southwestern states. By 1953/54, Texas, Louisiana, Oklahoma and New Mexico provided 79% of all marketed gas production and about the same percentage of interstate shipments.[7]

As the demand for natural gas increased faster than supplies in the early 1950s, gas prices were rising rapidly much to the dismay of consumer advocates. Pressures arose to broaden the interpretation of the meaning of the Natural Gas Act in an effort to stem these price increases. Since the legislature was not sympathetic to an expansion of federal control over natural gas resources, the courts became the focal point of this effort. In 1954, the Supreme Court reviewed the case of *Phillips Petroleum Company vs. Attorney General of Wisconsin*. Phillips' prices had been increasing and higher wellhead prices (which in turn were responsible for higher retail prices) were alleged to be contrary to the interests of consumers in Wisconsin and in violation of the Natural Gas Act of 1938. The question of whether Phillips was guilty of pricing above competitive market levels, as the plaintiffs asserted, was never assessed by the court, but the court ruled that independent gas producers that sold their gas production to unaffiliated interstate pipeline companies were subject to the 1938 Natural Gas Act and should be regulated as public utilities. This court decision brought independent natural gas producers under the regulatory umbrella of the Federal Power Commission (FPC) (see Sanders 1981).[8] In practice, the FPC's implementation of the Supreme Court decision involved the imposition of price ceilings and a transfer of wealth from gas producers in the Southwest to consumers across the country. Federal price controls on natural gas sold in the interstate market stimulated consumer demand, while at the same time discouraging supply. The natural consequence was a shortage of natural gas.

In the late 1950s, the cost of new exploration increased faster than gas prices. It became

the next smaller, and there are many of sufficiently large size relative to the largest to create significant competition for it. Under these conditions it would be almost inconceivable that any one seller could have any significant influence over price".

[7]Natural gas is more expensive to transport than oil and thus most natural gas consumed in the U.S. is produced in North America. Net imports of natural gas increased from less than 1% in 1950 to 15.2% in 2000, but 94% of the natural gas imports in 2000 came from Canada (see E.I.A. 2006d, table 6.3).

[8]This ruling contrasts with the court's earlier position in *Federal Power Commission vs. Hope Natural Gas Company*, 320 U.S. 591 (1944) in which the Supreme Court supported the FPC's jurisdiction over interstate sales of natural gas, but continued to restrict the FPC from exerting authority over natural gas production.

increasingly costly for gas producers to locate new reserves, but FPC regulated prices made no allowance for rising costs of exploration. As a result, the reserves-to-production ratio dropped from 18.5 in 1966 to 15.5 in 1968 and 8.5 in 1977 (see MacAvoy 1983, p.90). Early warnings about impending shortages in the gas market were dismissed. Actual curtailments of gas supplied to industrial customers began in 1970, and by 1974 service to industrial customers in interstate markets had been widely curtailed. A further complication arose from the fact that the FPC's jurisdiction did not extend to gas sold within gas-producing states. The existence of an unregulated intrastate gas market worsened the shortage in the FPC controlled interstate market. Whereas in 1970 the average price of gas in the regulated interstate and the unregulated intrastate markets was virtually identical, by 1972, the FPC was holding wellhead prices for interstate delivery well below the levels observed in the unregulated intrastate markets, and increasingly so over time.[9] Given the price differential between regulated interstate and unregulated intrastate markets, gas producers in the Southwest sold as much gas as possible to higher paying intrastate customers, adding to the shortage of natural gas in the Midwest and Mid-Atlantic region. Whereas in the 1964-1969 period, gas producers dedicated 67% of their new reserves to the interstate market, in 1970-1973 that figure fell to 8%.[10]

From September 1976 to August 1977, net curtailments of contracted interstate gas deliveries amounted to 20% of all supplies (see Braeutigam and Hubbard 1986). Prospects of increasing shortages brought the issue of natural gas regulation back before the legislature. The regulatory turmoil of the 1970s ultimately led to the passage of the Natural Gas Policy Act in 1978, which specified a phased deregulation of most prices for gas discovered after 1976. The 1978 Act was a political compromise intended to reduce shortages without completely eliminating the distortions of the old pricing system. After 1978, natural gas prices temporarily spiked, supplies expanded and curtailments were eliminated, but it was only in 1989 that all forms of regulation of gas producers were officially terminated (see Bradley 1996).

Thus, residential natural gas prices in the United States were subject to price ceilings during a 35-year period from 1954 to 1989. The purpose of this paper is to quantify the allocative costs associated with these price ceilings. We exploit the fact that by the 1990s, natural gas was widely available in the U.S. and, unlike in previous decades, households wanting to adopt natural gas heating systems were able to make that choice. Even in the 1950s, prior to regulation, households

[9]See, e.g., Braeutigam and Hubbard (1986, p.143) and MacAvoy (1983, p. 91).

[10]See Braeutigam and Hubbard (1986, p.146). Vietor (1984, p. 289) reports somewhat higher shares in the later period.

wanting natural gas faced constraints, as gas producers could not keep up with rising demand (see, e.g., American Gas Association (1951, p. 158)). Our empirical strategy is to ask how much natural gas would have been consumed in 1950-2000 based on choices made by households living in homes built during the 1990s. Controlling for the covariates that affect heating demand, these choices allow the estimation of household preferences. This strategy addresses one of the central difficulties in estimating the allocative cost of price ceilings. In particular, during periods of price regulation, one only observes households' behavior under the constraints imposed by regulation, making it difficult to identify households' unconstrained preferences. Our study sidesteps this difficulty by taking advantage of the fact that in the 1990s we observe unconstrained household behavior. Comparing households' actual choices with what they would have liked to choose in an unconstrained world as implied by the model, allows us to measure the allocative cost of price ceilings. In the following sections we develop this empirical strategy in more detail. We investigate the sensitivity of our results to alternative thought experiments in Section 6.6, where we also address the possibility that household preferences and heating characteristics may have changed over time.

3 Price Ceilings and Allocative Cost

Figure 1 describes the standard problem of imposing a price ceiling. At the competitive equilibrium, the market clears with price P^* and quantity Q^*. Now consider the effect of a price ceiling P^{**} imposed below P^*. The price ceiling reduces output to Q^{**}. At this level of output demand D(P^{**}) exceeds supply S(P^{**}). Compared to the competitive equilibrium, households gain P^*deP^{**} from paying $P^* - P^{**}$ less per unit but lose triangle bcd because of the decrease in quantity. Firms are unambiguously worse off, losing P^*deP^{**} because of the decrease in price and dce because of the decrease in quantity. Total deadweight loss is bce.

The welfare cost of price ceilings, however, is not necessarily limited to this triangle. Upon further inspection it becomes clear that welfare losses will be limited to the deadweight loss triangle bce if and only if the good is allocated to the buyers who value it the most. Under efficient rationing, buyers represented on the demand curve between a and b receive the good, while those represented by the demand curve between b and f do not. In some markets it may be reasonable to assume that a good is allocated efficiently. For example, when there is a secondary market where goods can be resold, this secondary market ensures that buyers with the highest willingness to pay receive the good. However, in many markets such as the market for natural gas there is no mechanism that ensures that customers with the highest reservation price will receive the good. In these markets the welfare costs of price regulation also depend on how the good is allocated. Inefficient rationing imposes additional welfare costs.

A commonly used benchmark in illustrating these additional welfare costs is the case in which goods are allocated randomly to buyers (see figure 2).[11] The random allocation is inefficient because it does not allocate goods to buyers with the highest willingness-to-pay. At the price ceiling P^{**}, demand for the good is $D(P^{**})$, but supply is only Q^{**}. If supply is allocated randomly then only a fraction $\frac{Q^{**}}{D(P^{**})}$ of buyers with a reservation price above P^{**} will be able to buy the good. This random allocation is depicted by the curve $\frac{Q^{**}}{D(P^{**})}D(P)$. Now, in addition to the deadweight loss, *bce*, there is an additional welfare loss, *abe*, that is the result of the loss of efficiency from not allocating the good to the consumers with the highest reservation price. This additional welfare loss represents the "allocative cost" of regulation in this example.

In practice, the level of the allocative cost will depend not only on how the good is rationed, but also on the distribution of reservation prices across households. The distribution of reservation prices across households is reflected in the slope of the demand curve. If all households have identical reservation prices there will be no welfare costs from misallocation. Allocative costs arise because household preferences and technologies are heterogeneous. In the market for natural gas this heterogeneity arises mainly for two reasons. First, there are differences across households in preferences for different types of heating systems. For example, households differ in how much they value the cleanliness and convenience of natural gas. Second, households differ in how much they value different heating systems because of technological considerations. Compared to electric heating systems, natural gas and oil heating systems are expensive to purchase but inexpensive to operate. As a result, households with high levels of demand for home heating tend to prefer natural gas and heating oil.

The conventional deadweight loss depends on the location and shape of the demand curve as well as the location and shape of the supply curve. In contrast, the allocative cost only depends on the location and shape of the demand curve and the equilibrium level of price and quantities, but not on the shape of the supply curve. Accordingly, our analysis abstracts from the supply side of the natural gas market. Our conclusions do not depend on the shape of the supply curve but they do depend on the observed level of natural gas sales by state, as well as observed prices by

[11]This analysis follows closely Braeutigam and Hubbard (1986), Glaeser and Luttmer (2003) and Viscusi, Harrington and Vernon (2005).

state. These data allow us to determine the magnitude of natural gas shortages by state and year, and to calculate the allocative cost conditional on the historically observed level of natural gas consumption. Given that households with access to natural gas were never rationed, as discussed in Section 6.2, our estimates of allocative cost are based on variations in the extensive margin (i.e., the choice of heating system) rather than the intensive margin (i.e., gas consumption conditional on having opted for a gas heating system). A limitation of our approach is that we cannot calculate a conventional measure of deadweight loss. For estimates of the deadweight loss see MacAvoy and Pindyck (1975) and MacAvoy (2000). With our model we are able to simulate demand for natural gas at the prices actually observed in the market during this period and calculate shortages, but we are not able to say what equilibrium price levels would have prevailed without price ceilings or under alternative forms of regulation. The latter question indeed is of no relevance for the measurement of the allocative cost.[12]

4 Residential Demand For Natural Gas

This section describes a model of residential demand for natural gas. The demand for heating equipment and the demand for heating fuels (natural gas, electricity, and heating oil) are modeled jointly as the solution to a household production problem. Households make two choices. First, households decide which heating system to purchase. Because this decision involves a substantial capital investment, households change heating systems infrequently. Second, conditional on the choice of the heating system, households decide how much heating fuel to purchase.

Joint discrete-continuous models of the form described in this section have been the standard for modeling energy demand at the household-level since Hausman (1979), Dubin and McFadden (1984) and Dubin (1985). Dubin and McFadden (1984) were among the first to illustrate the difficulties in modeling energy demand with cross-sectional data. In particular, because households choose which heating system to purchase, dummy variables for ownership of particular types of heating systems must be treated as endogenous in energy demand equations. Their approach of using a discrete choice model to address this simultaneity has been widely adopted by more recent studies of residential energy demand such as Bernard, Bolduc and Belanger (1996), Goldberg (1998),

[12]Even though the volume of natural gas available is fixed under the thought experiment of reallocating gas across households, the demand for heating oil relative to electricity could change as natural gas is reallocated. Since our analysis abstracts from the supply side of the electricity and heating oil markets, we are not able to say how these changes in turn might affect the demand for natural gas. However, there is reason to believe that this type of feedback would have been limited by the structure and regulatory environment of these markets.

Nesbakken (2001), West (2004), Feng, Fullerton, and Gan (2005), and Mansur, Mendelsohn and Morrison (2008).

Following Dubin and McFadden (1984), households are assumed to maximize an indirect utility function of the form:

$$U_{ij} = \left(\alpha_{0j} + \frac{\alpha_{1j}}{\beta_j} + \alpha_{1j} p_{sj} + \gamma_j w_i + \beta_j y_i + \eta_i \right) e^{-\beta_j p_{sj}} + \epsilon_{ij} \tag{1}$$

where i indexes households, $j \in \{1, ..., J\}$ indexes the heating system alternatives, p_{sj} is the price in state s for heating fuel j, w_i is a vector of household characteristics and y_i is household income. The key parameter in the heating-system choice model is α_{1j}. This parameter, which is assumed to be constant across households, reflects households' willingness to trade off the price of a heating fuel for other heating system characteristics. The parameter α_{0j} captures heating-system specific factors such as purchase and installation costs as well as preferences for a particular heating system that are common across households. For example, many households value the fact that natural gas is a cleaner-burning fuel than oil. The parameter β_j captures the effect of income on the relative desirability of different heating systems. The household-specific component, η_i, reflects unobserved differences across households in the demand for heat. The error, ϵ_{ij}, captures unobserved differences across households' preferences for particular heating systems. For example, households differ in how much they value the convenience and safety of natural gas heating.

The probability that household i selects alternative k is the probability of drawing $\{\epsilon_{i1}, \epsilon_{i2}, ..., \epsilon_{iJ}\}$ such that $U_{ik} \geq U_{ij} \quad \forall j \neq k$. We assume that ϵ_{ij} has a type 1 extreme value/Gumbel distribution and is i.i.d. across households and heating systems. Under this assumption, the probability that household i selects heating system k takes the well-known conditional logit form

$$P_{ik} = \frac{\exp\{\alpha_{0k} + \frac{\alpha_{1k}}{\beta_k} + \alpha_{1k} p_{sk} + \gamma_k w_i + \beta_k y_i\}}{\sum_{j=1}^{J} \exp\{\alpha_{0j} + \frac{\alpha_{1j}}{\beta_j} + \alpha_{1j} p_{sj} + \gamma_j w_i + \beta_j y_i\}}. \tag{2}$$

[13]

Since choice probabilities are invariant to additive scaling of utility, in expression (2) we omit factors that are identical across alternatives. Choices are also invariant to multiplicative scaling of utility,

[13] An important property of the conditional logit model is independence from irrelevant alternatives (IIA) which follows from this assumption that ϵ_{ij} is independent across alternatives. This is likely to be a reasonable approximation in models such as ours which allow the utility of alternatives to depend on a rich set of covariates. Moreover, Monte-Carlo evidence from Bourguignon, Fournier, and Gurgand (2004) indicates that even when the IIA property is violated, the Dubin and McFadden conditional logit approach tends to perform well.

so we follow the standard convention of normalizing the variance of the error term.[14]

Applying Roy's Identity to the indirect utility function (1) yields the heating demand function for heating fuel k,

$$x_{ik} = -\frac{\partial U_{ik}/\partial p_{sk}}{\partial U_{ik}/\partial y_i} = \alpha_{0k} + \alpha_{1k} p_{sk} + \gamma_k w_i + \beta_k y_i + \eta_i, \quad (3)$$

where x_{ik} denotes annual demand for heating fuel k, measured in British Thermal Units, or BTUs. Equation (3) illustrates that demand depends on p_{sk}, household income and household characteristics including weather, household demographics and features of the home such as the number of rooms.

This framework takes into account the correlation between the utilization and heating system choice decisions by allowing the unobserved household-specific component of natural gas demand to be correlated with the unobserved determinants of heating system choice. This correlation might arise for many reasons. Most importantly, households who prefer warm homes are likely both to choose natural gas heating systems and to use high levels of natural gas. As a result, the distribution of η_i among households who select natural gas may not be the same as the unconditional distribution of η_i. Dubin and McFadden (1984) address this endogeneity problem by postulating that the expected value of η_i is a linear function of $\{\epsilon_{i1}, \epsilon_{i2}, ..., \epsilon_{iJ}\}$ and using the density of the extreme value distribution to evaluate the conditional expectation of η_i analytically.[15] They derive a set of selection correction terms that are functions of the predicted choice probabilities from the household choice model. When these terms are included in the heating demand function (3) the parameters α_{0k}, α_{1k}, γ_k and β_k can be estimated consistently.[16]

Our specification follows previous studies (see Hausman 1979, Dubin and McFadden 1984, Goldberg 1998 and Mansur, Mendelsohn and Morrison 2008) in assuming that current prices are a reasonable proxy for future prices. This assumption is natural when energy prices are well

[14] In addition, we follow the approach described by Mannering and Winston (1985) and followed by Goldberg (1998) of subsuming $e^{-\beta_j p_{sj}}$ into the error term ϵ_{ij}.

[15] An alternative to using the conditional logit model would have been to estimate the heating-system choice model based on a multinomial probit specification allowing the unobserved differences across households, ϵ_{ij}, to be arbitrarily correlated across alternatives. However, in that case the conditional expectation of η_i no longer would have a closed form, thus precluding the standard approach of using selection terms to address the endogeneity issue. This fact prompted Dubin and McFadden to adopt the logit model.

[16] Following Dubin and McFadden (1984) and many subsequent studies including Goldberg (1998), West (2004), and Mansur, Mendelsohn, and Morrison (2008) we do not restrict parameters appearing in (2) to be identical to the parameters appearing in (3). Imposing this type of restriction not only would be computationally difficult, but the level of the parameters in the conditional logit model (2) is not identified, making it impossible to impose this restriction without further assumptions.

approximated by a random walk and changes in energy prices are unpredictable. In most contexts this will be a reasonable assumption, although a case could be made that during the late 1970s when deregulation was imminent, it might have been reasonable to expect natural gas prices to increase.[17]

5 Empirical Implementation

Our study is the first to use household-level data to analyze the effects of regulation in the natural gas market. The estimation of the model is based on a data set that we compiled from industry sources, governmental records and the U.S. Census 1960-2000. The 1960-2000 U.S. Census provides a forty-year history of household heating fuel choices, household demographics, and housing characteristics. Another important component of the analysis is the development of a matching data set of energy prices. We put considerable effort into constructing a 50-year panel of state-level residential prices for natural gas, electricity, and heating oil. This data set, together with the Census data, makes it possible to represent formally the alternatives available to households in the U.S. during this period.

5.1 Data

Table 1 provides descriptive statistics. The data come from a variety of sources. Heating system choices, energy expenditures, household demographics and housing characteristics come from the U.S. Census of 1960, 1970, 1980, 1990 and 2000.[18] The Census is the only household-level dataset

[17] One might also be concerned about changes in the volatility of heating fuel prices impacting the relative desirability of alternative heating systems. This is not a concern that can be addressed in the present framework. We also are implicitly assuming that households do not take future changes in household characteristics such as changes in household size into account when making decisions. Finally, we are assuming that observed choices reflect the preferences of the household and not preferences of some other party. In the case where home builders or landlords are involved, we assume that the relevant market is sufficiently competitive so that these parties act effectively as agents for the household. Although these assumptions are standard in this literature, there is reason to believe that they are unduly restrictive, and it will be important to relax these assumptions in future work. Finally, we do not allow the tradeoff between heating systems to depend on the real interest rate. When real interest rates are high, households may be more reluctant to invest in expensive natural gas heating systems whose cost savings accrue only gradually over many years. Controlling for the real interest rate is not feasible in our framework because it would require the estimation of the heating-system choice model during the years for which we do not observe household choices in the absence of regulation.

[18] The U.S. Census sample come from the Integrated Public Use Microdata Series. We use the 1960 1% sample, the 1970 1% Form 1 State sample, the 1980 5% sample, the 1990 5% sample, and the 2000 5% sample. All are national random samples of the population. The 1990 and 2000 samples are weighted samples. We use the appropriate probability weights. Steven Ruggles, Matthew Sobek, Trent Alexander, Catherine A. Fitch, Ronald Goeken, Patricia Kelly Hall, Miriam King, and Chad Ronnander. Integrated Public Use Microdata Series: Version 3.0. Minneapolis, MN: Minnesota Population Center, 2004, http://www.ipums.org.

in the U.S. that provides information about heating system choices and energy expenditures at the state-level for this time period.[19]

The long form census survey for all years includes questions about household demographics including household size, family income, and home ownership as well as questions about housing characteristics including number of rooms, number of units in the building, and decade of construction. In addition, since 1960 the long form survey has asked households about the primary energy source they use for heating, and since 1970 households have been asked to report annual expenditures on natural gas, heating oil and electricity. Table 1 reports heating system use in percent. We divided heating systems into natural gas, heating oil, and electricity. The natural gas category includes households with heating systems that use gas from underground pipes as well as households that use bottled, tank, or liquefied gas.[20] The heating oil category includes households that use heating oil, kerosene and other liquid fuels.[21] Finally, the electricity category includes households that use electric heating systems including baseboard heaters and portable electric heating units. We exclude households that use coal heating because coal was used only at the very beginning of the sample. In 1960, 12.2% of households used coal or coal coke for heating, but this decreased to 2.9% in 1970 and to 0.4% in 1980. Similarly we exclude households that use wood, solar energy, briquettes, coal dust, waste materials, purchased steam, other forms of heating, or that report not using heating. Together these categories represent less than 5% of all households. These households are treated as inframarginal in that no matter what happens to natural gas prices these households are assumed not to choose natural gas.

Table 1 also presents average residential prices for electricity, natural gas, and heating oil for the period 1950-2000. We constructed a state-level database of residential prices for this period by compiling information from a variety of different sources. Prices for 1970-2000 come from E.I.A.

[19] One possible alternative for household demographics and housing characteristics would be to use the American Housing Survey (AHS). The AHS is a survey of housing units that elicits information about the primary energy source used for heating and annual energy expenditures. The AHS includes two types of data collections, a national survey of housing units and a survey of housing units in a small-number of selected metropolitan areas. The advantage of the AHS is that it is collected at higher frequency. The AHS was annual between 1973 and 1980 and has been biennial since 1981. However, because the AHS is available beginning only in 1973 it does not provide data for the beginning of the period of price regulation. In addition, the sample size in the AHS is much smaller and the state of residence is not identified except for households living in the 11 selected metropolitan areas.

[20] According to E.I.A. (2006a), 71% of residential natural gas consumption in 2004 was used for space heating, 23% for water heating, 4% for cooking, 1% for clothes dryers and 1% for other uses.

[21] The Census questionnaire does not distinguish between different forms of liquid fuels. However, evidence from the American Housing Survey (AHS) suggests that distillate heating oil is by far the most common. Since 1977 when the AHS started making such a distinction, the share of households using distillate heating oil has always exceeded the share of households using kerosene by a factor of 10 to 1. See E.I.A. (2006d, table 2.7) "Type of Heating in Occupied Housing Units, Selected Years, 1950-2003".

(2006c). Prices for 1950-1969 are constructed following the E.I.A. methodology from industry sources. For each state and year, residential prices by state are constructed by dividing total revenue from residential service by total residential sales. State-level annual revenue and sales for electric utilities from residential customers come from Edison Electric Institute (1945-1969). State-level annual revenue and sales for natural gas from residential customers come from American Gas Association (1945-1969). State-level prices for residential heating oil do not exist for the period 1945-1969 (see EIA 2006c, "State Energy Data 2001: Prices and Expenditures, Section. 4 Petroleum"). Instead, for the earlier period we extrapolate back from 1970 using the annual growth rate in national average prices as reported for No. 2 heating oil at New York Harbor from McGraw-Hill (1945-1970). During the period for which state-level heating oil prices are observed there is little cross-state variation particularly relative to electricity and natural gas which demonstrate pervasive regional variation. The lack of cross-state variation in the later period suggests that this extrapolation is unlikely to bias the results. State-level revenue and sales are not available for all states and all years. For example, in 1960, revenue and sales for natural gas are not available for Alaska, Maine and Vermont. In these cases regional averages are used instead. Figure 3 shows the residential prices by region.

5.2 Estimates of the Heating-System Choice Parameters

Table 2 reports estimates of the heating-system choice model. The coefficients for price are negative and strongly statistically significant, indicating that everything else equal households prefer heating systems with a low price per BTU. The coefficient for the price of electricity is smaller than the coefficient for natural gas and heating oil prices consistent with the fact that electric heating systems are considerably more efficient in converting energy into heat.[22] The remaining parameters correspond to household characteristics interacted with indicator variables for natural gas or heating oil. The default category is electric heating systems. For example, the positive coefficient for the interaction of heating degree days and natural gas indicates that natural gas becomes more attractive relative to electricity as the number of heating degree days increases. The

[22]We constrain the impact of the price of natural gas and heating oil to be the same while allowing the impact of the price of electricity to differ. The rationale is that natural gas and heating oil furnaces tend to be very similar in terms of energy efficiency whereas electric heating systems require fewer BTUs of energy per unit of heat output. According to Wenzel et al. (1997), natural gas and oil heating systems have a base annual fuel utilization efficiency rate of 77.2% and 80.3%, respectively, compared with electric heating systems. An alternative to our specification would have been to allow the price coefficients to be different for all three heating systems. However, there is considerably less variation in residential heating oil prices than there is in residential prices for natural gas and electricity. This lack of variation together with the fact that in many states relatively few households choose heating oil would have made it difficult to identify the price coefficient for heating oil independently.

corresponding coefficient for heating oil is even larger indicating that all else equal climate is an even more important determinant for the adoption of heating oil. The other coefficients may be interpreted similarly. The constants incorporate all additional costs associated with purchasing and installing a heating system of a particular type, as well as the present discounted value of the flow of utility generated by the characteristics of a particular heating system. Both natural gas and heating oil appear less attractive to consumers than electric heating systems, perhaps reflecting larger purchase and installation costs associated with these systems. The particularly large negative constant for heating oil systems may reflect the fact that households tend to dislike heating oil because it is not as clean-burning as other heating systems and is less convenient.

The heating-system choice model is estimated using the household's reported primary energy source for home heating in the U.S. Census. Deregulation of natural gas prices was completed in 1989. In order to isolate choices that were made during the post-regulation period, we restrict the subset of households used in estimating the parameters of the heating-system choice model to households living in homes built after 1990. New home buyers during the 1990s did not face shortages of natural gas when deciding which heating system to purchase. As mentioned earlier, this is important because by observing these unconstrained choices we are able to identify the underlying structural parameters that govern household heating system choices.

5.3 Estimates of the Heating Demand Parameters

This subsection describes the specification used to estimate the heating demand function given in equation (3). The sample includes all households that use natural gas as the primary source of home heating. The dependent variable is annual demand for natural gas in BTUs, constructed by dividing reported annual expenditures on natural gas by the average residential price of natural gas for the appropriate state and year. Little previous work has been done to assess the reliability of these self-reported measures of expenditure. In order to assess this concern, in Section 6.1 we compare natural gas demand derived from the model with residential gas sales reported by natural gas utilities. Generally, the measure derived from self-reported expenditures is similar to the measure derived from reporting by utilities suggesting that the magnitude of the bias in the self-reported measures is small.[23]

The empirical analogue of our demand equation (3) does not include the price of natural gas.

[23] In 9.6% of the observations, the Census Bureau imputes expenditures. When these observations are excluded from the sample used to estimate the heating demand function the parameter estimates are very similar and the resulting estimates of allocative cost are almost identical.

Because our measure of demand is constructed using expenditures, any measurement error in price would cause a spurious correlation between demand and price, leading to estimates of the price elasticity that are biased away from zero.[24] To mitigate this concern we exclude price when estimating the heating demand function and instead rely on regional dummies to capture differences in utilization patterns due to persistent regional differences in energy prices. In addition, we allow demand to respond to price in the long-run by estimating the heating demand function separately by decade. For these reasons, we will refer to this model as a "heating demand function" even though price is not included explicitly. Our specification rules out short-run behavioral responses to annual price variations such as households turning down thermostats, closing off rooms, and weatherstripping. There are a number of previous studies that measure this short-run price elasticity of demand for residential heating demand. See Dubin and McFadden (1984), Dubin (1985) and Dubin, Miedema, and Chandran (1986). These papers have tended to find relatively small price elasticities, particularly Dubin, Miedema, and Chandran (1986) who, based on experimental evidence, find a short-run price elasticity of electrical heating between -0.08 and -0.12. These low estimates are consistent with our implicit assumption of a zero elasticity.

The heating demand function conditional on the choice of heating system is estimated separately for households in the 1980, 1990 and 2000 census. The advantage of estimating separate models for different years is that it allows the model to capture changes in heating demand over time that are not captured by observable characteristics such as global warming. Ideally, we would have liked to estimate heating demand equations for 1950, 1960 and 1970, as well, but the census responses do not provide sufficient information for these years. In the 1950 census households did not report heating system type or energy expenditures. In the 1960 census, households reported heating system type but not energy expenditures. In the 1970 census, all households again reported heating system type, but only renters were asked to report expenditures on energy. In contrast, in 1980, 1990 and 2000 all households filling out the long-form survey reported heating system type as well as expenditures on energy. Given that renters are unlikely to be representative of all households, we deal with the incomplete data prior to 1980 by using the estimated parameters for 1980 in predicting heating demand. The resulting estimates are conservative because it seems plausible that heating demand prior to 1980 would have tended to be higher than heating demand in 1980 because of the increasing availability of energy efficient materials such as energy efficient windows during the 1970s. As a

[24]Alternative sources of household-level data like the Residential Consumption Survey provide measures of energy consumption that avoid this problem, but none provide the geographical or historical coverage available in the U.S. Census.

robustness check we also computed estimates from a specification in which we predict demand for 1960 and 1970 based on the available sample for 1970. This alternative specification implies higher levels of natural gas demand prior to 1980, leading to somewhat higher estimates of mean annual allocative cost.

Table 3 presents estimates of the parameters of the heating demand function. Temperature is one of the most important determinants of energy demand for home heating. Our measure of temperature is annual heating degree days by state and year from the National Oceanic and Atmospheric Administration.[25] The coefficients for heating degree days are strongly statistically significant. All else equal, a change in heating degree days from the state at the 25th percentile of heating degree days (Oklahoma) to the state at the 75th percentile (Michigan) is associated in the 2000 sample with an annual increase of 17.1 million BTUs compared to an average level of heating of 103.0 million BTUs. The nine census region dummies control for additional variation in weather that is uncorrelated with heating degree days, as well as regional differences in building materials and construction styles. The results reveal that conditional on heating degree days and other covariates, heating demand tends to be highest in the East North Central region including, for example, Illinois, Michigan, and Ohio.

The covariates also include household demographics including the number of household members, total family income, and home ownership. These demographic characteristics capture systematic differences in demand for heating across households. For example, large households tend to demand more natural gas, perhaps because the home is occupied for more hours during the day or more rooms are maintained at a higher temperature. Covariates are also included to capture features of the housing units themselves. These variables include the number of rooms in the home, the decade of construction, and the number of units in the building.[26] Heating demand increases with the number of rooms and increases with the age of the home. Households in multi-unit structures tend to use less energy than households in single-family residences, perhaps because of shared walls and other scale effects. Overall, the estimates of the heating demand function demonstrate

[25] National Oceanic and Atmospheric Administration, "United States Climate Normals, 1971-2000", HCS 5-1 and HCS 5-2, 2002. The state averages are population-weighted within states in order to reflect conditions existing in the more populous sections of each state. If we were modeling total residential energy demand instead of heating demand then it would also be important to include cooling degree days. Air conditioning systems are rarely operated with natural gas.

[26] The purpose of the heating demand function is to provide a reasonable description of the distribution of heating demand across households, not to provide a perfect prediction of heating demand for particular households. The model does not purport to capture all of the components of heating demand captured by engineering models of residential energy demand like the E.I.A. (2006a). Indeed, modeling the shell efficiency, insulation, and heat transmission properties of different housing structures remains a large and active area of research. The model we present in this section proxies these factors in a parsimonious manner.

that heating demand varies substantially across homes with different weather, demographic and housing characteristics.

Finally, five out of the six selection terms are statistically different from zero at the 1% level suggesting that the unobserved determinants of heating demand and heating system choices are indeed correlated. The sign for the electricity selection term is positive for all decades, and the sign for the heating oil selection term is negative for all decades. This pattern is consistent with an ordering of heating systems in which households who prefer warm homes tend to prefer heating oil to natural gas and natural gas to electricity. For example, the positive coefficients on the electric selection term reflect that households who choose natural gas heating systems because of unobservables are also likely to use high levels of natural gas. Similarly, the negative coefficients on the heating oil selection term reflect that households who choose natural gas instead of heating oil because of unobservables tend to use low levels of natural gas.

5.4 Simulating Demand for Natural Gas

The heating-system choice model and heating demand function, together with energy prices and household characteristics are used to simulate heating system choices and heating demand for the U.S. year by year for the period 1950-2000. In the following section we compare the choices implied by the model with households' actual choices to calculate physical shortages of natural gas and to measure the allocative cost of price ceilings.

In order to simulate demand for natural gas, one must determine for each year the set of households purchasing a new heating system. The census long-form questionnaire does not elicit the year in which households buy a new heating system, but it does include a question about the age of the residence. We assume that all households buy a new heating system in the year the residence is constructed. For example, households in the 1980 census living in a 5-year old home are assumed to have purchased a new heating system in 1975. In practice, the census provides a range of ages of homes (such as 6-10 years), rather than the exact age, so in the model households are assigned at random to one of the years within the range. In addition, we assume that households in existing homes must occasionally replace broken equipment. E.I.A. (2006b) assumes that heating systems have an average lifetime of 17.5 years. Accordingly, we assume that households living in homes over 10 years old have a 5.71% annual probability of buying a new heating system.[27] Our model

[27]The annual replacement probability of (1/17.5) = 0.05714 implies an average heating system lifetime of 17.5 years.

abstracts from the possibility that households may retrofit their home with a new heating system before the existing system breaks down.[28]

Among the households in the market for a new heating system, household characteristics, energy prices, and the estimated parameters of the heating-system choice model are used to determine each household's probability of choosing a natural gas heating system. The expected level of demand for natural gas for a particular household is the probability that the household chooses a natural gas heating system multiplied by demand for heating measured in BTUs. Demand is aggregated by state and year for the period 1950-2000.[29]

6 Results

6.1 Physical Shortages

This section contrasts our model's predictions of residential demand for natural gas during the period 1950-2000 with the actual consumption. Although our ultimate objective is to measure the allocative cost of price regulation during this period, the measures of shortage that are discussed in this section provide a first check on the ability of the model to replicate the well-known qualitative pattern of physical shortages during this period. Moreover, these results are of independent interest in that we provide the most comprehensive assessment to date of the magnitude, timing, and geographic distribution of physical shortages.

Figure 4 describes residential demand for natural gas in the U.S. by year for 1950-2000. The dashed line is actual residential consumption of natural gas in the U.S. as reported by natural gas utilities in E.I.A. (2006c). The dotted line is actual residential consumption of natural gas as inferred from the Census microdata. For 1961-2000, this measure of actual consumption is

[28] Rust (1987, p. 903) points out that a potential weakness of the Dubin and McFadden (1984) framework is that the timing of replacement is assumed to be exogenous: "What is required is a formal dynamic programming model of the appliance investment decision, which models consumer expectations of future prices by specification of a parametric stochastic process governing their law of motion." While we defer this point for future research, it is reassuring that empirical evidence suggests that a substantial fraction of replacements of heating systems are the result of mechanical failures rather than pre-planned upgrades. Among households in the 1993 Residential Energy Consumption Survey that had recently purchased a new main heating system, 57% indicated that their old system was working "not well" or "not working at all" at the time of replacement.

[29] Balestra and Nerlove (1966) and Balestra (1967) were the first studies in the energy demand literature to make a distinction between new demand and total demand. In their model energy demand is a function of lagged energy demand and relative prices. In the section below, *new demand* refers to demand for natural gas derived from households that adopt natural gas during a particular year, either because they are purchasing a new home or because they are replacing the heating technology in an existing home. Because of large adjustment costs, households change heating fuels infrequently, so much of the responsiveness of demand over a short period of time is derived from new demand. *Total demand* is the sum of new demand in the current year and new demand accumulated during the previous 16.5 years, reflecting our assumption about the lifetime of natural gas heating systems.

constructed using reported heating system choices and reported levels of heating expenditures. For 1950-1960, consumption levels from utilities are used instead because the Census questionnaire did not elicit heating expenditures during this period. An important criterion of fit is the model's ability to replicate the actual consumption levels. Figure 4 shows that both measures of actual consumption of natural gas increase steadily between 1960 and 1970 and then level off during the later period. Although the fit is not perfect, it is reasonably close.[30]

The solid line in figure 4 is the level of natural gas demand predicted by our model at observed natural gas prices. Since our heating-system choice model is estimated using choices observed after natural gas deregulation, the model is able to describe the important counterfactual of what demand would have been at observed prices, had all households had access to natural gas. Our empirical strategy reveals how much natural gas would have been consumed during 1950-2000 based on preferences revealed in the post-regulation period, and controlling for household demographics and housing characteristics that affect heating demand.

Simulated demand follows actual consumption reasonably closely during the 1950s and 1960s, although even at the beginning of the sample period there is evidence of a small but growing physical shortage of natural gas. Our finding of a shortage as early as the 1950s and early 1960s runs counter to the conventional wisdom that shortages did not emerge until 1970. Our result is consistent, however, with anecdotal evidence that indicates that restrictions on new residential installations of natural gas were common in many parts of the U.S. during the 1950s and 1960s.[31]

Figure 4 indicates large differences between simulated demand and actual consumption during the 1970s, 1980s and 1990s, with the gap narrowing at the end of the 1990s.[32] The pattern of

[30]It is not clear why the utility-based measure of consumption increased more than the microdata-based measure during the 1990s. According to the census microdata, between 1990 and 2000 the total number of households with natural gas heating increased by 22.0% but the mean level of heating consumption per household decreased by 17.3%. This evidence is difficult to reconcile with the 12.9% increase in residential gas consumption during the same period reported by utility companies.

[31]Two quotes from the related literature illustrate this point. The American Gas Association (1951, p. 158) stressed that "as is well known, gas costs have been considerably less than other heating fuels in many parts of the country and this fact, in addition to the advantages of convenience and cleanliness have necessitated the imposition of restrictions on new installations in some areas because of the temporary inability to meet the peak demand which would be created". Likewise, MacAvoy (1983, p. 81) notes that "during the 1960s the FPC maintained wellhead prices at approximately the level that was being realized in open markets just before regulation got under way. [...] Gas demand increases, partly as a result of lower prices for gas relative to other fuels, exceeded the GNP and total energy consumption growth rates each year. Commensurate supply increases were forthcoming only at marginal costs higher than average historical costs. In unregulated markets prices would have risen to the level of those higher marginal costs. But because controlled price ceilings were based on average costs less than marginal costs, the regulated prices could not bring about the necessary increases in supply".

[32]In these figures and throughout the rest of the paper we use the measure of actual consumption that is derived from the Census Microdata. Although in principle one could use either of the two measures of actual consumption, in practice it is considerably more difficult to use the utility-based measure because new demand must be inferred from total demand. In contrast, the microdata is already disaggregated and can be used to construct new demand

a substantial increase in natural gas shortages beginning in the early 1970s is consistent with evidence of shortfalls in contractually-obligated deliveries to pipelines. According to Vietor (1984), these curtailments began in the early 1970s and reached 15% of the entire market for natural gas in 1976.[33] This timing is consistent with the pattern of physical shortages implied by the model.

Figure 5 describes residential demand by region for the same period. The pattern for the Northeast, Midwest, and South is similar to the national pattern, with large differences between simulated and actual demand throughout the period. The shortages in the Northeast are particularly severe. The pattern for the West is considerably different from the pattern for the other regions, with virtually no difference between simulated demand and actual consumption. The pattern for individual states reveals that shortages were widespread across states and regions, with the largest shortages observed in New York, Pennsylvania, and New Jersey. These results are available in a not for publication appendix.

We find that during 1950-2000 total U.S. demand for natural gas exceeded observed sales of natural gas by an average of 20.3%, with the largest shortages during the 1970s and 1980s. Our estimates of the physical shortage provide a more complete description of the degree of disequilibrium in the natural gas market than previously-used measures such as the curtailment of gas deliveries. In particular, our measure correctly incorporates not only demand from existing delivery contracts, but the unrealized demand from prospective new customers as well. The need for such a comprehensive measure of shortages has long been recognized in the literature. For example, MacAvoy (1983, p. 85) notes:

> "Regulatory rules against connecting new gas customers were put into effect in most northern metropolitan regions in the early 1970s. The excess demand of those excluded from gas markets was not listed as a 'shortage,' and yet substantial numbers of potential new residential and commercial customers denied service by state and federal regulations were 'short' by the entire amount of their potential demands."

We confirm MacAvoy's intuition that curtailments understate the degree of disequilibrium in the market because they fail to incorporate demand from potential new customers who are prevented from adopting gas heating by their local utilities in an effort to preserve service to existing customers.

Our results also differ significantly from previous interpretations of how the period of shortages

using the age of residence as described in Section 5.4.

[33]MacAvoy (1983, p.85) reports even larger curtailments: "Forced curtailments of committed deliveries increased from 12% of total interstate demand in 1973 to 30% in 1975. Further curtailments caused the short deliveries to exceed 40% of the total in 1978."

ended. The conventional wisdom is that shortages were alleviated in 1979. Many observers have pointed to the apparent "gas glut" in the early 1980s as evidence of the end of the era of price regulation. In sharp contrast, we find shortages throughout the 1980s and well after the complete deregulation of wellhead prices in 1989. These highly persistent shortages only become apparent owing to our use of a microeconometric model, illustrating the importance of explicit modeling of household decisions.

The intuition for these shortages is as follows: At any point in time, demand is derived from households that purchased their home heating systems many years ago. Thus, even many years after complete deregulation, a substantial fraction of households continued to be locked into suboptimal heating system choices, prolonging the effects of regulatory policies long beyond the official end of regulation. For example, under our assumptions, 70% of households in 2000 are living in homes with heating systems that were purchased prior to complete deregulation in 1989. The observed shortage in 2000 reflects the fact that many of these households would have preferred to purchase natural gas heating systems, had natural gas been available at the time of purchase.

6.2 The Within-State Allocation of Gas During Shortages

Allocative costs arise from the misallocation of natural gas across states and across households within states. In the previous section we examined the pattern of the allocation of gas across states. Consistent with the previous literature, we found that gas was widely available in gas-producing states and most Western states, whereas there were severe shortages in the Northeast and Midwest. An equally important question is how natural gas was allocated to households within states during shortages. As is well documented, for both political and technical reasons, gas distributors chose not to curtail service to existing residential customers.[34] When there was a shortage, service was suspended to non-residential customers. See, e.g., Vietor (1984, p. 275-277) and Braeutigam (1981, p. 156-158). In addition, shortages were dealt with by denying potential new residential customers access to natural gas.[35]

Who among potential new residential customers was granted access and who was not directly affects the size of the allocative costs to be computed in section 6.3. In particular, to the extent that the within-state allocation of gas favored households with high reservation prices, the magnitude

[34] As Vietor 1984 points out, "human need, consumer protection, and safety were real concerns. The problem of relighting pilot flames on 50 million [residential] gas burners easily identified the top priority user."

[35] As described in American Gas Association (1975, p. 67) the gas shortage caused widespread restrictions on new residential customers and severely limited expansion into new residential customer markets by many utilities. See also MacAvoy and Pindyck (1975, p. 2), Herbert (1992, p. 127) and American Gas Association (1976, p. 125).

of the allocative costs will be reduced. The key question addressed in this section is where the within-state allocation under regulation fell on the scale from optimal to random and why. Of particular concern is the role, if any, played by non-market allocation mechanisms such as queuing, bribes, or secondary markets. In this subsection we provide tentative evidence that the allocation of natural gas within states was essentially random among households interested in acquiring natural gas service, and we make the case that non-market allocative mechanisms did not play a major role during regulation.

In section 6.2.1 we study how access to natural gas varied within state with observables. We construct a crude test of the empirical importance of non-market allocative mechanisms. The results of this test suggest that non-market allocative mechanisms such as queuing, bribes, or secondary markets did not play a major role under regulation. It is important to understand why these mechanisms failed to improve the efficiency of the within-state allocation of natural gas. In section 6.2.2 we discuss the institutional features of the natural gas market that blunted the effectiveness of these non-market allocative mechanisms. We contrast the natural gas market with the market for the Toyota Prius, a prominent recent example of a market in which non-market allocative mechanisms were important.

6.2.1 How Does the Within-State Allocation Vary with Observables?

Table 4 reports mean household characteristics for U.S. households with and without natural gas heating from the 1980 census. We focus on households living in homes built between 1975 and 1978, the period of peak shortages. Statistically significant differences are highlighted in boldface.[36] The table reveals several substantive differences between the two groups. For example, households who report having natural gas heating have higher family incomes than households who report using electricity or heating oil for home heating. In addition, households with natural gas are more likely to be homeowners, tend to live in larger homes, and tend to live in single-family residences rather than multi-unit buildings. The patterns in table 4 are consistent with the parameter estimates reported in table 2 and reflect differences across households in preferences for natural gas heating systems. For example, the positive coefficient on the interaction between homeownership and natural gas in table 2 reflects the fact that, everything else equal, homeowners prefer gas heating systems more than non-homeowners.

[36]The construction of critical values for this test is complicated by the fact that our sample sizes are large. As is well known, for sufficiently large sample sizes, any null hypothesis is bound to be rejected at conventional significance levels. We follow Leamer (1978, p. 108-120) in constructing a critical value that is appropriate for this sample size.

Table 4 does not, however, provide direct evidence about how access to gas was rationed among households. What we would like to know is not how household characteristics differed between residential customers and non-customers, but rather whether *potential* new residential customers who were granted access to natural gas were systematically different along observable dimensions from those who were not. Only the latter comparison may be used to shed light on the extent to which non-market allocative mechanisms resulted in preferential access to natural gas for some households under regulation. The inherent difficulty is that, when we observe a household that does not use natural gas heating, the Census data do not reveal whether this household was rationed out of the market or was offered access to gas and chose not to receive gas.

A crude idea of how households with access to natural gas differed from households without access to gas may be obtained by examining a subset of households whom we would expect to want gas given their observable characteristics. The advantage of this strategy is that the control group will be mostly composed of households who were denied natural gas service rather than households who had the opportunity to purchase gas, but chose not to for idiosyncratic reasons. We focus on a set of households that according to our heating system choice model would have been likely to have chosen natural gas (see table 2). In particular, we focus on homeowners living in large single-family homes. To improve the power of the test, we restrict the sample to homeowners in New York, Pennsylvania, and Massachusetts, the three states with the largest physical shortages during 1975 to 1978.

Table 5 shows average characteristics of homeowners with and without natural gas living in homes built between 1975 and 1978. For all three states, the average characteristics for homeowners with natural gas are similar to the average characteristics for homeowners without gas. If non-market allocative mechanisms were resulting in preferential access to natural gas for some types of households, one would expect these observable characteristics to be substantially different across these two groups. This does not appear to be the case.

Tests of the equality of the sample means across the two groups indicate that in only one out of thirty cases the null hypothesis of equal means is rejected, which is well within the range of rejections one would expect in repeated applications of a statistical test (see, e.g. Inoue and Kilian, 2004). Moreover, the covariates do not follow any clear pattern. For example, in Massachusetts, the fraction of households for which the household head is non-white is higher among households with gas than households without gas, whereas in New York the pattern goes the other way. Finally, the differences are small in magnitude. For example, in all three states, family income is higher among the group of households with gas, but the difference averages only $\$1,605$ compared with a mean income level of $\$73,703$. We have examined average characteristics for other states including those in the Midwest and South-Atlantic regions and the results are similar. Among the ten states with the largest physical shortages during this period, the average difference in income was $\$1,542$ compared to a mean income level of $\$74,852$. This suggests that along the scale ranging from optimal to random, the within-state allocation was fairly close to random.

6.2.2 Institutional Features of the Natural Gas Market that Limit the Scope for Non-market Allocative Mechanisms

Section 6.2.1 demonstrated that there is no evidence of non-random rationing on observables among households interested in acquiring natural gas service, consistent with the view that non-market allocative mechanisms did not play a major role under regulation. As it turns out, there were several key institutional features of the natural gas market which explain why leading examples of such mechanisms such as queueing, bribes, and secondary markets, familiar from other markets, did little to improve the efficiency of the within-state allocation of natural gas.

It is important to understand the differences between the market for natural gas and the market for other goods subject to shortages. A prominent recent example is the Toyota Prius, a vehicle that was subject to severe shortages during 2004-2006 when there was a large increase in demand for hybrid vehicles at the list price set by Toyota. Even without a market clearing price, however, several features of the market for this vehicle made it possible for high willingness-to-pay buyers to receive the good.

First, an active secondary market emerged. There were many accounts of "lightly used" Prius vehicles being sold on Ebay or other outlets for used cars. As discussed in section 3, the existence of a secondary market mitigates the allocative costs of regulation. In contrast, no secondary market ever existed for natural gas. Unlike in the Toyota Prius example, it was impossible to purchase a natural gas connection from someone else either within state or across state lines. Nor is it likely that the efficiency of the within-state allocation gas would have been improved by households moving within state. Moving costs tend to be large, and a natural gas connection is only one of many home characteristics (such as school quality, property tax levels, commuting distance to work, resale value, age of home, size of home, neighborhood amenities, etc) considered by households. Whereas vehicle markets are national in scope and one can purchase a vehicle with virtually any bundle of characteristics, the housing market is considerably more local and tends to be thin, making it difficult to find a home that matches a household's preferences along all dimensions. Thus, there was little scope for household mobility to mitigate the misallocation of natural gas within state. Moreover, given that our heating system choice model predicts that preferences for natural gas are increasing in income, one would expect any such sorting in the housing market to result in systematic differences in income levels in table 5; yet there is no quantitatively important difference in income between households with and without natural gas.

Second, Toyota responded to the Prius shortage by creating a waitlist. In fact, Toyota Prius buyers could join waitlists at multiple Toyota dealerships and then travel to the appropriate dealer when a vehicle became available. In sharp contrast, there is no record of waitlists for residential natural gas service, despite abundant evidence on the use of non-market allocative mechanisms in the non-residential gas market.[37] This lack of direct evidence is not surprising. Even if a waitlist had existed, households would have been unlikely to use it. To the extent that occasionally additional natural gas became available for the residential sector, gas was allocated to homes that happened to be under construction at the time. Since households had to select a heating system as they moved in, there was little scope for queuing to improve the efficiency of allocation. For example, any delay in house construction involves a considerable opportunity cost measured in foregone interest. Similarly, if a household with an oil heating system happened to experience a breakdown in January in the state of Michigan (which is when breakdowns tend to occur, given that heating systems are not used during summer) the owner would be understandably reluctant to wait in line for months or years for natural gas heating. Finally, queuing is costly and one would expect a household's propensity to queue to be positively correlated with variables such as family income, yet there is no compelling evidence in table 5 of differences in income being quantitatively important.

Third, Toyota allowed the price mechanism to be restored selectively. Even though Toyota refused to increase the price of cars sold to dealers, there were steps taken by dealers to increase dealer markups, moving final prices closer to equilibrium prices. For example, dealers frequently packaged vehicles with expensive after-market options such as undercoating, stereo upgrades, and roof racks. In contrast, there was no scope for such price increases in the residential natural gas market. Local gas distributors were highly regulated during this period and it was illegal for them to price discriminate. Thus, a key difference between these markets is that Toyota Prius dealers stood to gain from allocating a Prius to buyers with high willingness-to-pay. Sallee (2008) reports

[37] For example, Braeutigam (1981, p. 156) describes in detail the rationing rules for industrial customers.

that dealers' mean incentive adjusted markup for the Toyota Prius between 2004 and 2006 averaged $\$2,300$ dollars. In contrast, natural gas distribution companies had no incentive to provide gas to customers with a high willingness to pay since the price was regulated.

This does not rule out other pecuniary incentives. For example, one could imagine households bribing utility officials to obtain preferential access to natural gas. This seems unlikely. Not only is there no documented case of such bribery, but given their small expenditure share on energy, households had little to gain from bribing officials, but potentially much to lose if caught. Moreover, one would expect the ability to bribe to be highly correlated with household characteristics such as income, yet, as mentioned before, there were no systematic differences in average family income in table 5.

In light of these institutional features of the national gas market, it is not surprising that there is no evidence in table 5 of rationing on observables. Based on the empirical and institutional evidence presented in this section, it appears that non-market allocative mechanisms did little to improve the efficiency of the within-state allocation of gas among households interested in acquiring natural gas service relative to a purely random allocation. We will exploit this feature of the data in section 6.3.

6.3 Allocative Costs

Physical shortages are important for describing the effect of price regulations, but in themselves do not provide a measure of economic costs. Whereas physical shortages and allocative cost are closely related, they are not linearly related. The nonlinearity arises as follows. In our model, households must choose between alternative heating technologies. Households respond differently to changes in market conditions depending on their proximity to the margin between natural gas and alternative forms of energy. As a result, the elasticity of substitution varies across households. Market demand for natural gas reflects the composition of households represented at each point along the demand curve. Thus, changes in the relative price of gas will not be linearly related to shifts in the demand for natural gas. Our household-level approach to modeling demand provides an alternative to the common assumption of linearity in aggregate analyses of the natural gas market. Although the assumption of a linear demand curve may not be unduly restrictive in many contexts such as simulating the effect of small changes in prices, it is a strong assumption for welfare analysis because the estimates depend on the shape of the entire demand function. The flexible treatment of substitution patterns is one of the advantages of using a household-level model.

As defined in Section 3, the allocative cost of a price ceiling is the welfare loss which results from not allocating a good to the buyers that value it the most, measured as the difference between the consumer surplus under the actual allocation and the consumer surplus under the allocation when buyers are rationed efficiently. Under efficient rationing, the good is provided to the buyers with the highest reservation prices and welfare cannot be improved upon by reallocating the good among buyers. In an unregulated market this allocation is achieved with a national market clearing price. In a regulated market, the actual allocation typically does not provide the good to the buyers that value it the most. The allocative cost refers to the welfare gains that can be realized from replacing the actual allocation by the allocation under efficient rationing. The consumption of natural gas is the same each year under efficient rationing as it is under the actual allocation.

By construction, the size of the allocative cost depends on the degree of physical shortage by state and year, the distribution of reservation prices across households, and the distribution of natural gas among households prior to redistribution. The technical appendix provides a detailed, step-by-step description of the calculation of the allocative costs. As described in the appendix, in calculating the allocative costs we assume that during shortages, the within-state allocation of natural gas is random among households with a reservation price higher than the observed price. This approximation, which is supported by the evidence in section 6.2, allows us to overcome the difficulty that the microdata do not distinguish between households who chose not to use natural gas and households who were rationed out of the market.

Figure 6 plots the allocative cost by year for the entire U.S. during 1950-2000. During the period 1950-2000, the mean annual allocative cost in the U.S. was \$4.6 billion with a peak of \$6.4 billion in 1980. This represents, on average, 16.4% of total residential expenditure on natural gas over the 1950-2000 period. It can be shown that most of these costs were borne by households in the Northeast, Midwest and South, with households in the West bearing a smaller amount. Total allocative cost in the Midwest and South decreased substantially during the 1980s and 1990s, though in neither case did costs disappear by 2000. In the Northeast costs were more persistent, with large costs remaining in 2000. This finding is not surprising. For example, with new heating system purchases limited to new construction and heating system replacements in existing homes, between deregulation in 1989 and 2000 only 30% of households would have purchased new heating systems. The adjustment was particularly slow in the Northeast because there was less new housing construction compared to the South or West.

Our estimates of the allocative costs are of the same order of magnitude as previous estimates in the literature for the conventional deadweight loss. MacAvoy (2000), for example, reports a mean annual deadweight loss of \$10.5 billion between 1968 and 1977. We find that during this same period, the mean annual allocative cost in the residential market was \$5.9 billion. Because this allocative cost is *in addition* to the conventional deadweight loss, our estimates suggest that total welfare losses from natural gas price regulation were considerably larger than previously believed.[38]

There are two obvious concerns about the reliability of our estimation procedure. The first concern is that the random assignment of households in computing the allocative cost introduces simulation error. A second concern is parameter estimation error. Sampling variation in the parameter estimates of our heating-system choice model and heating demand function induces variability of the welfare losses measured at the second-stage. Table 6 reports bootstrap standard errors for the estimated allocative cost based on randomly drawn sets of households of the same size as the original dataset. Bootstrap replicates of the allocative cost measure are constructed by reestimating all model parameters for each bootstrap sample and simulating the implied allocative cost.[39] As one would expect given the large sample size, the standard errors are generally negligible. For example, we find a standard error of only 0.036 billion around the mean annual allocative cost of \$4.56 billion.

We also assessed the robustness of our results to alternative model specifications. Table 6 also reports estimates of mean allocative cost for three alternative specifications of the utility function. All three specifications include covariates *in addition* to the set of covariates used in the benchmark specification. These additional covariates are included both in the heating-system choice model and in the heating demand function. The first alternative includes the age of the head of the household as well as indicator variables (again corresponding to the household head) for nonwhite, high school graduate, and college graduate. The second alternative specification includes indicator variables for each number of rooms, instead of treating the effect of number of rooms linearly. The third alternative specification includes a cubic in family income. Mean annual allocative cost in all three specifications is similar in magnitude to the estimate in the benchmark specification, suggesting that the benchmark specification does a reasonable job at controlling for observable determinants of heating demand and confirming that the results are not unduly sensitive to minor variations in functional form.

[38]These large allocative effects are consistent with theoretical evidence about the relative size of allocative cost and conventional deadweight loss. Glaeser and Luttmer (2003) show that allocative cost exceeds conventional deadweight loss when the demand curve is linear and price ceilings reduce quantity supplied by less than 50%.

[39]We use 100 bootstrap replications. This number is conventional in the statistical literature (see Efron and Tibshirani, 1994). Moreover, a larger number of replications would be computationally prohibitive.

As discussed earlier, we are interested in the thought experiment of redistributing natural gas across households to ensure the highest level of welfare. This reallocation involves redistributing the amount of natural gas actually consumed in each year both across state lines and across households within states. One component of allocative cost is associated with the gain in consumer surplus from reallocating gas within state to consumers with the highest reservation price, holding constant the actual allocation across states. The efficient within-state allocation is reached when there are no additional reallocations within state that can increase consumer surplus. A second component of the allocative cost is associated with the gain in welfare from reallocating natural gas across states, assuming efficient rationing within states. All else equal, total consumer surplus increases when natural gas is reallocated toward states where the marginal household has a high reservation price. Rationing is efficient across states and households when the marginal household in each state has the same reservation price.

Thus, the total allocative cost can be decomposed into a within-state component and an across-state component. We find that, during the period 1950-2000, the mean annual within-state allocative cost was \$3.70 billion and the mean annual across-state allocative cost was \$0.86 billion. This decomposition reveals that the bulk of the allocative cost comes from the misallocation of natural gas within states. Although we do find that efficient rationing requires large movements of natural gas across state borders, these shifts are not associated with large changes in the consumer surplus. The reason is apparent from equation (6) in the technical appendix. If reservation prices are high in areas with high actual prices, the change in the consumer surplus may be small, notwithstanding large shifts in quantities across state borders.

6.4 The Geographical Distribution of Allocative Cost

As described in Section 2, the political process leading to the regulation of the natural gas industry pitted gas consuming states in the Midwest and Northeast against gas producing states in the Southwest. Given these geographical divisions, an important question from a political economy point of view is how the allocative costs were distributed across regions and states.

Table 7 reports the results by state. One of the strengths of our microeconometric approach is that we are able to provide insights into the distributional effects of regulation that could not have been obtained using a model based on national or even regional data. We find that the most-affected states are in the Mid-Atlantic region (New York, Pennsylvania, New Jersey), New England (Massachusetts, Connecticut), the Midwest (Indiana, Illinois) and the South Atlantic region (Virginia, North Carolina, Maryland). These results substantiate beliefs widely held in previous studies. There are also a few mild surprises. It is generally accepted that the Northeast and the Midwest suffered the most from price regulation (see, for example, Tussing and Barlow 1984 or Viscusi, Harrington, and Vernon 2005). The South Atlantic states, however, have not typically been included in this discussion. Although these states are not subject to the extended cold temperatures common in more northern states, households in the South Atlantic states do use large amounts of energy for home heating, and our simulation evidence suggests that they were consistently unable to satisfy their demand for natural gas.[40]

Another somewhat surprising finding is the overall level of cost borne by states in the Northeast. As mentioned in the introduction, there have been few studies that have looked at the effect of the natural gas price ceilings by region. An important exception is MacAvoy and Pindyck (1975) who use a structural dynamic simultaneous equation model to simulate shortages by region. They conclude that, had prices continued at 1974 levels throughout the 1970s, residential and industrial shortages in 1978 (in trillions of cubic feet) would have been 4.3 in the Midwest, 1.7 in the Southeast, 0.7 in the Northeast and 0.2 in the West. Thus for 1978 they expected to find 62% of the shortage in the Midwest. We find that although the Midwest residential market was indeed affected, the Northeast was affected more severely, both in terms of physical shortages and allocative cost.[41]

As states differ in size and population, it is of additional interest to express these costs on a per capita basis. The lower panel of table 7 reports the states with the largest annual allocative cost per person. It is striking that many of the states are from sparsely-populated, northern states. In 1954, there were $419,670$ miles of natural gas pipeline in the U.S. with $63,980$ miles in the northeast and $126,640$ miles in the Midwest.[42] The network included every state in the continental U.S. except for Maine, Vermont, Idaho, Washington and Oregon. During the mid 1950s the network was expanded to include customers in the Northwest, but some parts of New England and the Dakotas were slow

[40] This finding that households living in the South Atlantic states bore large allocative costs is consistent with anecdotal evidence from the period. Sanders (1981, p.139) reports that, "A minority of households in the region used natural gas, although Southerners in the fuel-deficit states would clearly have preferred gas to the far more expensive electricity and alternative fuels upon which the region's households depended."

[41] The geographical distribution is very similar when misallocation is measured using physical units rather than allocative cost. Under efficient rationing there would have been higher natural gas consumption in the Northeast and South Atlantic states in particular and lower natural gas consumption elsewhere. We find that on average Northeastern states (such as New York, Pennsylvania, and New Jersey) and South Atlantic States (such as Virginia and Maryland) received between 27% and 48% less natural gas than they would have under efficient rationing. In contrast, gas-producing states such as Texas, Oklahoma, New Mexico, and Louisiana received between 27% and 45% more natural gas.

[42] American Gas Association (1955), table 46.

to be connected to the pipeline network.[43] This provides an explanation for the disproportionate representation of northern states with low population densities among the top ten states with the highest per-capita allocative cost. If households were not able to purchase natural gas because it was not available, this would appear in our model as evidence of allocative cost.[44]

Figure 7 shows the geographic distribution of the average annual allocative cost per capita. The plot emphasizes the regional pattern of the distribution of costs. Households living in gas-producing states and households in most Western states tended to face low allocative costs. In contrast, households living in the Midwest, Northeast and South Atlantic states faced comparatively high costs. The per capita costs were highest in the Northeast and Midwest.

It is interesting to contrast this pattern with the distribution of the political support for regulation. As noted by Sanders (1981) and Vietor (1984) it is widely believed that support for natural gas regulation was most entrenched in the gas consuming states east of the Mississippi, while gas producers in the Southwest staunchly advocated deregulation. This belief is at least partially confirmed by voting records from 1973. Figure 8 indicates the extent of Congressional support for regulation as evidenced by the Senate voting pattern for a 1973 motion to table the 1973 Buckley Amendment (S2776).[45] This amendment, which would have deregulated prices for new sales of natural gas, was defeated 45-43. There is a distinct regional pattern in the voting record. Senators from gas-producing states in the Southwest (Louisiana, Texas, and Oklahoma) clearly supported deregulation, whereas senators from Midwestern, Northeastern, and South Atlantic states generally supported regulation. It is evident from comparing figures 7 and 8 that price regulation was supported even in states where households faced large allocative costs. This finding is consistent with the view that politicians in 1973 focused on the benefits of price regulation for existing customers and discounted the costs to customers without access to natural gas. Regulation was supposed to protect consumers in Northern markets from high gas prices, and it may have been that senators in those states continued to act on this belief even in 1973, even as the adverse consequences of regulation were becoming increasingly apparent. Our analysis suggests that Senators were slow to catch on because much of the shortage did not manifest itself in overt curtailments of service to residential customers, but involved restricting access to new residential customers.

[43] American Gas Association (1955), p.78.

[44] If we exclude Maine, New Hampshire, Vermont and North Dakota our results are virtually unchanged. Mean annual allocative cost decreases by only 4.6%.

[45] The correlation between states with high allocative costs per capita (defined as costs in excess of $10 annually per capita) and states with strong senatorial support for regulation (defined as both senators voting in support of regulation) is 0.46 and statistically significant at the 1% level. Disregarding western states that had little vested interest in this debate the correlation is even higher.

6.5 Out-of-Sample Fit of the Model

Our empirical results in sections 6.3 and 6.4 hinge on the idea that, conditional on observables, households' unconstrained choices in the 1990s can be used to predict the choices that households would have made during earlier decades in the absence of regulation. There are several approaches to verifying the realism of this thought experiment. In this subsection we show that our estimation procedure yields only minimal estimates of allocative cost when applied to settings where the market operates freely. The fact that the model performs well in these out-of-sample contexts adds credibility to the results presented in the previous subsections.

One approach is to evaluate the out-of-sample fit of the model for Texas, Louisiana, New Mexico and Oklahoma, the four states accounting for the bulk of U.S. natural gas production during the period of regulation. As discussed previously, a key characteristic of the price regulation implemented during this period is that it applied only to *interstate* sales of natural gas. Because the FPC did not have jurisdiction over intrastate sales, prices for gas sold in gas-producing states were unregulated. Thus, there is no reason to expect a shortage in Louisiana, New Mexico, Oklahoma and Texas under regulation. As a result, simulated demand for these states, based on households' choices in the 1990s for the entire United States, should closely follow actual consumption. Furthermore, the allocative costs in these states should be negligible.

Figure 9 plots the demand for gas implied by our model and actual consumption in Louisiana, New Mexico, Oklahoma and Texas. The model does well at describing the basic pattern of actual consumption in these states, particularly in contrast to the often dramatic shortages observed in non-gas producing states. Moreover, allocative cost in these gas-producing states is effectively zero, averaging only \$3.64 million (or \$0.56 per capita) annually during the period 1950-1989, compared with \$1470 million (or \$81.70 per capita) in New York, one of the leading examples of states affected by the regulation of natural gas.

An alternative approach to evaluating the out-of-sample fit of the model involves estimating the allocative cost for households that installed heating systems since deregulation of natural gas prices was completed in 1989. Since these households did not face price ceilings, their allocative cost should be negligible. This proposition can be tested by splitting the 2000 Census data into two random samples. One of the subsamples is used to estimate household preferences conditional on covariates; the model is then used to predict allocative cost for the households in the other subsample. We find that the mean annual allocative cost among households who made heating system choices during the period of regulation was \$98.69 per household. In contrast, the mean annual allocative cost among households living in homes purchased in 2000 was \$16.28 per household. This is a small amount compared to the allocative cost estimated for the earlier period. Suppose, nevertheless, we interpret that estimate as a measure of the potential model mispecification, a revised estimate of mean annual allocative cost can be constructed by subtracting this baseline from the estimate of \$4.56 billion reported in table 6, resulting in a mean annual allocative cost of \$3.49 billion. This alternative estimate, while smaller than the baseline estimate, is still of the same order of magnitude.

6.6 Sensitivity Analysis with Alternative Counterfactuals

Our empirical strategy relies on household behavior during the 1990s to infer household preferences during the entire postwar period. Although the model constructed under this counterfactual fits the data well, it is important to assess the robustness of our results to alternative identifying assumptions. In this section we estimate the model using an alternative counterfactual that exploits the fact that not all states were subject to natural gas price regulation. As discussed previously, price regulation applied only to *interstate* sales of natural gas. As a result, states that were net exporters of natural gas were not subject to price ceilings and provide another benchmark for estimating the model of household preferences. For this purpose we compile a dataset of all net exporters of natural gas by decade. We re-estimate household preferences using data for these states from the entire post-war period. This alternative empirical strategy provides an important test of the robustness of our results, but it is not without its limitations. One disadvantage is that we reduce the number of households used in estimating preferences from 708,320 under the baseline counterfactual to 326,431. A second, and more important limitation is that gas-producing states tend to be geographically concentrated and as a result, are relatively homogenous. For example, there is limited variation across gas-producing states in control variables such as heating degree days, making it difficult to identify and to control for the effects of this variable on household demand in gas-consuming states such as New York or Michigan with much colder temperatures.

Nevertheless, the estimates obtained under this alternative counterfactual are not unreasonable. We estimate a mean annual allocative cost of \$9.62 billion (or 34% of consumption), about twice the baseline estimate. Despite the higher level of allocative cost, the geographic distribution and pattern over time of shortages and allocative cost are very similar to the baseline counterfactual. Given the additional caveats associated with this counterfactual, we prefer to focus on the more conservative baseline estimate.

An attractive feature of this alternative counterfactual is that it allows us to test whether the parameters of the heating-system choice model are changing over time. This is an important concern because preferences may have changed since the 1950's, making it difficult to extrapolate back from households' choices in the 1990s. Another reason for possible time variation in the model parameters are secular changes in heating system characteristics. Both phenomena may be captured by allowing the parameters of the heating-system choice model to evolve over time. When estimating a specification of the model that allows all model parameters for demographic characteristics, housing characteristics, heating degree days, and fuel prices to vary by decade, we indeed find evidence of statistically significant differences in parameters across decades. The implied mean annual allocative cost of $8.31 billion, however, is not very different from the model with time-invariant parameters. Likewise, the geographic distribution and pattern over time of shortages and allocative cost are very similar.

Table 8 provides additional detail on which coefficients are changing in the time-varying preference exercise and how they are linked to estimates of physical shortages and allocative costs. For each decade, the table reports how the parameter estimates change relative to the result for all exporters when parameters are not allowed to vary across decades. Each row highlights the change in physical shortages and allocative costs associated with allowing only the parameter in this row to change while holding all other parameters constant. Table 8 shows that the baseline results for the gas exporters are remarkably robust to allowing for time variation in housing characteristics and demographic characteristics. The results are somewhat more sensitive to allowing the effect of heating degree days to vary over time. This is not surprising because gas-producing states tend to be concentrated in the Southwest. There is little variation in heating degree days across gas producers, making the parameters in question poorly identified. Likewise, the parameters on price per BTU, which are by far the most sensitive parameters, are particularly poorly identified when allowing for time-varying preferences. The lack of variation in the data is associated with unusually high standard errors for these parameters in the regressions underlying table 8. Overall, table 8 provides no evidence of economically interpretable changes in preferences. Moreover, it is reassuring that the net effect of allowing for all changes combined (shown in the last row) is small compared to the magnitude of the baseline estimate for net exporters.

The sensitivity analysis in this section underscores that among the alternative counterfactuals considered in this paper the original baseline model based on household behavior during the 1990s is likely to be the most reliably identified and hence the most credible. While the alternative estimates of allocative cost are about twice as large as the original baseline estimate, there is reason to interpret these estimates with some caution, leading us to interpret the estimate of section 6.3 as a conservative lower bound.

7 Conclusion

Whereas the importance of allocative costs is well recognized as a theoretical matter, its quantitative importance in real-life markets has remained uncertain, owing to the difficulties of empirically quantifying such costs. Our study is the first to demonstrate how allocative costs in a market subject to price ceilings may be estimated. We focused on the U.S. residential market for natural gas. Our analysis showed that the allocative cost in this market averaged $4.6 billion annually during the period of 1950-2000. We found that the allocative cost was borne disproportionately by households in the Northeast and in selected states in the Midwest and South Atlantic region. While our estimates of allocative cost are large, total allocative cost for all consumers is likely to be even larger than the magnitudes reported here, given that our analysis has been restricted to the residential market.

Our analysis illustrates the importance of careful ex ante economic analysis. Price ceilings for natural gas were supposed to help consumers, particularly consumers in northern markets, who in the 1950s were concerned about rising natural gas prices. We found that these very consumers ended up bearing a disproportionately large share of the allocative cost. This is exemplified by the case of the state of Wisconsin. As described in Section 2, the post-war era of price regulation in natural gas markets in the U.S. began with the Supreme Court's ruling on *Phillips vs. Wisconsin*. This case was brought to court in an effort protect Wisconsin consumers from increasing natural gas prices. The actual effects of regulation on Wisconsin consumers was far less clear cut. While consumers with access to natural gas indeed benefited from lower prices, when there is a shortage, not all consumers will have access to the market, and those who have access will not necessarily be the consumers who value the good the most. Our estimates show that households in Wisconsin suffered an average annual allocative cost of $125 million between 1950 and 2000, in addition to the conventional deadweight loss. Households in many other northern states who were supposed to be protected by the Supreme Court decision fared even worse.

From a national perspective, the costs to consumers of regulating the price of natural gas outweighed the benefits to consumers. MacAvoy (2000) estimates that at the national level between 1968 and 1977 natural gas price ceilings transferred an average of $6.9 billion annually from producers to consumers while causing consumers a deadweight loss of $9.3 billion. Thus, even abstracting from allocative cost, price ceilings made consumers worse off by $2.4 billion. Adding the allocative cost effectively triples the estimated net welfare loss to U.S. consumers. Alternative modeling assumptions tend to raise the estimate of the allocative costs, suggesting that our baseline estimate is, if anything, conservative.

Our analysis is not only relevant for understanding the consequences of regulation in the U.S. residential natural gas market, but it has implications for other markets as well. Allocative costs due to price ceilings arise more generally whenever the good in question cannot be readily traded in secondary markets, as would be the case, for example, in insurance, health care, or telecommunications markets. The broader conclusion of our paper is that policymakers in conducting an ex ante economic analysis of regulatory reform ought to take careful account of the allocative cost of price regulation in addition to the conventional deadweight loss. In particular, our analysis showed that the effects of price ceilings may be very uneven across households and states, that it is difficult to determine in advance how the cost will be distributed geographically, and that the adverse effects of price ceilings tend to last much longer than the regulatory policies themselves.

8 Appendix: Calculating the Allocative Cost

The calculation of the allocative cost discussed in Section 6.3 involves the following steps: In step 1, we compute the reservation price for each household i. The reservation price, P_i^*, is defined implicitly by equation (4) as the natural gas price that makes household i indifferent between natural gas and the next best heating alternative (i.e., electricity or heating oil):

$$U_{ig}(P_i^*) = max\left(U_{ie}, U_{io}\right). \tag{4}$$

We refer to these alternatives as g for natural gas, e for electricity, and o for heating oil. Substituting the form of the utility function from equation (1), subsuming $e^{-\beta_j p_{ij}}$ into the error term as discussed in Section 4, eliminating η_i because it is identical across alternatives, and solving for P_i^* yields the reservation price for household i,

$$P_i^* = \frac{\max(U_{ie}^*, U_{io}^*) - \alpha_{0g} - \frac{\alpha_{1g}}{\beta_g} - \gamma_g w_i - \beta_g y_i - \epsilon_{ig}}{\alpha_{1g}}, \tag{5}$$

where

$$U_{ie}^* = \alpha_{0e} + \frac{\alpha_{1e}}{\beta_e} + \alpha_{1e} p_{se} + \gamma_e w_i + \beta_e y_i + \epsilon_{ie}$$

and

$$U_{io}^* = \alpha_{0o} + \frac{\alpha_{1o}}{\beta_o} + \alpha_{1o} p_{so} + \gamma_o w_i + \beta_o y_i + \epsilon_{io}.$$

Thus, the reservation price is a function of observable characteristics w_i and y_i, unobservable characteristics ϵ_{ig}, ϵ_{ie}, and ϵ_{io}, prices p_{se} and p_{so}, and model parameters such as β_g and α_{1g}. We treat the unobservable characteristics for each household i and heating system j as a random component, ϵ_{ij}, with an extreme value distribution. In other words, we draw a different ϵ_{ij} for each household depending on the alternative j.[46] This component captures unobserved differences across households' preferences for particular heating systems. As discussed in Section 4, ϵ_{ij} is assumed to be i.i.d. across households and heating systems conditional on the observed covariates. We compute P_i^* from equation (5) using these ϵ_{ij} terms, the observable characteristics w_i and y_i for each household from the Census microdata, the prices from our price data, and the parameter estimates reported in table 2. This procedure is also used for predicting reservation prices in section 6.2.2 when examining the within-state allocation of natural gas.

In step 2, we calculate the consumer surplus for each household.[47] Let p_{st} denote the actual price for natural gas in state s and year t. A household's annual consumer surplus is the difference between its reservation price and p_{st}, multiplied by the household's annual demand for gas, $\hat{x}_{ig}$. Annual demand for gas is the predicted value from equation (3) using the parameter estimates in table 3:

$$CS_i = \left(P_i^* - p_{st}\right) \hat{x}_{ig}. \tag{6}$$

In step 3, we compute total consumer surplus for all households in the market under efficient

[46] This procedure introduces simulation error because for each household the calculated reservation price represents one possible realization. However, because the number of households in our sample is very large, the procedure introduces little variation in national and state measures of the allocative cost. Moreover, the bootstrap standard errors reported in the paper take this simulation error into account.

[47] Our measure of consumer surplus coincides with both compensating variation and equivalent variation in response to a change in price because in the model the marginal utility of income does not depend on the price level.

rationing:

$$CS^{er} = \sum_{i=1}^{n} \sum_{t=1}^{T} CS_i * 1(er_{it}) * \mu_i \tag{7}$$

where $1(er_{it})$ is an indicator variable equal to 1 if household i receives natural gas in year t under efficient rationing and μ_i refers to the Census population weights. Under efficient rationing, natural gas is allocated to the households with the highest reservation price first, until all available gas has been allocated.[48] We repeat this procedure for each year, assuming that households that received natural gas in the past will be able to continue to receive natural gas, so that the allocation problem is limited to reallocating gas among potential new customers. Consumer surplus for sets of states and for specific years are calculated by summing the consumer surplus over the appropriate subsample.

In step 4, we calculate θ_{st}, the fraction of households that had access to natural gas among all households in state s and year t that would have wanted to choose natural gas heating,

$$\theta_{st} = \frac{\sum_{i \in s,t} \hat{x}_{ig} * 1(actual_{it}) * \mu_i}{\sum_{i \in s,t} \hat{x}_{ig} * 1(P_i^* > p_{st}) * \mu_i} \tag{8}$$

where $1(actual_{it})$ is an indicator variable equal to 1 if household i receives natural gas in year t and the indicator variable $1(P_i^* > p_{st})$ is equal to one for households with a reservation price that exceeds the actual price for natural gas in state s and year t. Thus, $1 - \theta_{st}$ is a percent measure of the shortage of natural gas for a given state and year.[49] The numerator in equation (8) represents the actual consumption of natural gas in state s among households choosing a heating system in year t, as observed in the Census microdata. The denominator is simulated demand, i.e., what demand would have been at observed actual prices had all households had access to natural gas as predicted by the model. In a small number of cases, θ_{st} is smaller than zero or larger than 1. These cases are treated as zero and 1, respectively.

In step 5, we compute the total consumer surplus under the assumption that the within-state allocation of natural gas was random among households interested in acquiring natural gas service. Section 6.2 provides evidence that, within states subject to regulation, households interested in acquiring natural gas had similar observable characteristics whether they received natural gas or not, consistent with the actual within state allocation of gas being well approximated by a random allocation. It is important to emphasize that this random allocation assumption is invoked only for determining the allocation of natural gas *within states* among those households that are interested in acquiring natural gas service during a given year. The consumer surplus is calculated by allocating natural gas at random to a fraction, θ_{st} of the potential new natural gas customers in each state and year. Consumer surplus is then calculated by summing over all households with a reservation price in excess of the observed price. The consumer surplus obtained under the actual allocation

[48] When ordering households under efficient rationing we use reservation prices rather than consumer surplus. To maximize social welfare it is necessary to provide gas to households with the highest willingness-to-pay *per unit*, not the highest total consumer surplus.

[49] It is important to clarify that θ_{st} is calculated as a function of *new demand* rather than *total demand*. *New demand* refers to demand for natural gas derived from households that adopt natural gas during a particular year, either because they are purchasing a new home or because they are replacing the heating technology in an existing home. As we have done throughout, households that have received natural gas in the past are assumed to be able to continue to receive natural gas, so that the allocation problem is limited to reallocating gas among potential new customers. Thus, the t subscript in θ_{st} refers to a cohort of households making a heating system in year t. Total demand for natural gas is calculated by summing *new demand* over time.

across states and the random allocation within states is denoted as

$$CS^{rr} = \sum_{i=1}^{n} \sum_{t=1}^{T} CS_i * B_{\theta_{st}} * \mu_i \tag{9a}$$

where B is a Bernoulli random variable with success probability θ_{st} with success indicating access to natural gas. Using the definition of CS_i in equation (6), this is equivalent to

$$CS^{rr} = \sum_{i=1}^{n} \sum_{t=1}^{T} (P_i^* - p_{st})\, \hat{x}_{ig} * B_{\theta_{st}} * \mu_i. \tag{9b}$$

In step 6, we compute the allocative cost as

$$AC = CS^{er} - CS^{rr}. \tag{10}$$

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Figure 1: Conventional Deadweight Loss

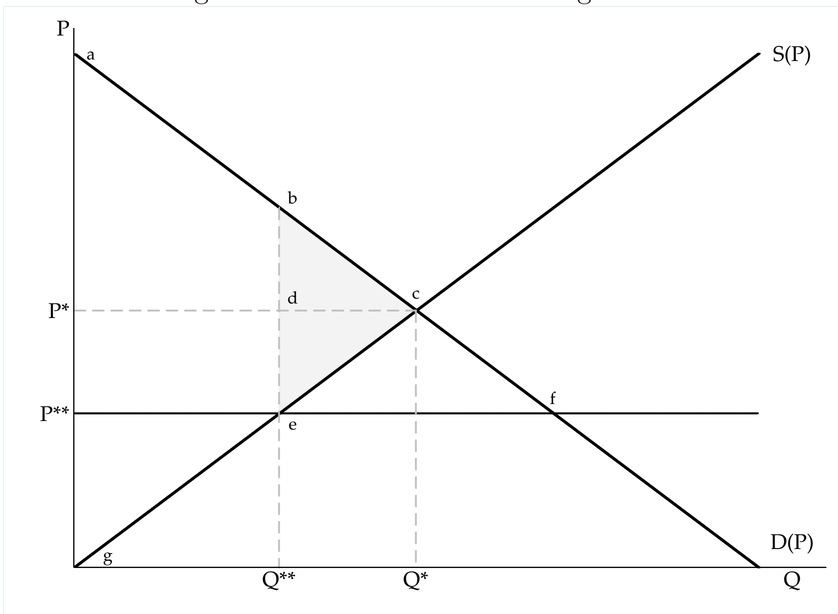

Figure 2: Allocative Cost Under Random Assigment

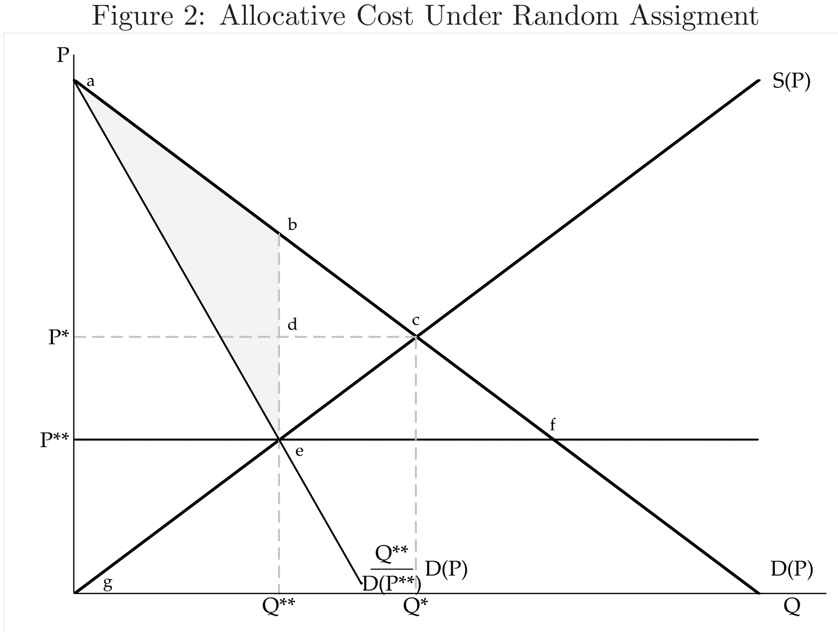

Figure 3: Residential Energy Prices in the U.S., By Region

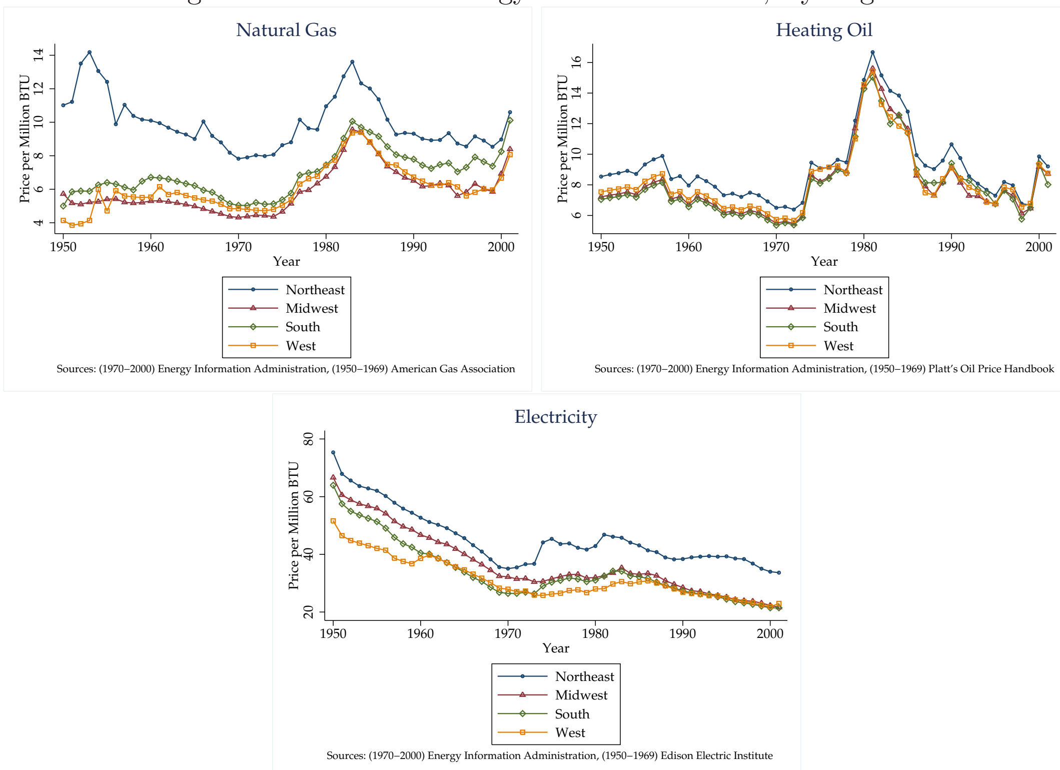

Figure 4: Residential Demand for Natural Gas in U.S.

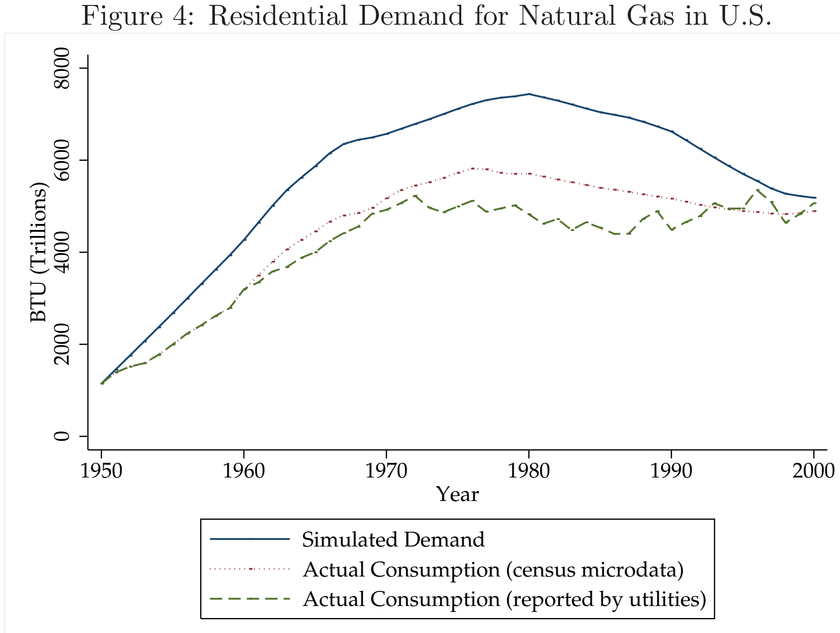

Figure 5: U.S. Residential Demand for Natural Gas by Region

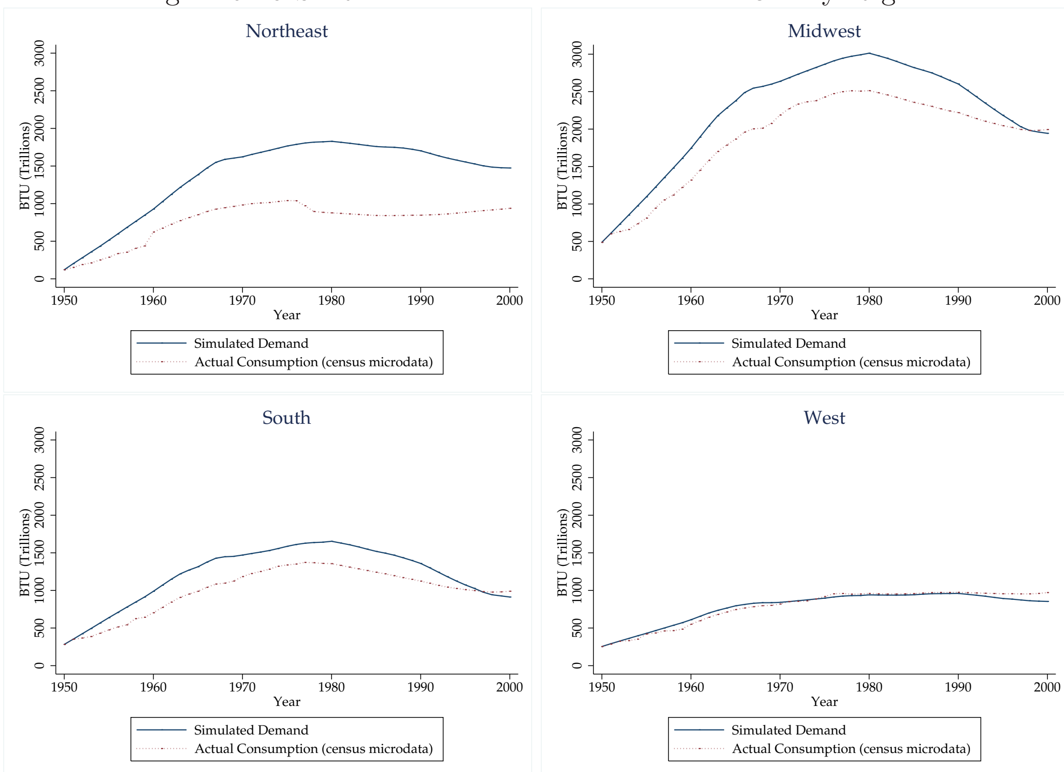

Figure 6: The Allocative Cost of Price Ceilings in the U.S. Natural Gas Market

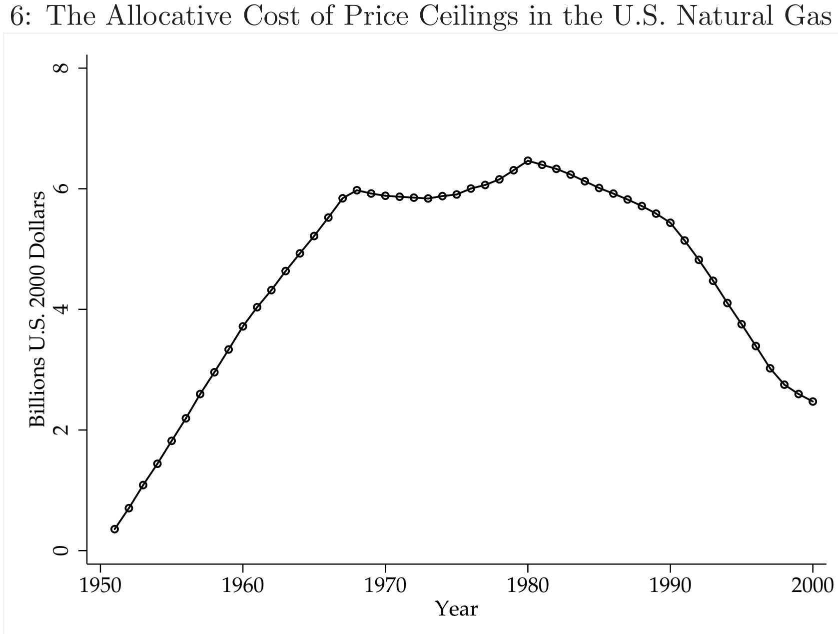

Figure 7: Average Annual Allocative Cost per Capita, 1950-2000

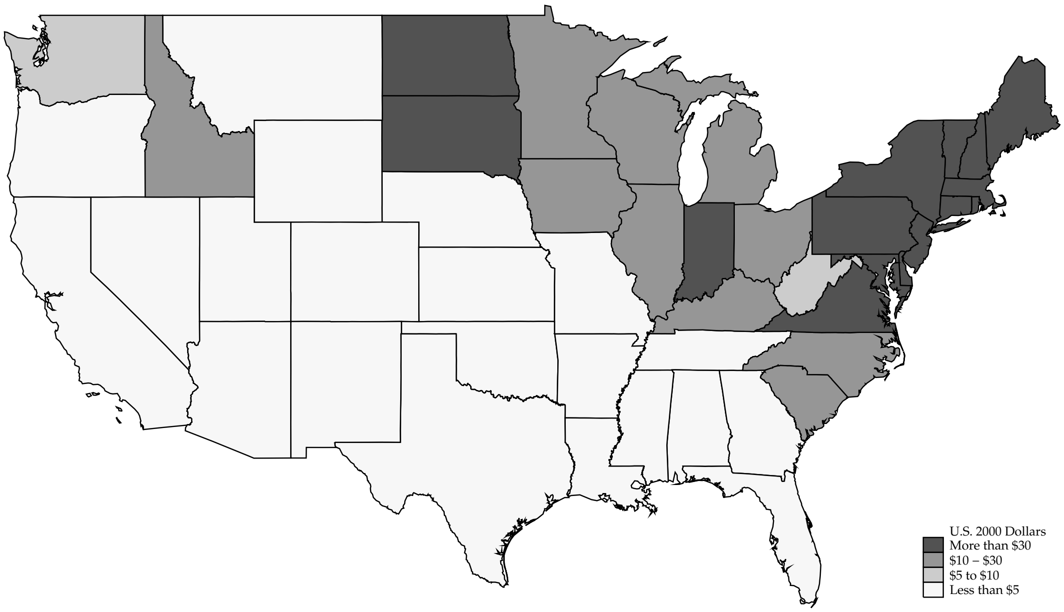

Figure 8: States Supporting Regulation, Senate Vote 1973

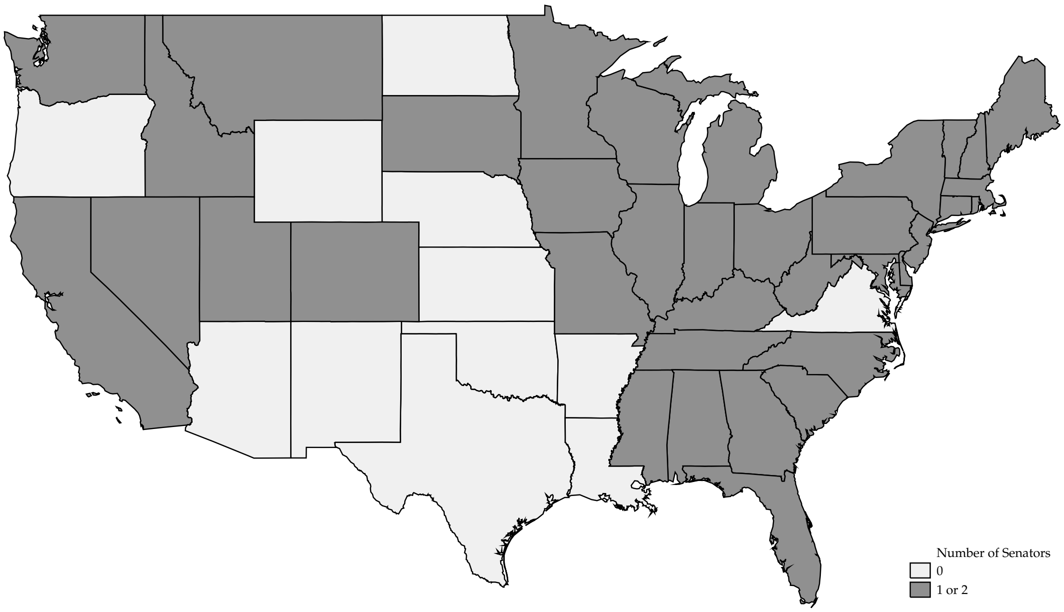

Figure 9: Residential Demand for Natural Gas in Main Gas-Producing States

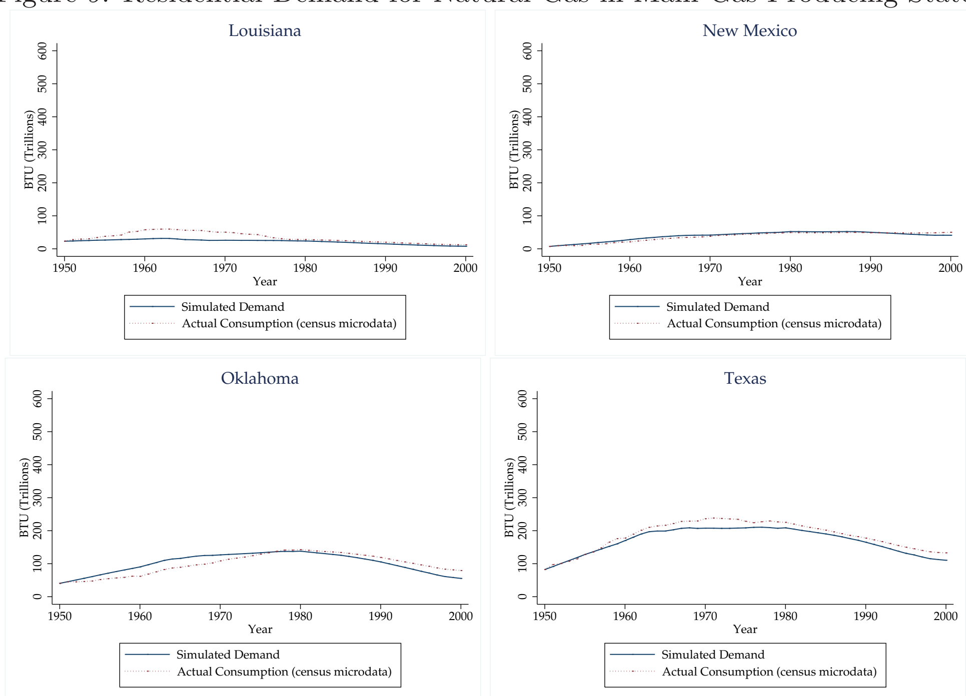

Table 1
Descriptive Statistics

	1960	1970	1980	1990	2000
Number of Households (millions)	.414[a]	.547	3.42	3.76	4.42
Primary Energy Source Used for Home Heating (percent)					
Natural Gas	57.3	64.3	62.8	62.4	63.2
Heating Oil	40.8	28.7	20.7	15.6	11.6
Electricity	1.8	7.0	16.5	22.0	25.2
Fuel Price per million BTUs					
Natural Gas	6.6	5.1	7.9	7.6	7.9
Heating Oil	7.0	5.7	14.5	9.4	9.7
Electricity	44.8	30.8	35.0	32.3	25.9
Household Demographics					
Household Size (persons)	3.3	3.1	2.7	2.6	2.6
Family Income (1000s)	34.1	43.6	40.7	48.3	54.2
Home Ownership Dummy (percent)	61.9	63.4	64.5	67.3	68.5
Housing Characteristics					
Number of Rooms	5.0	5.2	5.4	5.5	5.6
Multi-Unit (percent)	24.3	28.0	29.3	23.4	22.8
Home Built in 1940's (percent)	14.2	12.5	11.2	8.9	7.7
Home Built in 1950's (percent)	26.2	21.7	17.5	15.3	13.2
Home Built in 1960's (percent)	0.0	25.2	19.7	16.2	13.6
Home Built in 1970's (percent)	0.0	0.0	24.4	20.7	17.8
Home Built in 1980's (percent)	0.0	0.0	0.0	18.2	14.2
Home Built in 1990's (percent)	0.0	0.0	0.0	0.0	16.0

[a]Of the households who filled out the long-form questionnaire in 1960, a 20% random sample answered one set of additional questions which included the heating fuel question, and the other 80% answered an alternative set of questions which included the question about the number of units in the building.

Note: As described in detail in the text, the household and housing characteristics are from the U.S. Census, 1% samples for 1960 and 1970 and 5% samples for 1980, 1990, and 2000. For 1970, 1980, 1990 and 2000, energy prices come from E.I.A. (2006c). For 1960, state-level energy prices are from Edison Electric Institute (1961), American Gas Association (1961) and McGraw-Hill (1965). Dollar amounts are expressed in year 2000 dollars.

Table 2
Estimates, Heating-System Choice Model

Price per BTU (Gas and Oil)		-0.392	(0.002)	
Price per BTU (Electricity)		-0.117	(0.001)	
	Gas		Oil	
Heating Degree Days (HDD)				
HDD (1000s)	0.291	(0.009)	1.42	(0.022)
HDD Squared (10,000,000s)	0.034	(0.010)	-0.494	(0.018)
Demographic Characteristics				
Two Household Members	-0.032	(0.009)	0.050	(0.021)
Three Household Members	-0.164	(0.010)	0.083	(0.023)
Four Household Members	-0.152	(0.010)	0.137	(0.023)
Five Household Members	-0.162	(0.013)	0.140	(0.028)
Six or More Members	-0.162	(0.016)	0.111	(0.036)
Total Family Income (10,000s)	0.032	(0.001)	0.022	(0.001)
Homeowner Dummy	0.293	(0.010)	0.112	(0.023)
Housing Characteristics				
Rooms	0.146	(0.002)	0.046	(0.004)
Building Has 2 Units	-0.114	(0.023)	-0.790	(0.052)
Building Has 3-4 Units	-0.546	(0.018)	-1.67	(0.056)
Building Has 5-9 Units	-0.755	(0.017)	-2.46	(0.067)
Building Has 10-19 Units	-0.876	(0.018)	-2.67	(0.076)
Building Has 20-49 Units	-0.979	(0.020)	-2.07	(0.061)
Building Has 50+ Units	-1.14	(0.018)	-2.05	(0.055)
Constant	-2.20	(0.030)	-8.43	(0.071)

Note: The model was estimated using maximum likelihood with 708,320 observations.

Table 3
Estimates, Heating Demand Function

	1980		1990		2000	
Heating Degree Days (HDD)						
HDD (1000s)	26.7	(.279)	18.3	(.222)	12.5	(.198)
HDD Squared (1,000,000s)	-1.93	(.027)	-1.04	(.022)	-0.67	(.021)
Regional Dummies						
New England Region	12.0	(.446)	5.70	(.365)	17.6	(.333)
Middle Atlantic Region	18.9	(.357)	11.8	(.281)	27.7	(.279)
East North Central Region	51.2	(.355)	29.3	(.273)	25.9	(.240)
West North Central Region	46.9	(.392)	12.2	(.296)	3.45	(.252)
South Atlantic Region	37.5	(.255)	10.6	(.246)	15.2	(.217)
East South Central Region	58.7	(.311)	20.9	(.290)	17.1	(.255)
West South Central Region	54.0	(.258)	21.0	(.230)	12.8	(.205)
Mountain Region	22.4	(.379)	3.08	(.294)	11.2	(.252)
Demographic Characteristics						
Two Household Members	9.46	(.183)	4.96	(.145)	3.72	(.130)
Three Household Members	21.7	(.217)	12.4	(.178)	9.23	(.163)
Four Household Members	25.5	(.231)	14.8	(.189)	11.2	(.171)
Five Household Members	35.1	(.290)	21.6	(.256)	16.5	(.234)
Six or More Members	52.8	(.358)	33.2	(.342)	23.2	(.313)
Total Family Income(10,000s)	0.05	(.026)	1.42	(.018)	1.04	(.013)
Homeowner Dummy	2.81	(.203)	.293	(.174)	1.98	(.169)
Housing Characteristics						
Rooms	8.74	(.054)	7.91	(.044)	4.84	(.040)
Home Built in 1940's	-12.7	(.229)	-8.63	(.222)	-6.24	(.224)
Home Built in 1950's	-20.1	(.192)	-13.0	(.184)	-10.1	(.182)
Home Built in 1960's	-21.2	(.195)	-14.5	(.185)	-11.2	(.184)
Home Built in 1970's	-27.0	(.238)	-17.8	(.185)	-13.1	(.180)
Home Built in 1980's	-	-	-25.7	(.187)	-16.2	(.188)
Home Built in 1990's	-	-	-	-	-20.3	(.209)
Building Has 2 Units	5.94	(.312)	3.40	(.328)	2.06	(.319)
Building Has 3-4 Units	-12.6	(.377)	-10.1	(.375)	-8.50	(.338)
Building Has 5-9 Units	-26.4	(.418)	-26.4	(.370)	-20.3	(.335)
Building Has 10-19 Units	-29.6	(.440)	-30.5	(.372)	-23.4	(.364)
Building Has 20-49 Units	-38.1	(.541)	-40.5	(.445)	-32.9	(.406)
Building Has 50+ Units	-26.9	(.656)	-39.2	(.621)	-25.5	(.481)
Selection Terms						
Electricity Selection Term	28.0	(.816)	10.7	(.617)	8.30	(.630)
Heating Oil Selection Term	-26.6	(1.07)	-9.43	(.839)	-0.64	(.733)
Constant	3.22	(.811)	5.02	(.639)	22.0	(.683)
n	1,893,915		2,128,210		2,552,137	
R^2	0.23		0.24		0.17	

Note: The heating demand function is estimated separately by decade. The dependent variable is annual natural gas consumption in millions of BTU. Heteroskedasticity-robust standard errors are in parentheses. The excluded region is the Pacific region and the excluded home vintage is homes built before the 1940s. Observations are weighted using probability weights.

Table 4
The Allocation of Gas in the United States 1975-1978

	Households With Gas	Households Without Gas
Two Household Members	0.29	0.29
Three Household Members	0.19	0.19
Four Household Members	**0.21**	**0.20**
Five Household Members	**0.10**	**0.09**
Six or More Members	**0.05**	**0.04**
Total Family Income (10,000s)	**4.99**	**4.52**
Homeowner Dummy	**0.74**	**0.68**
Age of Household Head	**40.5**	**40.0**
Household Head High School Graduate	**0.81**	**0.80**
Household Head College Graduate	**0.26**	**0.25**
Household Head Non-White	**0.09**	**0.08**
Total Number of Rooms	**5.69**	**5.47**
Single Family Residence	**0.65**	**0.61**
Number of Households	143,245	171,644

Note: This table reports mean characteristics for households from the 1980 census living in homes built between 1975 and 1978, the period of peak shortages. Households with gas are those who report using natural gas as their primary form of home heating. Households without gas are those who report using electricity of heating oil as their primary form of home heating. Statistically significant differences using Leamer (1978) critical values are highlighted in boldface. Dollar amounts are in year 2000 dollars.

Table 5
The Allocation of Gas Within States 1975-1978, Homeowners Living in Large Single-Family Homes

	New York		Pennsylvania		Massachusetts	
	Homeowners With Gas	Homeowners Without Gas	Homeowners With Gas	Homeowners Without Gas	Homeowners With Gas	Homeowners Without Gas
Two Household Members	0.14	0.12	0.16	0.16	0.15	0.11
Three Household Members	0.18	0.19	0.18	0.18	0.19	0.18
Four Household Members	0.35	0.33	0.35	0.35	0.31	0.37
Five Household Members	0.18	0.23	0.20	0.19	0.20	0.20
Six or More Members	0.14	0.11	0.09	0.10	0.16	0.12
Total Family Income (10,000s)	7.26	7.17	7.29	7.01	7.94	7.82
Age of Household Head	39.2	38.0	38.8	38.5	**41.5**	**38.3**
Household Head High School Graduate	0.93	0.93	0.96	0.94	0.96	0.95
Household Head College Graduate	0.47	0.45	0.52	0.47	0.59	0.59
Household Head Non-White	0.04	0.06	0.03	0.03	0.05	0.03
Number of Homeowners	445	1235	394	1875	186	494

Note: This table reports average characteristics for homeowners with and without natural gas (i.e., who report using heating oil or electricity). The sample includes homeowners living in large (more than 7 total rooms), single-family homes. Statistically significant differences using Leamer (1978) critical values are highlighted in boldface. Dollar amounts are in year 2000 dollars.

Table 6
Average Annual Allocative Cost 1950-2000, in Billions

Benchmark Estimate	$4.56	(0.036)
Alternative Specifications of Utility		
Additional Household Demographics	$4.27	(0.037)
Flexible Specification for Number of Rooms	$4.62	(0.033)
Flexible Specification for Family Income	$4.50	(0.030)

Note: These estimates are based on the baseline counterfactual in which household preferences are estimated based on households' unconstrained choices during the 1990s. Bootstrap standard errors based on 100 replications are shown in parentheses. Dollar amounts are expressed in year 2000 dollars.

Table 7
Results by State, 1950-2000

Average Annual Allocative Cost, in Millions of Dollars			
1.	New York	1398	(14.0)
2.	Pennsylvania	778	(8.76)
3.	New Jersey	369	(5.41)
4.	Massachusetts	332	(5.80)
5.	Virginia	292	(7.75)
6.	North Carolina	228	(3.80)
7.	Maryland	207	(4.73)
8.	Connecticut	194	(2.92)
9.	Indiana	192	(5.25)
10.	Illinois	127	(8.34)
Average Annual Allocative Cost per Person, in Dollars			
1.	Delaware	76.3	(1.68)
2.	New York	73.7	(0.74)
3.	Maine	71.3	(1.35)
4.	New Hampshire	68.3	(1.06)
5.	Pennsylvania	63.4	(0.72)
6.	Vermont	61.1	(1.17)
7.	North Dakota	59.0	(3.10)
8.	Rhode Island	58.6	(1.44)
9.	Alaska	58.0	(1.82)
10.	Connecticut	56.9	(0.86)

Note: These estimates are based on the baseline counterfactual in which household preferences are estimated based on households' unconstrained choices during the 1990s. Bootstrap standard errors based on 100 replications are shown in parentheses. Dollar amounts are expressed in year 2000 dollars.

Table 8
How Allowing for Shifts in the Demand Parameters Affects Physical Shortages and Allocative Cost

Parameters	Change in Parameter Estimates Relative To Net Exporter Benchmark 1960s	1970s	1980s	1990s	Change in Average Annual Physical Shortage	Change in Average Annual Allocative Cost
Price per BTU (Gas and Oil)	0.13	-0.02	-0.02	-0.18	-0.75	5.68
Price per BTU (Electricity)	0.00	-0.01	-0.03	-0.02	3.19	1.34
Heating Degree Days (HDD) for Gas						
HDD (1000s)	-0.65	-0.53	0.13	0.38	-10.28	-3.80
HDD Squared (10,000,000s)	0.00	0.00	0.00	-0.00		
Demographic Characteristics for Gas						
Two Household Members	-0.03	0.04	0.04	-0.07	0.02	0.00
Three Household Members	0.16	0.11	0.11	-0.15	0.21	0.13
Four Household Members	0.31	0.13	0.06	-0.12	0.26	0.23
Five Household Members	0.23	0.12	0.12	-0.18	0.13	0.08
Six or More Members	0.34	0.08	0.14	-0.27	0.14	0.06
Total Family Income (10,000s)	-0.03	-0.04	-0.02	0.01	-1.68	-0.64
Homeowner Dummy	0.58	0.13	-0.10	0.12	0.90	0.87
Housing Characteristics for Gas						
Rooms	-0.13	-0.08	-0.03	0.08	-5.49	-1.90
Building Has 2 Units	0.38	0.20	-0.16	-0.15	-0.22	0.14
Building Has 3-4 Units	0.33	0.17	-0.35	0.17	-0.27	0.09
Building Has 5-9 Units	0.73	0.18	-0.55	0.30	-0.33	0.13
Building Has 10-19 Units	0.26	0.14	-0.65	0.33	-0.32	0.16
Building Has 20-49 Units	0.06	0.21	-0.61	0.17	-0.33	0.08
Building Has 50+ Units	0.05	0.11	-0.92	0.19	-0.35	0.03
Constant	1.95	1.42	-0.93	-0.59	3.13	3.43
Heating Degree Days (HDD) for Oil						
HDD (1000s)	0.67	0.27	-0.03	-0.37	3.71	3.31
HDD Squared (10,000,000s)	-0.01	0.00	0.00	0.00		
Demographic Characteristics for Oil						
Two Household Members	-0.06	-0.04	0.21	-0.36	-0.23	0.04
Three Household Members	0.23	0.08	0.03	-0.46	-0.25	0.04
Four Household Members	0.09	0.07	-0.01	-0.43	-0.24	0.06
Five Household Members	-0.26	0.05	0.21	-0.70	-0.23	0.06
Six or More Members	-0.24	-0.04	0.24	-0.60	-0.22	-0.02
Total Family Income (10,000s)	-0.01	0.0	0.00	0.01	-0.23	0.04
Homeowner Dummy	1.03	0.35	-0.21	0.06	-0.67	0.02
Housing Characteristics for Oil						
Rooms	-0.12	-0.06	0.01	0.13	-0.11	-0.26
Building Has 2 Units	0.17	0.38	-0.08	-0.19	-0.24	0.20
Building Has 3-4 Units	0.82	0.43	-0.42	-0.01	-0.29	0.06
Building Has 5-9 Units	0.96	0.49	-0.25	0.25	-0.29	0.08
Building Has 10-19 Units	0.55	0.58	-0.52	-0.08	-0.28	0.08
Building Has 20-49 Units	-0.09	0.67	-0.28	-0.61	-0.28	0.01
Building Has 50+ Units	0.81	0.56	-0.05	-1.54	-0.28	0.07
Constant	-1.43	-0.25	-0.82	0.36	0.09	0.30
All Changes Combined					-4.33	-1.32

Note: This table describes how the parameters of the heating-system choice model change across time in the alternative counterfactual that exploits the fact that price regulation applied only to *interstate* sales and thus states that were net exporters of natural gas were not subject to price ceilings (see section 6.6 for details). For each decade, the table reports the change in parameter estimates relative to the baseline in which parameters are not allowed to vary across decades, as well as the implied changes in average annual physical shortages (in percentage points) and allocative costs (in billions). We do not display results for the 1950s because not all of the covariates are observed, making the results incompatible with other decades. In the baseline specification for net exporters average annual physical shortages are 21.1% and average annual allocative cost is $9.62 billion.