Natural Gas
Demand and Regulatory

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Davis, Kilian. “The allocative cost of price ceilings in the US residential market for natural gas.” JPE, 2011, Auffhammer, Rubin (2018) Natural Gas Price Elasticities and Optimal Cost Recovery Under Consumer Heterogeneity: Evidence from 300 million natural gas bills. NBER

Introduction

- Welfare costs of price ceilings (rental housing, telecommunications, insurance, energy, health care)
- Price ceilings reduce the quantity transacted below competitive $\Rightarrow$ deadweight losses
- Additional costs: with excess demand + no secondary markets $\Rightarrow$ welfare loss occurs when the good is not allocated to the buyers who value it the most
- Empirical question,
- While some households were enjoying access to cheap price-controlled natural gas, new residential connections were unavailable in many parts of the country.
- Allocative cost

Introduction

- Natural gas is good to empirically examine allocative costs
  1. Natural gas is a homogeneous good, eliminating concerns about differences in quality that complicate the estimation of allocative costs in other markets.
  2. 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.
  3. Residential market for natural gas affects millions of consumers, suggesting that allocative costs could be very large.
  4. Market was continuously regulated between 1954 and 1989 before experiencing complete deregulation.
  5. Some states remained unregulated throughout this period allows us to evaluate the out-of-sample fit of our model in settings in which markets operate freely
  6. Availability of comprehensive household-level data by state and year as well as the corresponding state-level price data.

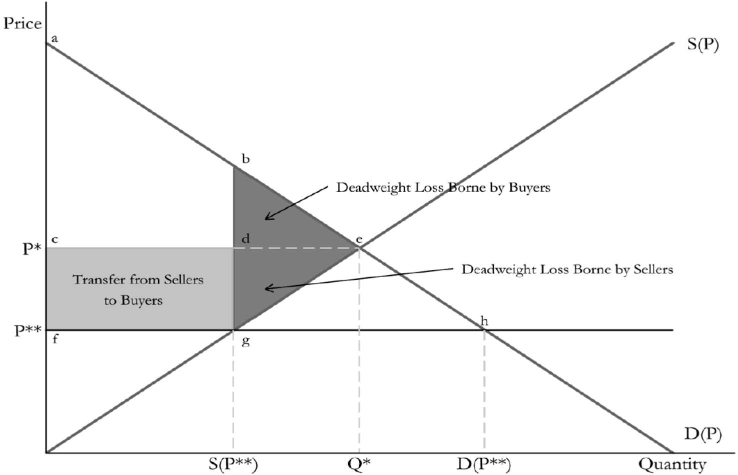
Introduction

- by 1990s, deregulated and, after that all households purchasing new homes were free to choose natural gas heating systems
- Question: how much natural gas would have been consumed in 19502000 based on the household preferences revealed in the 1990s data.
- First estimate household preferences based on choices in the 1990s
- Compare households actual choices under regulation with counterfcatural of an unconstrained world
- Shortage cost: demand for natural gas exceeded sales of natural gas 19.4 %
- Allocative cost: \$3.6 billion annually, 14 % of total residential expenditure on natural gas.

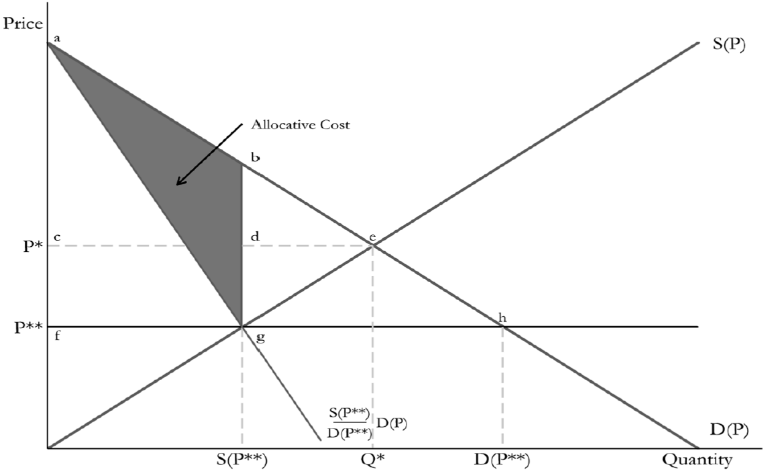
Price Ceilings and Allocative Cost

- Next figure
- Market clear $P^{*} \& Q^{*}$
- Price ceiling P^{**}
- Welfare cost of price ceilings not limited to the deadweight loss
- It is deadweight loss, if only if the good is allocated to the buyers who value it the most.
- Consumer a-b receive the good and b-h not receive it
- When secondary market ensures that buyers with the highest willingness to pay receive the good.

welfare analysis of the effect of price ceilings



Allocative cost under random assignment



Price Ceilings and Allocative Cost

- If random allocation, only a fraction $S(P^{**})/D(P^{**})$ of buyers with a reservation price above P^{**} will be able to buy the good
- Random assignment correspond to new demand curve : $D(P)S(P^{**})/D(P^{**})$
- Additional allocative cost in the figure
- Allocative cost can be measured as the difference between the consumer surplus under efficient rationing and the consumer surplus under the actual rationing
- Depends on distribution of reservation prices across households
- This suggests that in estimating the allocative cost, it is important to specify a model that accounts for the heterogeneity of households

History of Natural Gas Regulation

- Most natural gas from Texas, Louisiana, New Mexico, and Oklahoma and transported by pipeline to gas consumers in the Midwest and Northeast.
- In 1930s and 1940s the problem of overproduction.
- In 1950s pipeline system expanded, supply could barely keep up with demand
- Prices increased and pressures arose to regulate interstate
- 1954 Supreme Court decision that imposed federal price controls on natural gas sold in the interstate market.
- Because federal jurisdiction extended only to interstate sales of natural gas, natural gas markets in gas-producing states were left unregulated.

History of Natural Gas Regulation

- The price ceilings stimulated consumer demand while at the same time discouraging supply.
- Starting in the 1950s, utility companies deny access to new residential customers
- The shortage became widely apparent in the 1970s, when utility companies were forced to curtail deliveries to the industrial sector.
- Evidence of increasing physical shortages $\Rightarrow$ Natural Gas Policy Act in 1978, which specified a phased deregulation of the price of natural gas.
- Natural gas prices temporarily spiked, supplies expanded, and curtailments were eliminated, but it was only in 1989 that all forms of price controls were officially terminated

History of Natural Gas Regulation

- Texas is unregulated, New Jersey importing:

	During Height of Regulation (1969–78)	During Phased Deregulation (1979–89)	After Deregulation (1990–2000)
New Jersey	40	63	80
Texas	43	31	33

- A much higher share of households to demand natural gas in New Jersey with its colder climate than in Texas

Dynamic Model

- Energy demand is derived from demand for household services such as heating, cooling, and refrigeration that are produced in the home using durable goods.
- Two choice: how much energy + from which sources (gas, electricity, heating oil)
- Conditional demand for natural gas:

$$x_i = \beta_0 + \beta_1 p_{ig} + \beta_2' \omega_i + \eta_i$$

- x_i consumption in Btu, p_{ig} price of natural gas function of i, ω_i characteristics,

Dynamic Model

- Our model postulates that households choose which heating system to purchase by evaluating the indirect utility function

$$u_{ij} = \alpha_{0j} + \alpha_{1j} p_{ij} + \alpha'_{2j}\omega_i + \alpha'_{3j} p_{ij} z_i + \varepsilon_{ij}$$

- where the utility for household i of heating system $j \in \{g, e, o\}$ is a function of $p_{ij}, \omega_i, and \quad z_i$, a vector that includes HDDs (heating degree days), household size, and number of rooms
- α_{0j} include installation costs, preferences for particular heating
- α'_{3j} different energy prices to vary across households with different levels of demand for heat

Dynamic Model

- i selects alternative k with the probability of drawing $\{\varepsilon_{i1}, \varepsilon_{i2}, \cdots, \varepsilon_{iJ}\}$ such that $u_{ik} \geq u_{ij}$ for all $j \neq k$
- ε_{ij} is iid with a type 1 extreme value distribution, $exp[-exp(-\varepsilon)]$, then

$$Pr_{ik} = \frac{exp(\alpha_{0k} + \alpha_{1k}p_{ik} + \alpha'_{2k}\omega_i + \alpha'_{3k}p_{ik}z_i)}{\sum_{j=1}^{J} exp(\alpha_{0j} + \alpha_{1j}p_{ij} + \alpha'_{2j}\omega_i + \alpha'_{3j}p_{ij}z_i)}$$

- Discrete and continuous components of the model are correlated
  - if i prefer warm homes $\Rightarrow$ choose natural gas and consumer more
  - so distribution of η_i of choosing gas is not equivalent to unconditional distribution

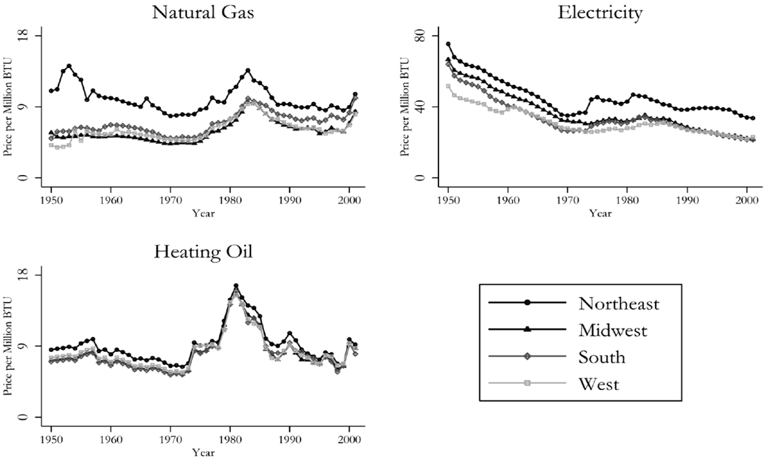
Dynamic Model

- Solution: η_i linear function of $\{\varepsilon_{i1}, \varepsilon_{i2}, \cdots, \varepsilon_{iJ}\}$
- Because of extreme value, can analytically compute conditional η
- Correction term based on heating system choice $\hat{P}r_{ie} ln(\hat{P}r_{ie})/(1 - \hat{P}r_{ie}) + ln(\hat{P}r_{ig})$ and $\hat{P}r_{io} ln(\hat{P}r_{io})/(1 - \hat{P}r_{io}) + \hat{P}r_{ig}$
- These selection term put into demand function then consistent β
- Assumption: current price a reasonable proxy for future prices

Dynamic Model

- Assume price is not endogenous:
  - micro data, so control for responsiveness of demand to climate, household, and housing characteristics, nothing remain to make it endogenous
  - identification by institutional characteristics of U.S. retail energy markets.
  - residential natural gas prices by cross-sectional differences in transportation and distribution costs
  - so little scope for unmodeled regional demand shocks to influence prices
- Similar arguments for electricity and heating oil prices
- Cheap electricity in regions with hydroelectric
- sustained declines in prices because of technologies

Dynamic Model



Empirical Implementation

- Data
  - census 19602000 for household heating system choices, household demographics, and housing characteristics.
  - state-level residential prices for natural gas, electricity, and heating oil
- Next table estimates of heating system choice model
- Coefficients for price are negative $\Rightarrow$ households prefer a low energy price
- Estimates of household characteristics are normalized relative to heating oil

Estimates of the Heating System Choice Model

	Gas and Oil	Electric
Energy prices and interactions:		
Price (per Btu)	−.383 (.003)	−.119 (.0006)
Price and HDD (1,000s)	−.057 (.002)	.003 (.0004)
Price and number of rooms	−.020 (.001)	.004 (.0003)
Price and number of household members	−.020 (.002)	−.006 (.0004)
	Gas	**Electric**
HDD:		
HDD (1,000s)	−.99 (.03)	−1.93 (.04)
HDD^2 (10,000,000s)	.37 (.03)	.50 (.03)
Demographic characteristics:		
Two household members	−.15 (.02)	−.03 (.03)
Three household members	−.32 (.02)	−.04 (.03)
Four household members	−.37 (.02)	−.08 (.04)
Five household members	−.42 (.03)	−.06 (.05)
Six or more members	−.39 (.04)	.06 (.07)
Total family income (10,000s)	.02 (.00)	−.02 (.00)
Homeowner dummy	.15 (.03)	−.13 (.03)
Housing characteristics:		
Number of rooms	.14 (.01)	−.31 (.01)
Building has 2 units	.85 (.06)	.71 (.06)
Building has 3–4 units	1.33 (.06)	1.59 (.06)
Building has 5–9 units	1.93 (.07)	2.39 (.07)
Building has 10–19 units	2.08 (.08)	2.66 (.08)

Estimates of the Heating Demand Function

- Next table estimates heating demand function given
- Heating system choice model only by households living in homes built during the 1990s (after deregulation)
- Heating demand function by all households in the 1980, 1990, and 2000 Census that primarily use natural gas
- Selection bias:
  - NG consumption is observed only for households that chose natural gas heating
  - not included in this sample are households that preferred natural gas but were excluded from the market because of shortages.
  - if rationing mechanism is correlated with unobserved components of heating demand $\Rightarrow$ bias our estimates.
  - minimize this bias by including a rich set of household and housing characteristics in the regressions.

Estimates of the Heating Demand Function

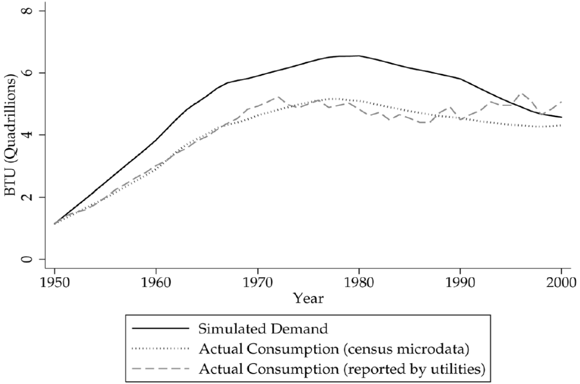
	1980	1990	2000
Price of natural gas	−7.70 (.06)	−3.54 (.06)	−1.29 (.07)
HDD:			
HDD (1,000s)	46.5 (.24)	29.1 (.19)	26.9 (.18)
HDD^2 (10,000,000s)	−31.9 (.23)	−18.2 (.20)	−21.3 (.21)
Demographic characteristics:			
Two household members	8.1 (.18)	4.9 (.15)	3.6 (.14)
Three household members	19.8 (.21)	12.7 (.19)	9.5 (.17)
Four household members	23.9 (.23)	15.4 (.20)	10.9 (.18)
Five household members	32.9 (.29)	22.4 (.27)	16.3 (.25)
Six or more members	50.2 (.36)	33.9 (.36)	23.0 (.33)
Total family income (10,000s)	.6 (.03)	1.5 (.02)	.9 (.01)
Homeowner	7.2 (.20)	2.2 (.19)	2.9 (.18)
Housing characteristics:			
Number of rooms	11.1 (.05)	8.6 (.05)	5.2 (.04)
Home built in 1940s	−10.2 (.23)	−8.7 (.23)	−6.2 (.24)
Home built in 1950s	−17.9 (.19)	−13.5 (.19)	−10.5 (.19)
Home built in 1960s	−21.6 (.19)	−15.9 (.19)	−12.5 (.20)
Home built in 1970s	−41.4 (.26)	−21.2 (.20)	−15.9 (.19)
Home built in 1980s	. . .	−26.6 (.20)	−19.2 (.20)
Home built in 1990s	. . .	. . .	−29.0 (.23)
Building has 2 units	14.7 (.32)	6.3 (.34)	7.6 (.33)
Building has 3–4 units	−10.5 (.37)	−10.5 (.38)	−3.0 (.34)
Building has 5–9 units	−27.7 (.40)	−27.2 (.37)	−14.5 (.33)
Building has 10–19 units	−32.6 (.42)	−32.5 (.36)	−18.2 (.35)
Building has 20–49 units	−41.6 (.51)	−42.4 (.43)	−28.1 (.38)
Building has 50+ units	−30.5 (.63)	−42.0 (.60)	−21.6 (.45)
Selection terms:			
Electricity selection term	−12.0 (.66)	−.47 (.58)	40.8 (.59)
Heating oil selection term	13.7 (.89)	−1.93 (.87)	−43.8 (.80)
Constant	−7.7 (.77)	2.49 (.64)	23.2 (.83)
Number of households	1,719,743	1,882,971	2,177,998
R^2	.25	.24	.17

Estimates of the Heating Demand Function

- Estimated separately by decade.
- Dependent variable: annual consumption of natural gas in millions of Btu, constructed by dividing reported annual expenditure on natural gas by the average residential price of natural gas for the appropriate state and year.
- Instrument for price of NG using regional indicator variables (measurement error in price)
- Decreasing price sensitivity over time: -0.34 in 1980 to -0.10 in 2000
- Temperature (HDD) are strongly statistically significant
- Natural gas consumption increases with household size, number of rooms, age of the home
- Selection terms are significant ⇒ unobserved determinants of heating demand and choices are indeed correlated.

Results-Physical Shortages

- Residential demand for natural gas

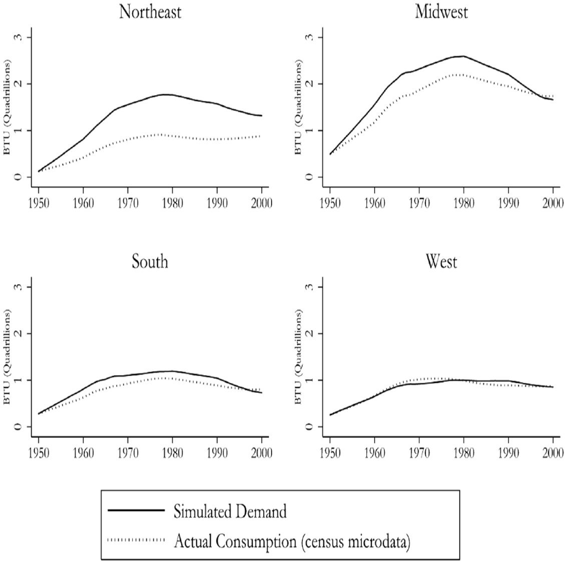


- Solid: counterfactual of what demand would have been at observed prices had all households had access to natural gas

Results-Physical Shortages

- Large differences between simulated demand and actual consumption during the 1970s and 1980s
- Next figure, the same graph by region
- Northeast massive shortage
- West no difference
  - natural gasproducing states, no shortage
  - warmer climate and greater access to cheap hydroelectric electricity
  - following deregulation, much more new housing construction in these regions

Results-Physical Shortages



Results-Physical Shortages

- Shortage: curtailment+those excluded 19.4 %
- Persistence of the effects of price regulation.
- Previous studies assumed that the effects of regulation
- Simulated demand exceeded actual consumption throughout the 1980s
- 71 % of households in 2000 are living in homes with heating systems that were purchased prior to complete deregulation in 1989

Results-Allocative Costs

- Allocative cost : welfare loss that results from not allocating a good to the buyers that value it the most
- Calculation steps:
  1. simulate the reservation price for each household p^*_{ig} (natural gas price that makes household i indifferent between g and best of alternatives)

$$p^*_{ig} = \frac{max(u_{ie}, u_{io}) - \alpha_{0g} - \alpha'_{2g}\omega_i - \varepsilon_{ig}}{\alpha_{1g} + \alpha'_{3g}z_i}$$

  2. calculate each household's consumer surplus for this household's simulated reservation price (difference in actual and reservation price by its demand of gas $\hat{x}_{ig}$)

$$CS_i = (p^*_{ig} - p_{ig})\hat{x}_{ig}$$

Results-Allocative Costs

3. total consumer surplus for all households under efficient rationing ($1(er_{it})$ if i receive gas under efficient rationing)

$$CS_i^{er} = \sum_{i=1}^{n} CS_i \times 1(er_{it})$$

old consumer can hold NG, so reallocation among potential new customers

4. compute $\theta_{st} = \frac{\sum_{i\in s,t} \hat{x}_{ig} \times 1(census_{it})}{\sum_{i\in s,t} \hat{x}_{ig} \times 1(p^*_{ig} > p_{ig})}$ $1 - \theta_{st}$ percentage measure of the shortage of natural gas for a given state and year
5. total consumer surplus under actual rationing

$$CS_t^{ar} = \sum_{i=1}^{n} CS_i \times 1(ar_{it})$$

6. Allocative costs:

Results-Allocative Costs

- Estimation of annual allocative cost in millions of year 2000 $

	Estimate
Nationwide	$3,560 (34.1)
10 most affected states:	
New York	$1,081 (12.4)
Pennsylvania	$652 (10.3)
New Jersey	$284 (4.9)
North Carolina	$259 (5.1)
Virginia	$253 (4.9)
Massachusetts	$196 (4.0)
Maryland	$162 (4.0)
Indiana	$145 (5.2)
Connecticut	$125 (3.0)
South Carolina	$81 (3.0)

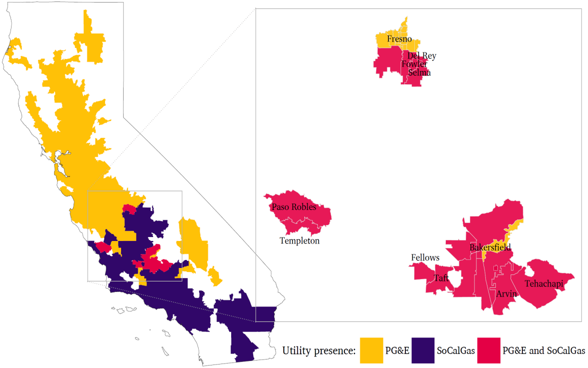
- Average $3.6 billion, 14% of total residential expenditure
- Within state ($2.93) and across-state ($0.63)allocative costs

Introduction

- Naturak gas: 50% to heat homes, 43% to heat water
- First microdata-based estimates of residential natural gas demand elasticities
- 300 million bills in California
- Sources of endogeneity:
  - Price change monthly due to wholesale price (traditional supply/demand shock)
  - Block pricing (higher consumption, higher prices) (reverse causality)
- Solution to endogeneity:
  - spatial discontinuity along border between two major natural-gas utilities
  - IV: Henry hub prices as determined in advanced (first endogeneity)
  - IV: block pricing of previous demand (Ito 2014)

Institutions: Utilities

- Spatial Discontinuity of two utilities.



Institutions: bills

- Household's bill depends upon five elements
  1. two-tiered price schedule set by the utility
  2. total volume of natural gas consumed during the billing period
  3. season (summer or winter) in which the bill occurs
  4. climate zone into which the household's physical location falls
  5. household's CARE (California Alternate Rates for Energy) status (for low income, 80% price of the rest)

Price Variable

- In contrast to Ito (2014) to discuss which prices, they regress on all potential prices
- (1) Marginal price (2) average price (3) average marginal price (4) baseline (first-tier) price, (5) simulated marginal price

Simulated marginal price

- Ito (2014) version: $z_{it} = p_{it}(q_{t-k})$
- No shock from current consumption but current block pricing
- Benchmark should be last year consumption.

$$s_{it} = \frac{1}{5} \sum_{k=10}^{14} 1_{q_{i,t-k} > \bar{A}_{it}}$$

- $\bar{A}_{it}$ where price change in block pricing
- Then to get prices: $z_{it} = 1_{s_{it} < 0.5} \times p_{it}^{base} + 1_{s_{it} > 0.5} \times p_{it}^{excess}$

Endogeneity Exists

- Border: zip codes that are in both borders (discontinuity)
- 5% CA: random 5% of residence.

	Dependent variable: Log(Consumption, daily avg.)					
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Marginal price)	0.4698***	0.4346***	0.4276***			
	(0.0106)	(0.0136)	(0.0134)			
Log(Baseline price)				0.0217	−0.0918***	−0.1009***
				(0.0147)	(0.0201)	(0.0209)
Bill HDDs	T	T	T	T	T	T
Household FE	T	T	T	T	T	T
Month-of-sample FE	T	T	F	T	T	F
City by month-of-sample FE	F	F	T	F	F	T
Sample	5% CA	Border	Border	5% CA	Border	Border
N	12,855,910	5,754,088	5,754,088	12,855,910	5,754,088	5,754,088

- Biased and wrong elasticity

Contribution 1: Elasticity

- Robust estimates of -0.17 to -0.23 after correcting for endogeneity (second stage)

Dependent variable: Log(Consumption, daily avg.)

	(1) Marginal	(2) Average	(3) Avg. Mrg.	(4) Baseline	(5) Sim. Mrg.
Panel A: First-stage results					
Spot price	0.3679***	0.3697***	0.3384***	0.4699***	0.3949***
	(0.0774)	(0.0521)	(0.0570)	(0.0434)	(0.0840)
Spot price × SoCalGas	0.7868***	0.7174***	0.9389***	0.8212***	0.8174***
	(0.0299)	(0.0186)	(0.0198)	(0.0176)	(0.0317)
Panel B: Second-stage results					
Log(Price) *(instrumented)*	−0.2098***	−0.2312***	−0.1734***	−0.2030***	−0.1705**
	(0.0706)	(0.076)	(0.0585)	(0.065)	(0.0698)
First-stage F stat.	418.4	899.4	1,311.0	1,333.2	369.9
Bill HDDs	T	T	T	T	T
Household FE	T	T	T	T	T
City mo.-of-sample FE	T	T	T	T	T
N	5,754,085	5,754,085	5,754,085	5,754,085	4,682,526

Contribution 2: Elasticity Heterogeneity

- Inelastic in summer, low income are elastic in winter

Dependent variable: Log(Consumption, daily avg.)

	Marginal Price			
	(1) Summer CARE	(2) Summer Non-CARE	(3) Winter CARE	(4) Winter Non-CARE
Log(Price)	0.0457	0.0742^{**}	-0.5226^{***}	-0.3173^{**}
instrumented	(0.0353)	(0.0324)	(0.1424)	(0.1498)
First-stage F stat.	303.4	237.1	145.6	156.7
Bill HDDs	T	T	T	T
Household FE	T	T	T	T
City month-of-sample FE	T	T	T	T
N	1,293,144	1,772,773	1,141,991	1,546,177