Natural gas elasticities and optimal cost recovery under heterogeneity

Evidence from 300 million natural gas bills in California

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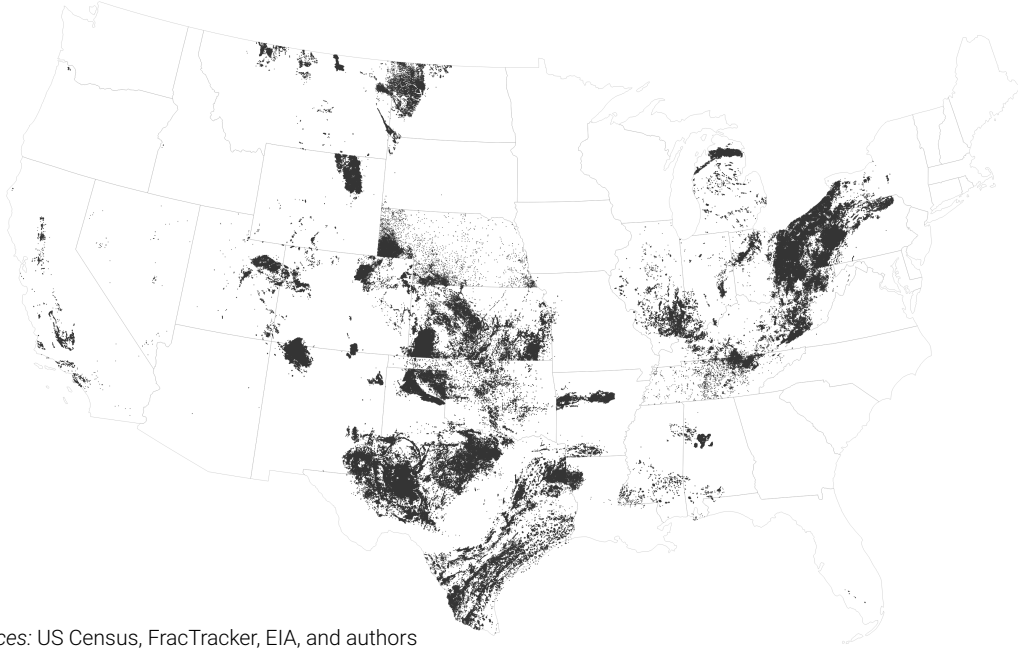
February 6, 2018

Sources: US Census, FracTracker, EIA, and authors



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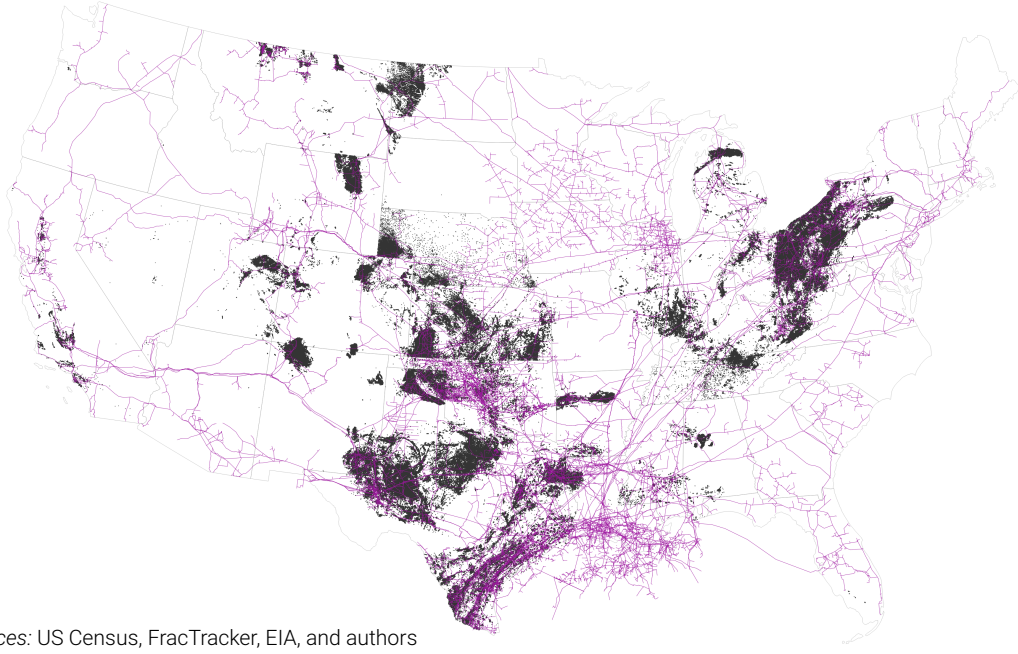

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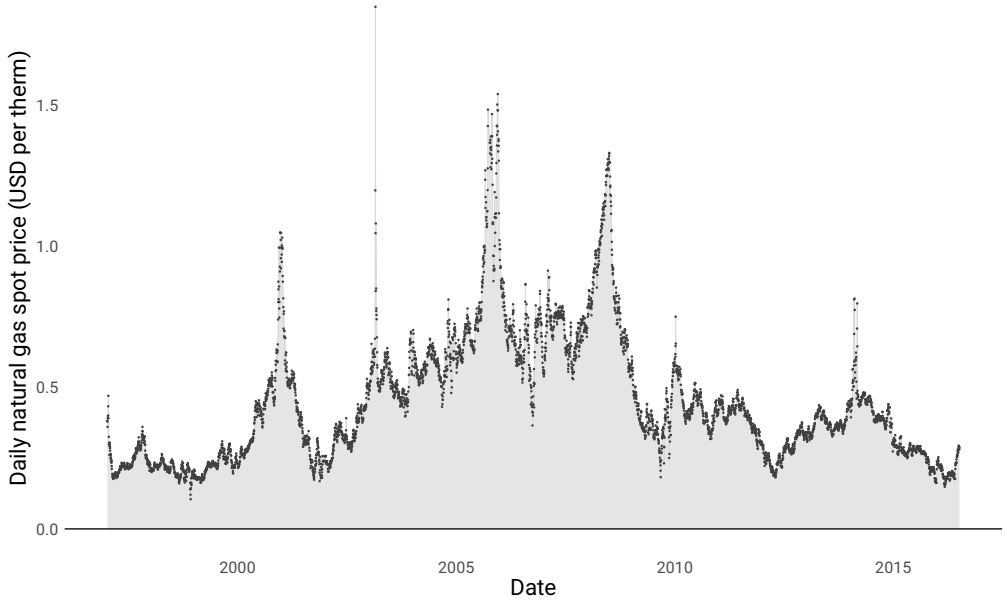
Henry Hub spot price for natural gas, 1997–2017



Natural gas

Gas matters

Residential natural gas matters too.

- The majority of US households heat primarily with natural gas (AHS),
- Households expend $50B–$80B each year on natural gas (EIA & CE),
- Households spend similar amount on their natural gas bills and water bills (CE),
- Natural-gas use is not uniform across income groups (CE).

This paper

Goals

This paper sets out with two main goals:

1. Causally estimate the **own-price elasticity of demand** for residential natural gas.
2. Estimate the **heterogeneity** underlying this commonly *pooled* parameter.

Motivation

Elasticity of demand

The motivation for this paper stems for two observations:

1. **Policy relevance:** Numerous policy questions require knowledge of the price elasticity of demand for natural gas, *e.g.*,
   - Welfare benefits of natural gas regulation and pricing (*e.g.*, Davis and Muehlegger, 2010)
   - Welfare benefits of fracking (*e.g.*, Hausman and Kellogg, 2015)
   - Distributional effects of carbon/GHG taxes
2. **Dearth of identified estimates:** Current literature lacks carefully-identified, microdata-based price elasticities of demand for residential natural gas.

Existing literature

Natural gas, in general

Less attention than electricity: While natural gas plays a substantial role both in the US energy market and in the lives of residential consumers, it has received a relatively low amount of attention, in comparison to related literatures (Rehdanz, 2007).

Focuses on regulation and organization: Much of the natural-gas related literature focuses on regulation and organization of the industry (*e.g.*, Brown and Yücel, 1993; Davis and Muehlegger, 2010; Davis and Kilian, 2011; Borenstein and Davis, 2012; Hausman and Muehlenbachs, 2016), with fewer papers considering residential/consumer behavior.

Existing literature

Own-price elasticity of demand for residential natural gas

The existing literature can be broadly broken into two groups:

1. **Aggregated data**
   - Utility-month, county-month, or state-month data
   - Generally used en route to another result
   - Instrument (aggregated average) prices with weather histories
   - Davis and Muehlegger, 2010; Borenstein and Davis, 2012; Hausman and Kellogg, 2015
2. **Microdata**
   - Consumption surveys or bills—often cross sections or short panels
   - Lack identification strategies (average price may be endogenous)
   - Metcalf and Hassett, 1999; Rehdanz, 2007; Meier and Rehdanz, 2010; Alberini *et al.*, 2011

Existing literature

Point estimates for the elasticity of demand for residential natural gas

Paper	Data	Estimate
Houthakker and Taylor (1970)	Time series	–0.15
Herbert and Kreil (1989)	Monthly time series	–0.36
Maddala *et al.* (1997)	US state panel	–0.09 to –0.18
Metcalf and Hassett (1999)	RECS HH panel	–0.08 to –0.71
Garcia–Cerrutti (2000)	Calif. county panel	–0.11
Rehdanz (2007)	Germany HH panel	–0.44 to –0.63
Davis and Muehlegger (2010)	US state panel	–0.28
Meier and Rehdanz (2010)	UK HH panel	–0.34 to –0.56
Hausman and Kellogg (2015)	US state panel	–0.11

Sources: Alberini et al. (2011) and authors

Contribution

Overcoming common challenges

- **Two flavors of simultaneity**
  1. Price and quantity result from the equilibrium of a system of equations.

     Problem: Simultaneity bias from failing to separate supply and demand shocks.

     Solutions:

     - Border discontinuity between two utilities
     - Supply instruments: Henry Hub spot price
  2. Price is mechanically a function of quantity in multi-tiered pricing regimes.

     Problem: Marginal and average price are endogenous.
     Solution: Proxy/instrument with baseline price or simulated instruments
- **Insufficient data**

  Problem: Lacking consumer-level data on consumption and prices

  Solution: Better data: We combine a large panel of HH bills with utilities' actual prices

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3. We are the first paper to **decompose elasticities by season and income**.
4. We illustrate how this heterogeneity may be used in tax policy that is both **more efficient and more progressive**.

This paper

Overview

Main question: What is the elasticity of demand among residential natural gas consumers?

Methods:

- Within-zip-code spatial discontinuities
- Supply-shifting instruments for price
- Simulated instruments

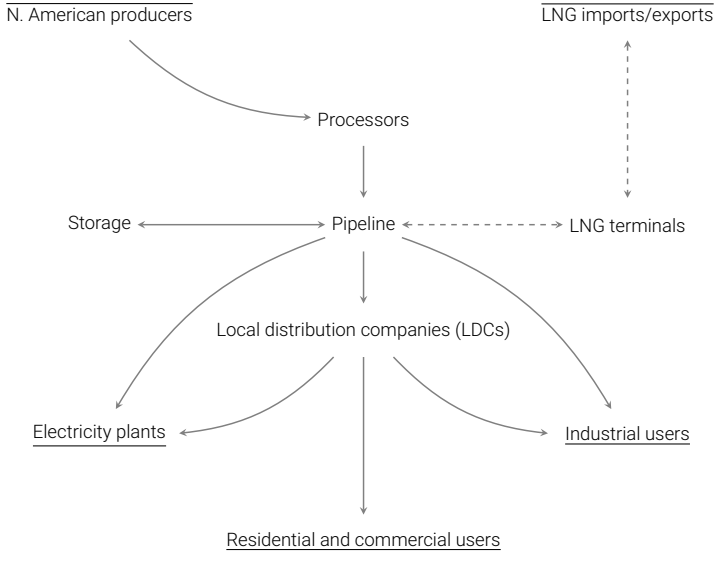
Data: 300M+ natural gas bills from PG&E and SoCalGas

Results:

- We estimate the elast. of demand for residential nat. gas is between –0.23 and –0.17.
- This elasticity varies considerably by season and by income.

Institutional context

Natural gas system



Sources: Authors; Levine, Carpenter, and Thapa (2014); and Brown and Yücel (1993)

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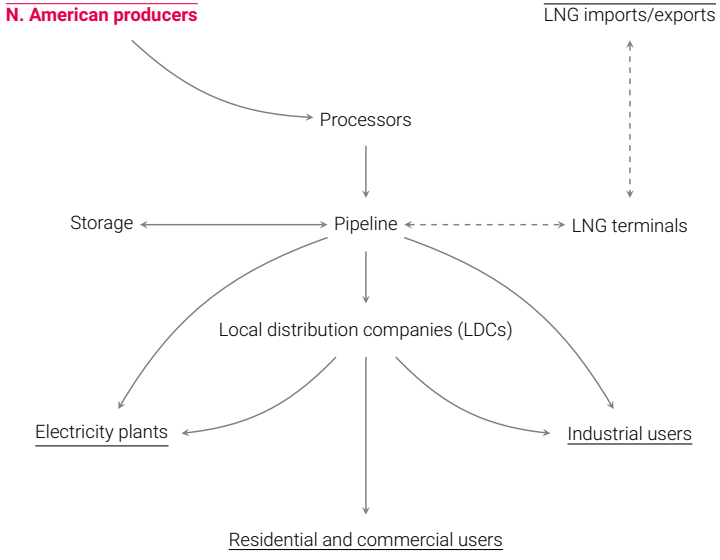

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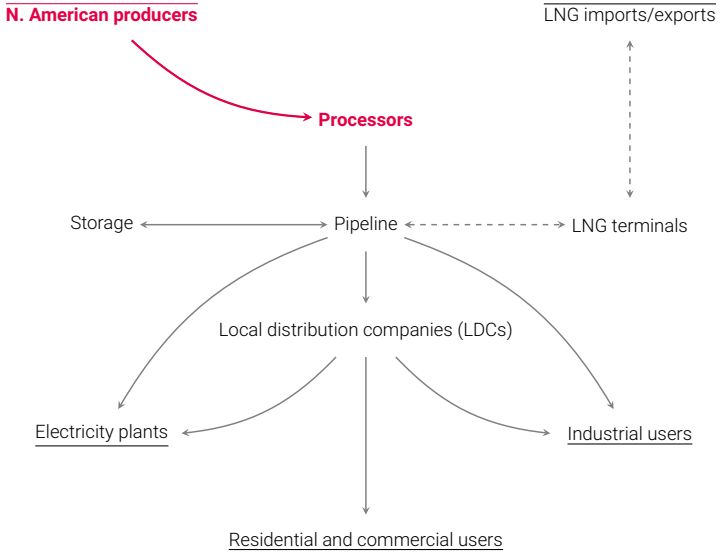

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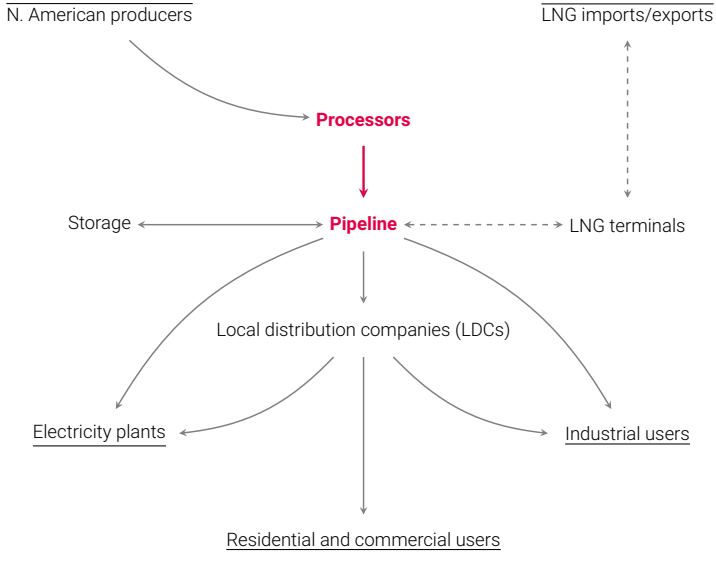

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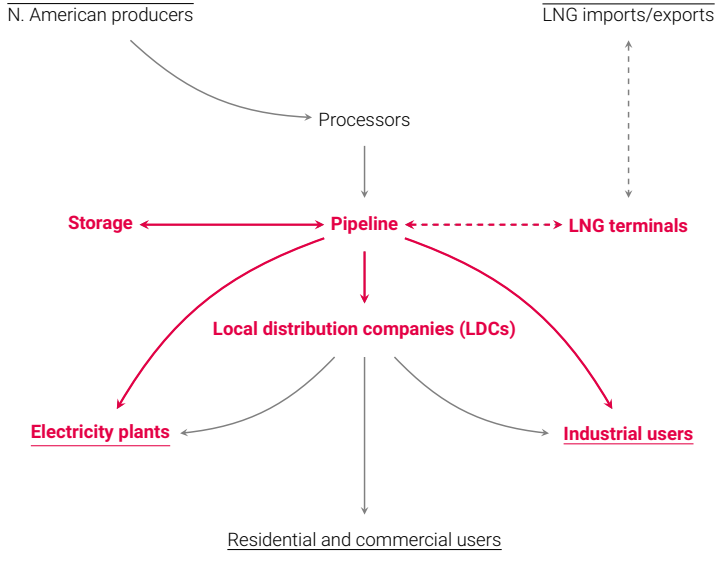

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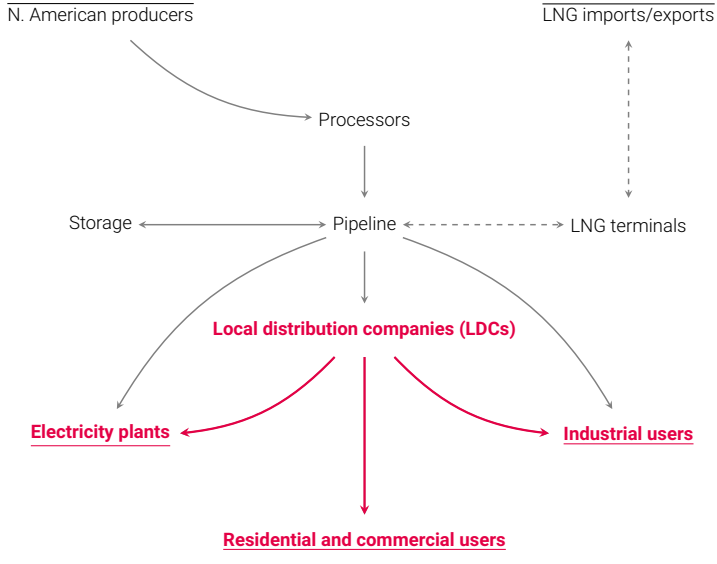

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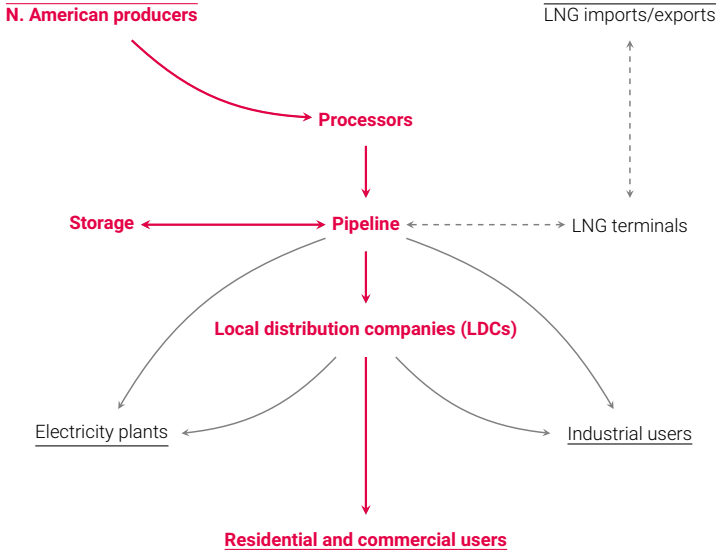

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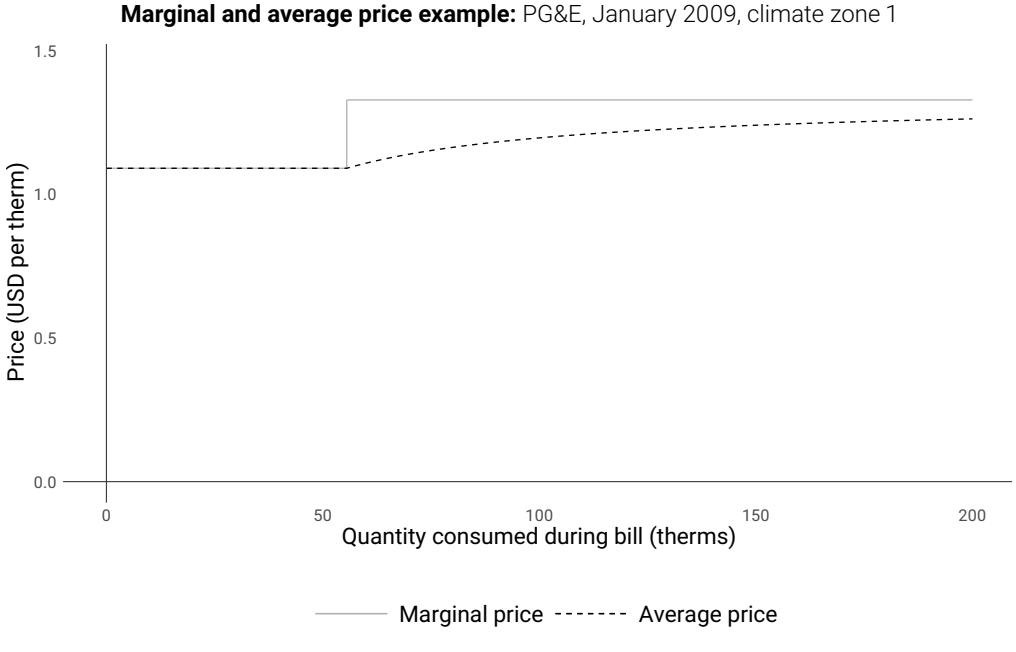
Institutional context

Residential natural gas in California

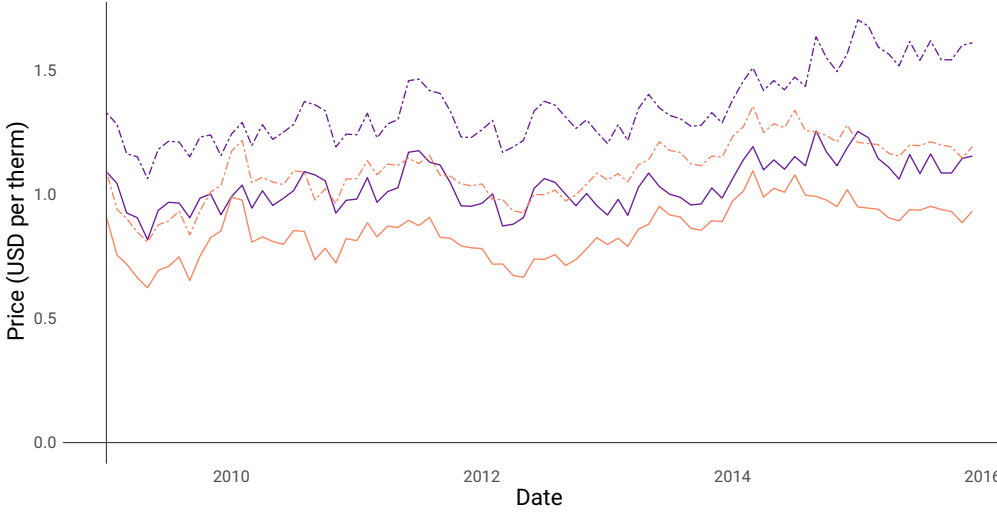
For PG&E's and SoCalGas's residential consumers, a bill depends upon six variables

1. The household's **utility** (LDC)
2. The **tiered price regime** set by the utility and CPUC
3. The total **volume** of natural gas consumed during the bill period
4. The **season** in which the bill occurs (*i.e.*, "winter" or "summer")
5. The **climate zone** of the household's physical location
6. The household's **CARE status** (California Alternate Rates for Energy)

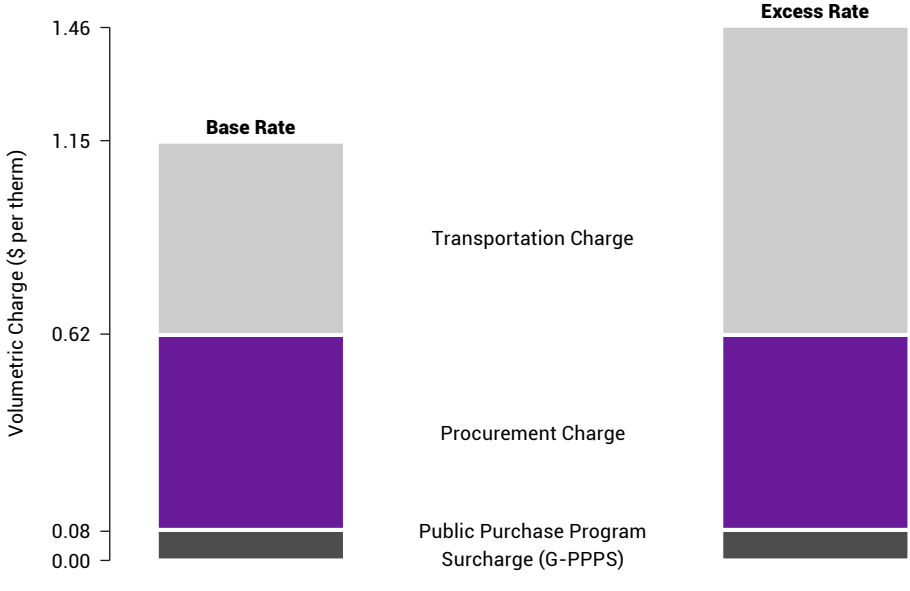
In pictures...

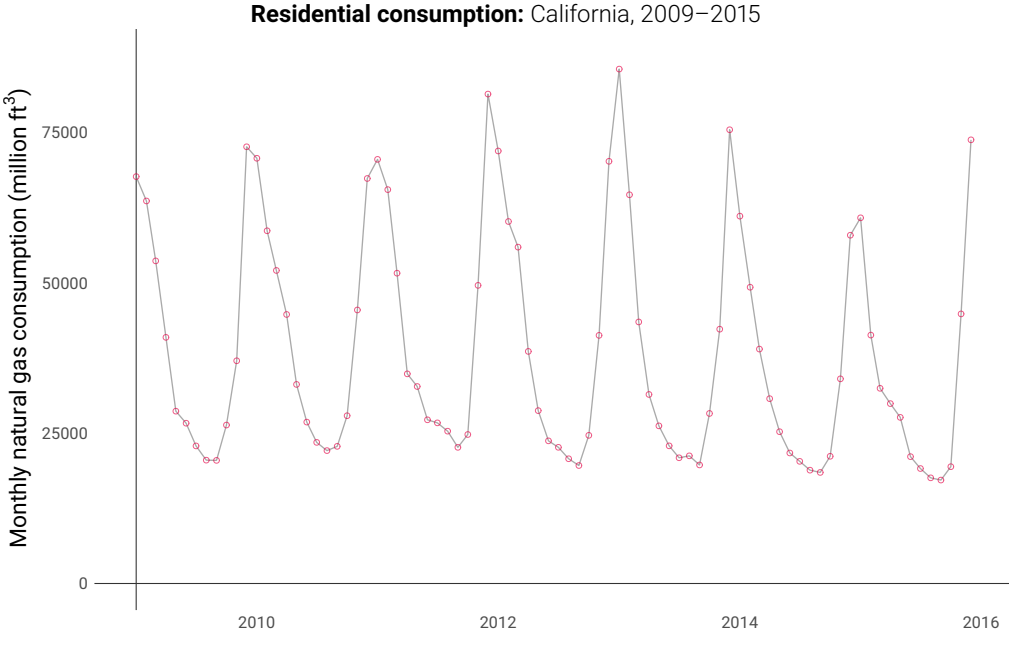

Marginal and average price example: PG&E, January 2009, climate zone 1
1.5
1.0
0.5
0.0
Price (USD per therm)
0
50
100
150
200
Quantity consumed during bill (therms)
Marginal price
Average price

Price regimes over time: PG&E and SoCalGas, 2009–2015



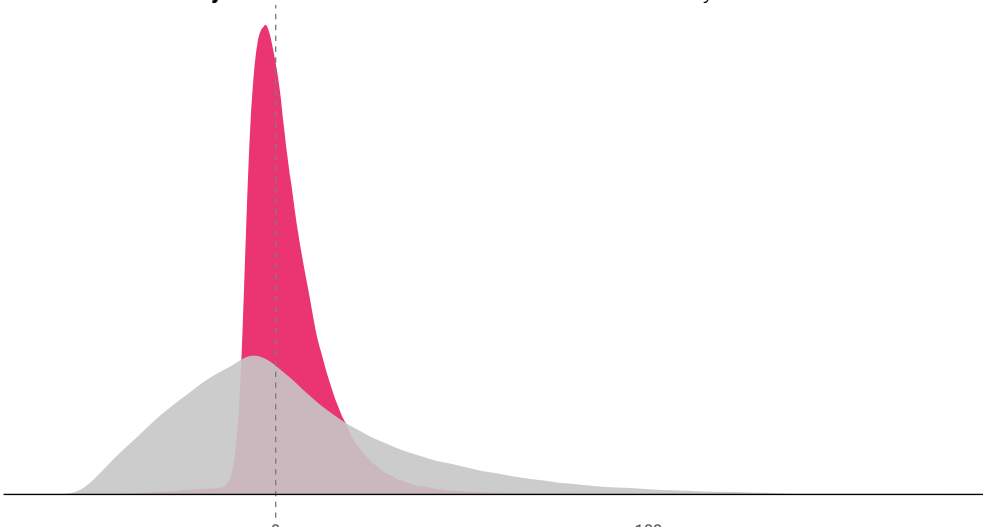
Decomposing residential rates: PG&E in a single month




Residential consumption: California, 2009–2015
Monthly natural gas consumption (million ft^3)
75000
50000
25000
0
2010
2012
2014
2016

Daily tier-one allowances over time: PG&E and SoCalGas, one climate zone each, 2009–2015

Density of bills' distances from first-tier allowance by season



California's 16 CEC climate zones: determine daily allowance within season

Source: California Energy Commission

ENERGY STATEMENT

www.pge.com/MyEnergy

Account No:
Statement Date: 11/14/2017
Due Date: 12/05/2017

Details of Gas Charges

10/07/2017 - 11/06/2017 (31 billing days)

Service For:
Service Agreement ID:
Rate Schedule: G1 X Residential Service

10/07/2017 – 10/31/2017	**Your Tier Usage**	1	**2**

Tier 1 Allowance	14.75 Therms (25 days x 0.59 Therms/day)	
Tier 1 Usage	14.750000 Therms @ $1.20062	$17.71
Tier 2 Usage	19.120970 Therms @ $1.73201	33.12
Gas PPP Surcharge ($0.09589 /Therm)		3.25

11/01/2017 – 11/06/2017	**Your Tier Usage**	1	2

Tier 1 Allowance	11.88 Therms (6 days x 1.98 Therms/day)	
Tier 1 Usage	8.129030 Therms @ $1.22746	$9.98
Gas PPP Surcharge ($0.09589 /Therm)		0.78

Total Gas Charges **$64.84**

Service Information

Meter #	
Current Meter Reading	547
Prior Meter Reading	507
Difference	40
Multiplier	1.047851
Total Usage	42.000000 Therms
Baseline Territory	X
Serial	M

Gas Procurement Costs ($/Therm)

10/07/2017 - 10/31/2017	$0.31496
11/01/2017 - 11/06/2017	$0.34180

Data

Data

Overview

The main datasets in this paper come from 275M+ household bills (all in California).

	Full dataset		Border-area dataset	
	PG&E	**SoCalGas**	**PG&E**	**SoCalGas**
N. 5-digit zip codes	597	611	18	18
N. unique households	5,888,276	2,526,503	152,418	68,407
N. bills	180,663,705	95,335,393	3,401,947	2,352,141
Approx. value (USD)	$5.71B	$3.28B	$120M	$70.5M

Household information: Zip code, climate zone, CARE participation

Bill information: Dates, quantity, revenue

Full dataset: All PG&E and SoCalGas bills in the data.

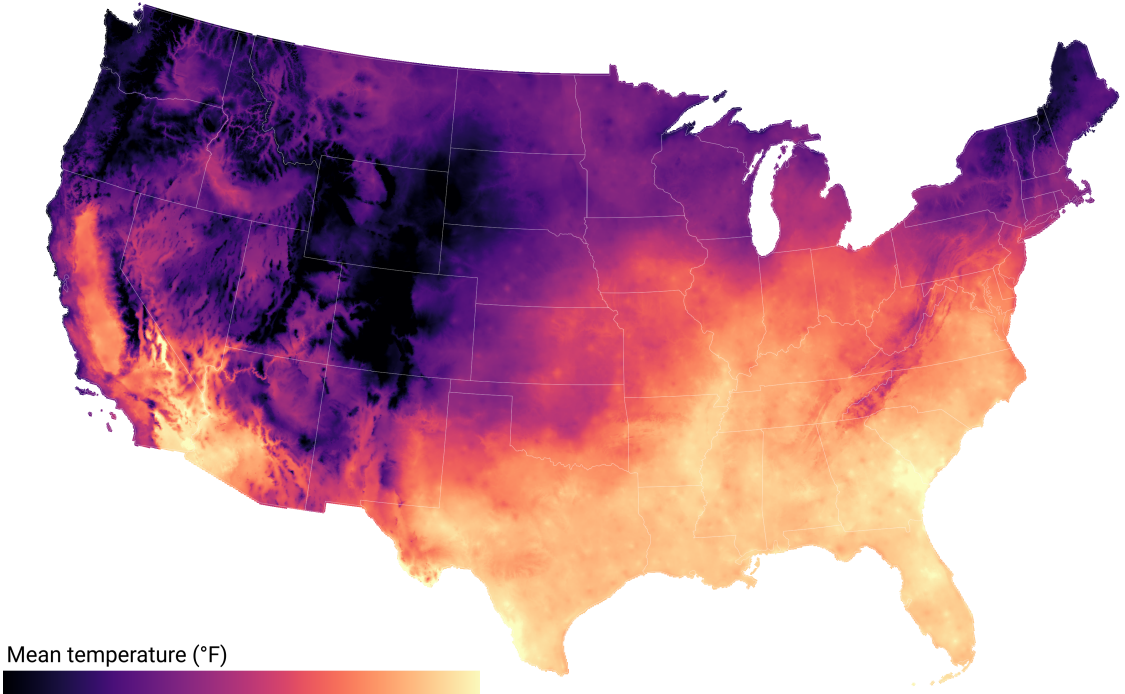
Border-area dataset: HHs in the 18 5-digit zip codes served by both utilities.

Data

Summary of border-area dataset

		Split by season		Split by CARE	
	Overall	Winter	Summer	CARE	Non-Care
Baseline price	0.9026	0.8836	0.9204	0.8080	0.9811
Excess price	1.1690	1.1477	1.1891	1.0445	1.2725
Average price	1.0211	1.0008	1.0402	0.9086	1.1147
Marginal price	1.0387	1.0121	1.0637	0.9338	1.1259
Total bill	34.9508	52.0750	18.8573	30.3135	38.8040
Therms	33.8273	50.9544	17.7311	33.1136	34.4204
Exceeded allowance	50.01%	45.93%	53.85%	51.82%	48.51%
Days	30.3994	30.5876	30.2225	30.4040	30.3955
Within-bill HDDs	0.9398	1.7136	0.2126	0.9291	0.9488
(Percent) CARE	45.38%	45.00%	45.74%	100%	0%

Notes: Means of the variables. Summaries based upon the study area. More...



Sources: NOAA and authors

Empirical strategy

Empirical strategy

Price elasticity of demand

Estimating an elasticity:

$$\log(q_{i,t}) = \eta \log(p_{i,t}) + \gamma_i + \delta_t + \lambda_{g(i),t} + \varepsilon_{i,t}$$

where i and t index household and time; $g(i)$ denotes i's geography (city or zip); q denotes quantity consumed; and p denotes price.

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OLS estimates of η in this equation suffer from two sources of bias/endogeneity:

1. **Simultaneity:** Price and quantity result from the equilibrium of a system of equations.
2. **"Reverse causality":** Two-tiered pricing regime means price is a function of quantity.

Empirical strategy

OLS "elasticity" results

	Dependent variable: Log(Consumption, daily avg.)					
	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)	(**6**)
Log(Marginal price)	0.7306***	0.4346***	0.4276***			
	(0.0062)	(0.0136)	(0.0134)			
Log(Baseline price)				0.0526***	–0.0918***	–0.1009***
				(0.0051)	(0.0201)	(0.0209)
Bill HDDs	T	T	T	T	T	T
Household FE	T	T	T	T	T	T
Month-of-sample FE	F	T	F	F	T	F
City by month-of-sample FE	T	F	T	T	F	T
Sample	Full CA	Border	Border	Full CA	Border	Border
N	621,935,402	5,754,088	5,754,088	621,935,402	5,754,088	5,754,088

Notes: Each column denotes a separate regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). Each price in the table is the second lag of price, *i.e.*, the prices from two bills prior to the current bill. *Significance levels:* *10%, **5%, ***1%.

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Household FE	T	T	T	T	T	T
Month-of-sample FE	F	T	F	F	T	F
City by month-of-sample FE	T	F	T	T	F	T
Sample	Full CA	Border	Border	Full CA	Border	Border
N	621,935,402	5,754,088	5,754,088	621,935,402	5,754,088	5,754,088

Notes: Each column denotes a separate regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). Each price in the table is the second lag of price, *i.e.*, the prices from two bills prior to the current bill. *Significance levels:* *10%, **5%, ***1%.

Empirical strategy

OLS "elasticity" results

	Dependent variable: Log(Consumption, daily avg.)					
	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)	(**6**)
Log(Marginal price)	0.7306***	0.4346***	0.4276***			
	(0.0062)	(0.0136)	(0.0134)			
Log(Baseline price)				0.0526***	−0.0918***	−0.1009***
				(0.0051)	(0.0201)	(0.0209)
Bill HDDs	T	T	T	T	T	T
Household FE	T	T	T	T	T	T
Month-of-sample FE	F	T	F	F	T	F
City by month-of-sample FE	T	F	T	T	F	T
Sample	Full CA	Border	Border	Full CA	Border	Border
N	621,935,402	5,754,088	5,754,088	621,935,402	5,754,088	5,754,088

Notes: Each column denotes a separate regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). Each price in the table is the second lag of price, *i.e.*, the prices from two bills prior to the current bill. *Significance levels:* *10%, **5%, ***1%.

Empirical strategy

Potential solutions

To break the potential sources endogeneity, we employ a multi-part strategy:

1. **Border discontinuity**
2. **Supply-shifting instrument**

Robustness: **Baseline price** or **simulated instruments**

Empirical strategy

Border discontinuity

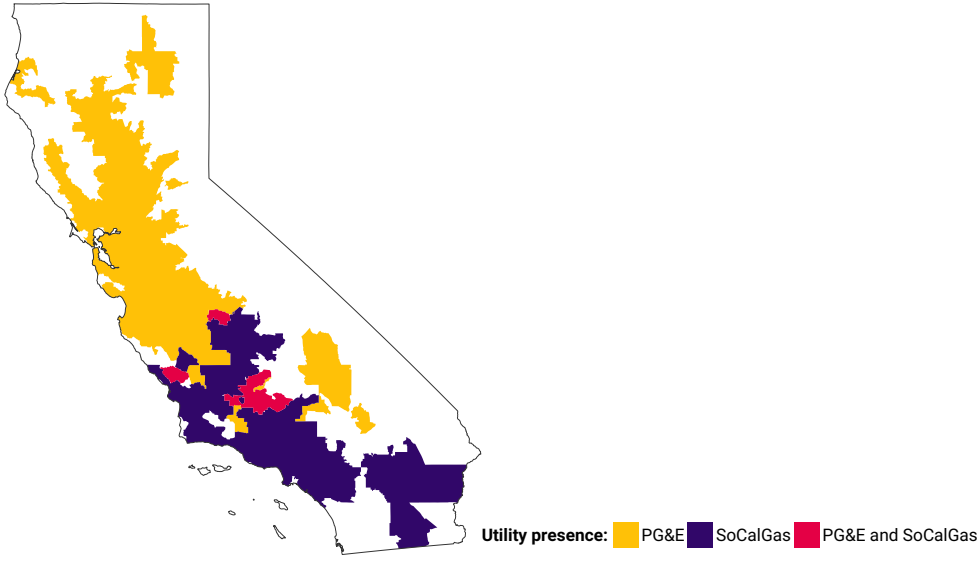
Discontinuity: The border between PG&E and SoCalGas bisects 11 cities (39 zip codes) in southern California (akin to Ito, 2014).

Motivation: Represents edge of long-established underground networks of pipes.

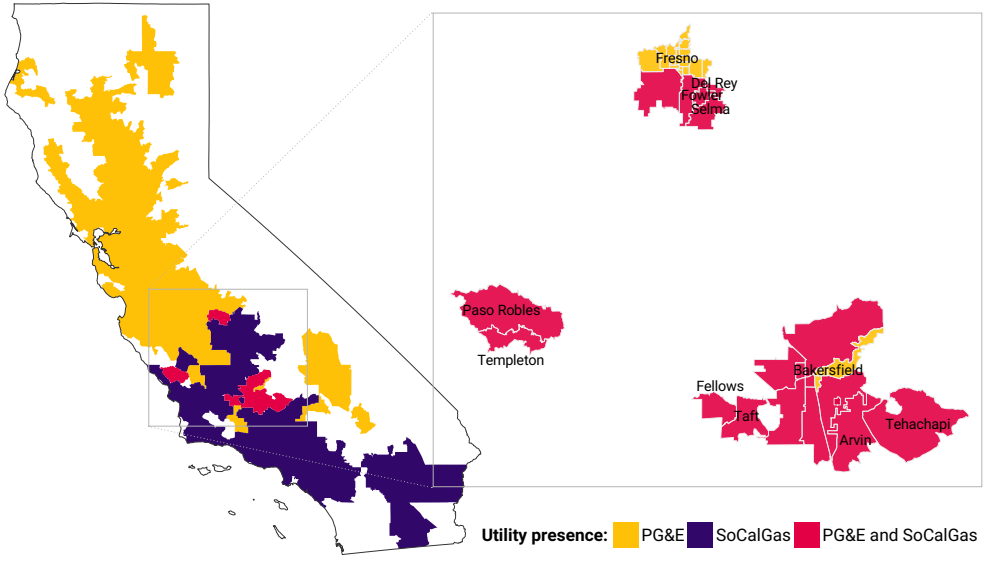
Identification: If the boundary is orthogonal to consumers' preferences, then we can identify off of the within-city differences in prices and consumption across this discontinuity (*i.e.*, one side controls for the other).

Common concern: Sorting.

Study-area discontinuity: Zip codes in cities served by both utilities



Study-area discontinuity: Zip codes in cities served by both utilities



Supply-shifting instrument

Henry Hub spot-price instrument

Instrument: Avg. spot price at Louisiana's Henry Hub in the week preceding price changes, interacted with utility.

Motivation: Reflects national price of natural gas: utilities purchase gas from a nationally integrated market. Utilities are rate-of-return earners.

Identification: Valid instrument if

1. Spot prices predict residential prices, and
2. Spot prices are uncorrelated with demand shocks, after controlling for within-bill HDDs and city by month-of-sample fixed effects.

Empirical strategy

Henry Hub spot-price instrument

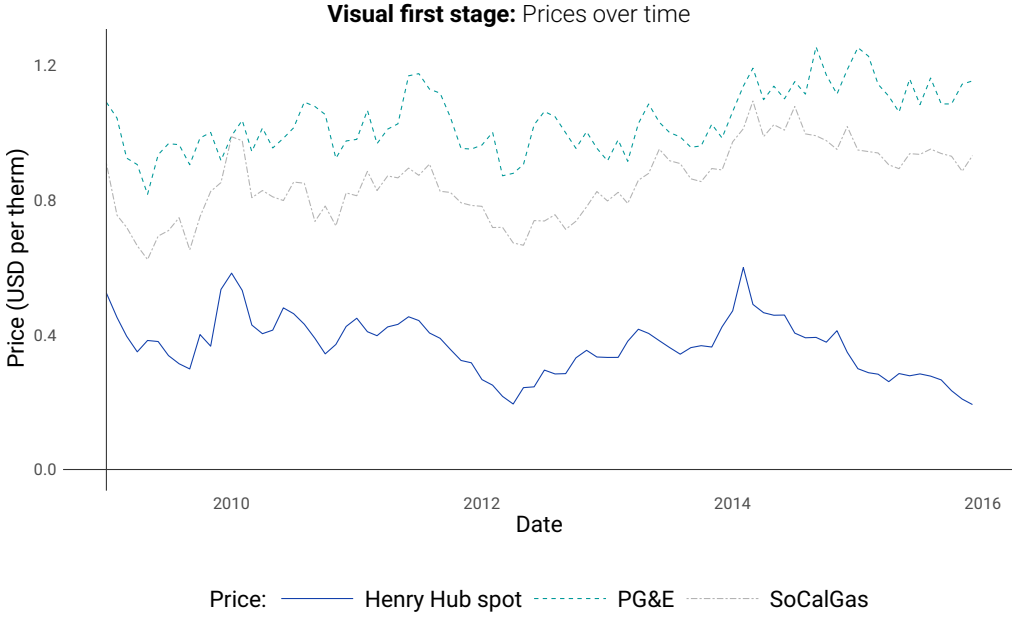
The first- and second-stages for this IV strategy:

$$\log(p_{i,t}) = \pi_{1a} p_{i,t}^{\text{spot}} + \pi_{1b} p_{i,t}^{\text{spot}} \times \text{SCG}_i + \pi_2 \text{HDD}_{i,t}^{\text{bill}} + \text{HH}_i + \text{City}_{i,t} + u_{i,t}$$

$$\log(q_{i,t}) = \eta_1 \widehat{\log(p_{i,t})} + \eta_2 \text{HDD}_{i,t}^{\text{bill}} + \text{HH}_i + \text{City}_{i,t} + v_{i,t}$$

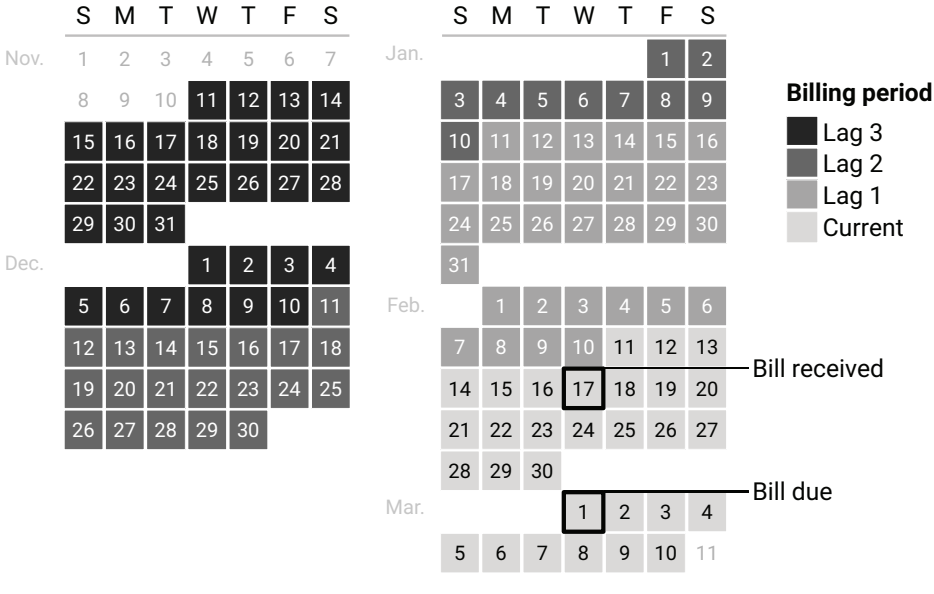
where

$p_{i,t}$	household i's price in period t
$p_{i,t}^{\text{spot}}$	the spot price in the weeks preceding i's utility setting $p_{i,t}$
SCG_i	indicator for whether household i's utility is SoCalGas
$\text{HDD}_{i,t}^{\text{bill}}$	number of HDDs during household i's bill in time period t
HH_i	fixed effect for household i
$\text{City}_{i,t}$	fixed effect for i's city in month-of-sample t
$q_{i,t}$	household i's average daily consumption during their bill in t


Visual first stage: Prices over time
1.2
0.8
0.4
0.0
Price (USD per therm)
2010
2012
2014
2016
Date
Price:
Henry Hub spot
PG&E
SoCalGas

Which bill?

Billing cycle example



Elasticity results

Elasticity results

Two-stage least squares

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

Notes: Each column denotes a separate 2SLS regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%.

Robustness. Simulated IV results. Heterogeneity results.

Elasticity results

Two-stage least squares

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Robustness. Simulated IV results. Heterogeneity results.

What about lags?

Comparing lags: Second-stage results

Marginal price with Henry Hub spot price IV

Dependent variable: Log(Consumption, daily avg.)					
	Lag of Marginal Price				
	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
	1 Lead	No lag	1 Lag	2 Lags	3 Lags
Log(Mrg. Price)	0.0480	–0.1121	–0.0223	–0.2098***	–0.1582**
instrumented	(0.0902)	(0.0762)	(0.0668)	(0.0706)	(0.0698)
First-stage F stat.	326.7	337.9	410.8	418.4	403.4
Bill HDDs	T	T	T	T	T
Household FE	T	T	T	T	T
City month-of-sample FE	T	T	T	T	T
N	5,501,467	5,754,088	5,754,088	5,754,085	5,754,079

Notes: Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%.

Comparing lags: Second-stage results

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Household FE	T	T	T	T	T
City month-of-sample FE	T	T	T	T	T
N	5,501,467	5,754,088	5,754,088	5,754,085	5,754,079

Notes: Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%.

Comparing lags: Second-stage results

Marginal price with Henry Hub spot price IV

Dependent variable: Log(Consumption, daily avg.)

	Lag of Marginal Price				
	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
	1 Lead	No lag	1 Lag	2 Lags	3 Lags
Log(Mrg. Price)	0.0480	–0.1121	–0.0223	–0.2098***	–0.1582**
instrumented	(0.0902)	(0.0762)	(0.0668)	(0.0706)	(0.0698)
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What about heterogeneity?

Heterogeneity by season or income

Second-stage results: Marginal price with Henry Hub spot price IV

Dependent variable: Log(Consumption, daily avg.)

	Split by **Season**		Split by **CARE (Income)**	
	(**1**)	(**2**)	(**3**)	(**4**)
	Summer	Winter	CARE	Non-CARE
Log(Mrg. Price)	0.0519*	−0.3769***	−0.2443***	−0.1413**
instrumented	(0.0285)	(0.1399)	(0.0794)	(0.0684)
First-stage F stat.	319.6	174.2	393.7	335.8
Bill HDDs	T	T	T	T
Household FE	T	T	T	T
City month-of-sample FE	T	T	T	T
N	3,065,917	2,688,168	2,435,135	3,318,950

Notes: Each column denotes a separate regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%.

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Heterogeneity by income and season

Second-stage results: Marginal price with Henry Hub spot price IV

Dependent variable: Log(Consumption, daily avg.)

	(**1**)	(**2**)	(**3**)	(**4**)
	Summer	Summer	Winter	Winter
	CARE	Non-CARE	CARE	Non-CARE
Log(Mrg. 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

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Discussion

Utilizing elasticity heterogeneity

Motivating observation: Utilities, public utility commissions, and local governments add fees and taxes to bills throughout the year.

In California, most of these fees and taxes are volumetric.

Discussion

Utilizing elasticity heterogeneity

Policy implication: By shifting fees and taxes to the less elastic times of the year (*i.e.*, the summer), utilities and governments can decrease the dead-weight losses associated with these charges (**increased efficiency**).

Further, because CARE households are substantially more elastic in the winter, this shift is **potentially progressive**.

Two nuances:

- Relevant for **all fees** (volumetric and fixed) if consumers respond to avg. price/total bill.
- Implications vary if there are **unpriced costs** to natural gas consumption (*e.g.*, GHGs).

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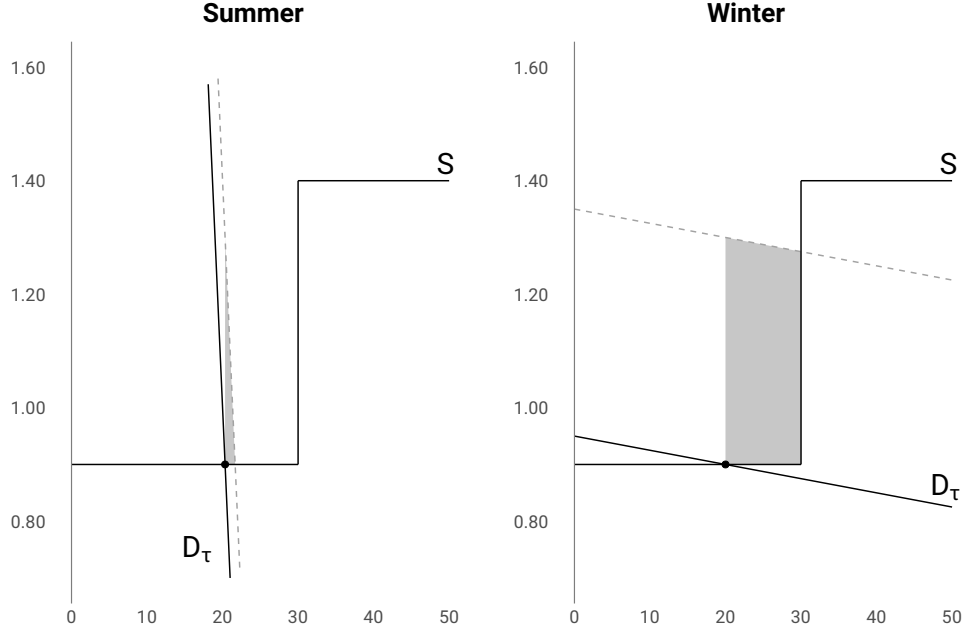
Summer
Winter
1.60
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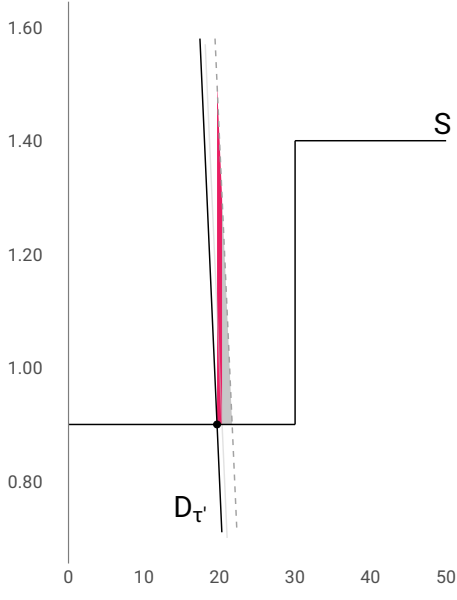
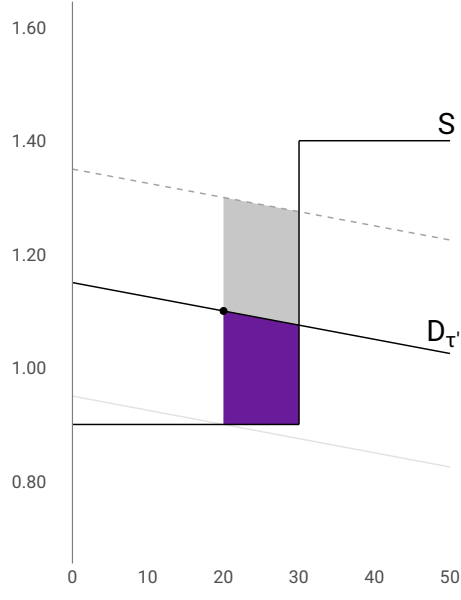
Summer: ↑ tax by \$0.20 ⇒ ↑ DWL



Winter: ↓ tax by \$0.20 ⇒ ↓ DWL



Conclusion

"Pooled" results: Through a variety of specifications, our point estimates for the "pooled" price elasticity of demand for residential natural gas range from –0.23 to –0.17.

Heterogeneity: However, we find significant evidence of heterogeneity within this elasticity—both with respect to season and with respect to income.

Implications: Taking this heterogeneity into account offers

1. Empirical insights into heterogeneity underlying more standard "pooled" elasticities, and
2. Unexplored avenues for potentially more efficient and progressive policies.

'Big data' insights: Size ($N > 600$M) does not guarantee identification. N allows (**1**) flexibility for identification and (**2**) power for policy-relevant heterogeneity.

Thank you!

Ed Rubin
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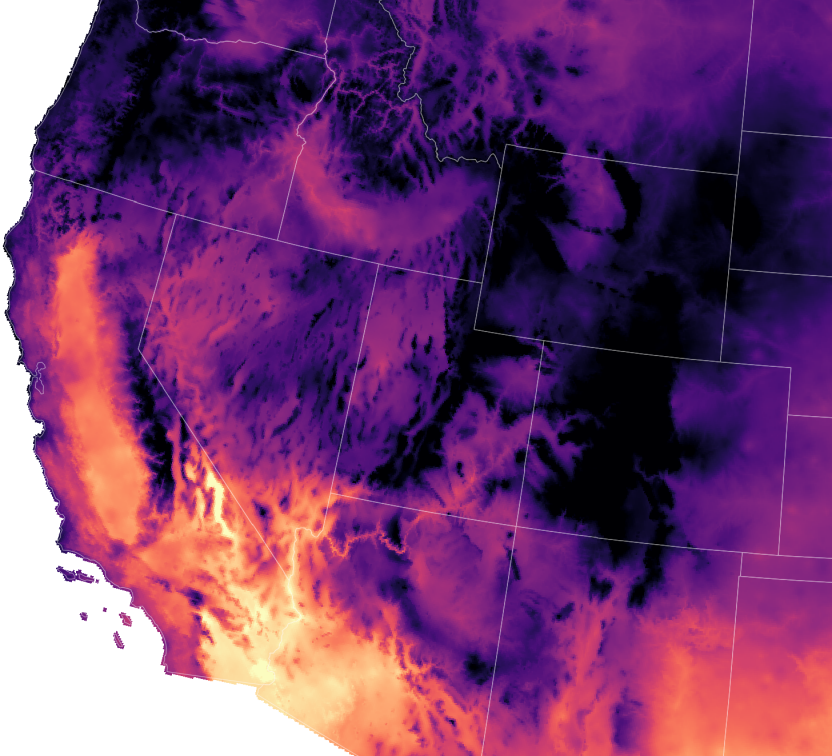

Ongoing projects

- → Health effects of lead exposure through pipes and consumers' attention to environmental risks
- → Experimental evidence on the role of consumers in marketplace discrimination
- → The (heterogeneous) effects of recreational cannabis dispensaries on neighborhood crime
- → Prisons: Deaths, conditions, temperature shocks, and incentives
  Related: (Machine) learning about commercial AC from satellites

New projects

- → Revisiting travel-cost valuation of non-market amenities using high-resolution phone data
- → Political economy of resource protection: Deforestation and fishing in Indonesia
- → Short- and long-run effects of discriminatory institutions: Slavery and the Confederacy
- → Indoor air quality, health, and employment in the developing world

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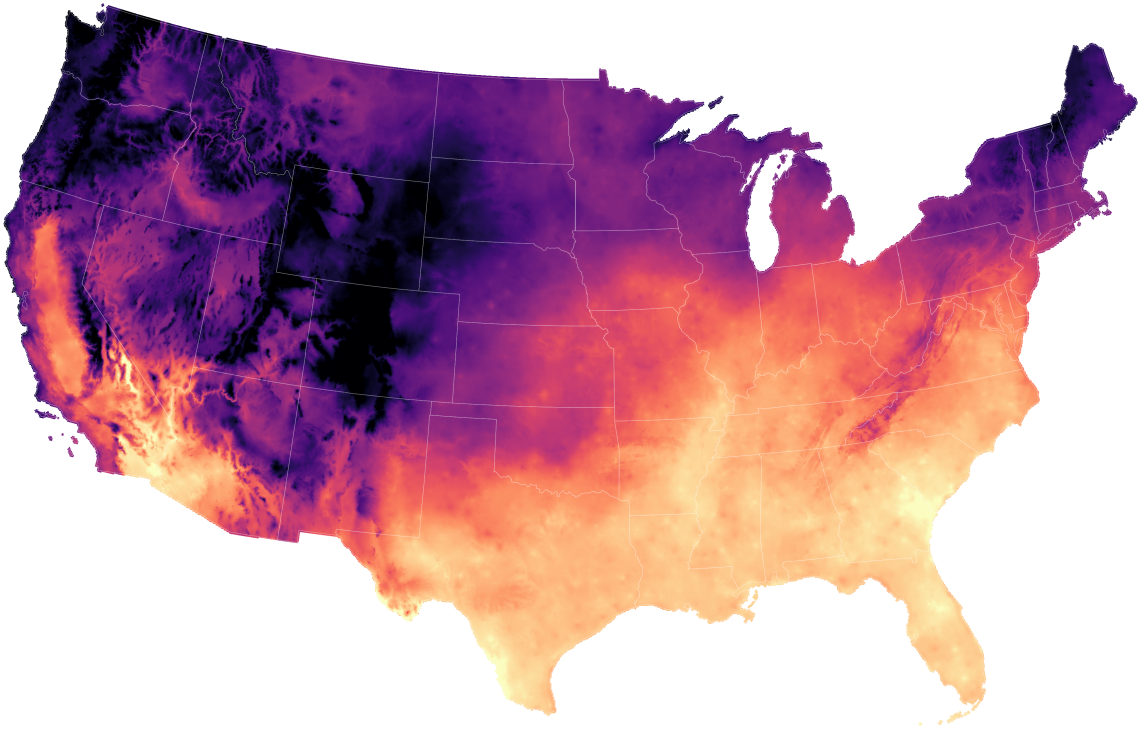

Robustness: Specification

Robustness to specification

Second-stage results: Marginal price with Henry Hub spot price IV

Dependent variable: Log(Consumption, daily avg.)

	(**1**)	(**2**)	(**3**)	(**4**)
Log(Marginal price) *instrumented*	–0.3623*** (0.0854)	–0.2098*** (0.0706)	–0.1705*** (0.0621)	–0.1495** (0.063)
First-stage F stat.	416.1	418.4	415.2	367.0
Bill HDDs	F	T	T	T
Household FE	T	T	T	T
City by month-of-sample FE	T	T	F	F
City by week-of-sample FE	F	F	T	F
Zip by week-of-sample FE	F	F	F	T
N	5,754,085	5,754,085	5,754,085	5,754,085

Notes: Each column denotes a separate regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%. Back.

Robustness: Simulated instruments

Empirical strategy

Remedies to reverse causality

Options to break the price-as-a-function-of-quantity endogeneity (*reverse causality*):

1. **Baseline price**
2. **Simulated instruments**
3. **Other instruments**

Empirical strategy

Remedies to reverse causality

Options to break the price-as-a-function-of-quantity endogeneity (*reverse causality*):

1. **Baseline price**
   - **Definition:** The price on a household's first unit of gas (first-tier price).
   - ***Pro:*** Baseline prices are good proxies for marginal prices—tiers often move in parallel.
   - ***Con:*** Does not capture multi-tiered price structure.
2. **Simulated instruments**
3. **Other instruments**

Empirical strategy

Remedies to reverse causality

Options to break the price-as-a-function-of-quantity endogeneity (*reverse causality*):

1. **Baseline price**
2. **Simulated instruments**
   - **Definition:** Value(s) of lagged consumption plugged into the current price regime. Provides an instrument if prior consumption predicts current consumption.
   - ***Pro:*** Matches multi-tiered price structure.
   - ***Con:*** Can introduce more noise.
3. **Other instruments**

Empirical strategy

Remedies to reverse causality

Options to break the price-as-a-function-of-quantity endogeneity (*reverse causality*):

1. **Baseline price**
2. **Simulated instruments**
3. **Other instruments**
   - ***Pro:*** Instrumenting price with any valid instrument (*e.g.*, spot price) will purge the endogeneity.
   - ***Con:*** Does not capture multi-tiered price structure.

Empirical strategy

Simulated instruments

Definition: Instrument current price with value(s) of lagged consumption plugged into the current price regime, *i.e.*,

$$z_{i,t} = p_{i,t}\left(q_{t-k}\right)$$

Pro: Matches multi-tiered price structure and removes mechanical price-quantity link.
Con: Can introduce more noise.

Empirical strategy

Simulated instruments

Building the instrument:

We use quantity lags 10–14 to "vote" whether the household is on the first or second tier, *i.e.*,

$$v_{i,t} = \frac{1}{5} \sum_{k=10}^{14} \mathbb{1}\left\{q_{i,t-k} > \bar{A}_{i,t}\right\}$$

where $\bar{A}_{it}$ is household i's baseline allowance in time t.

The actual instrument:

$$z_{i,t} = \mathbb{1}\left\{v_{i,t} \leq 0.5\right\} \times p_{i,t}^{\text{base}} + \mathbb{1}\left\{v_{i,t} > 0.5\right\} \times p_{i,t}^{\text{excess}}$$

Testing the simulated instrument

Regressing marginal price on *simulated* marginal price

Dependent variable: Marginal price		
	(**1**)	(**2**)
Simulated marginal price	0.6425***	0.6444***
	(0.00435)	(0.00433)
Bill HDDs	T	T
Household FE	T	T
City month-of-sample FE	T	T
Lags used for sim. inst.	10–14	11–13
N	4,892,064	4,785,877

Notes: Each column denotes a separate regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). The numbers of observations differ due to the lags required to calculate the *simulated instrument* for marginal price. *Significance levels:* *10%, **5%, ***1%.

Price correlations...

Elasticity results

Two-stage least squares

	Dependent variable: Log(Consumption, daily avg.)				
Panel A: First stage	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
Type of price:	Marginal	Average	Avg. Mrg.	Baseline	Sim. Mrg.
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					
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

Notes: Each column denotes a separate 2SLS regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%. Main results. Robustness.

Elasticity results

Two-stage least squares

Dependent variable: Log(Consumption, daily avg.)

Panel A: First stage	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
Type of price:	Marginal	Average	Avg. Mrg.	Baseline	Sim. Mrg.
Spot price	0.3679***	0.3697***	0.3384***	0.4699***	0.3949***
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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

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Elasticity results

Two-stage least squares

Dependent variable: Log(Consumption, daily avg.)

Panel A: First stage	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
Type of price:	Marginal	Average	Avg. Mrg.	Baseline	Sim. Mrg.
Spot price	0.3679***	0.3697***	0.3384***	0.4699***	0.3949***
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N	5,754,085	5,754,085	5,754,085	5,754,085	4,682,526

Notes: Each column denotes a separate 2SLS regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%. Main results. Robustness.

Elasticity results

Two-stage least squares

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Panel A: First stage	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
Type of price:	Marginal	Average	Avg. Mrg.	Baseline	Sim. Mrg.
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Elasticity results

Two-stage least squares

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Type of price:	Marginal	Average	Avg. Mrg.	Baseline	Sim. Mrg.
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Elasticity results

Two-stage least squares

Dependent variable: Log(Consumption, daily avg.)

Panel A: First stage	(**1**)	(**2**)	(**3**)	(**4**)	(**5**)
Type of price:	Marginal	Average	Avg. Mrg.	Baseline	Sim. Mrg.
Spot price	0.3679***	0.3697***	0.3384***	0.4699***	0.3949***
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Elasticity results

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Elasticity results

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Elasticity results

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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

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Elasticity results

Two-stage least squares

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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

Notes: Each column denotes a separate 2SLS regression. Errors are two-way clustered within (1) household and (2) utility by climate-zone by billing-cycle (the level at which price varies). *Significance levels:* *10%, **5%, ***1%. Main results. Robustness.

Appendix

		Split by season		Split by CARE	
	Overall	Winter	Summer	CARE	Non-Care
Baseline price	0.9026 [0.1419]	0.8836 [0.1361]	0.9204 [0.1448]	0.8080 [0.0854]	0.9811 [0.1311]
Excess price	1.1690 [0.1742]	1.1477 [0.1708]	1.1891 [0.1751]	1.0445 [0.1009]	1.2725 [0.1534]
Average price	1.0211 [0.1621]	1.0008 [0.1583]	1.0402 [0.1633]	0.9086 [0.1004]	1.1147 [0.1430]
Marginal price	1.0387 [0.1983]	1.0121 [0.1905]	1.0637 [0.2021]	0.9338 [0.1448]	1.1259 [0.1944]

Notes: Unbracketed values provide the means of the variables; bracketed values denote the variables' standard deviations. Summaries based upon the study area. Back to data or map.

	5% Sample of California			Border-discontinuity sample				
		Split by utility			Split by season		Split by CARE	
Variable	**Overall**	PG&E	SoCalGas	**Overall**	Winter	Summer	CARE	Non-Care
Baseline price	0.8901 [0.1686]	0.9823 [0.1206]	0.7432 [0.1242]	0.9026 [0.1419]	0.8836 [0.1361]	0.9204 [0.1448]	0.8080 [0.0854]	0.9811 [0.1311]
Average price	1.0138 [0.1845]	1.1053 [0.1439]	0.8680 [0.1439]	1.0211 [0.1621]	1.0008 [0.1583]	1.0402 [0.1633]	0.9086 [0.1004]	1.1147 [0.1430]
Marginal price	1.0206 [0.2260]	1.1277 [0.186]	0.8500 [0.173]	1.0387 [0.1983]	1.0121 [0.1905]	1.0637 [0.2021]	0.9338 [0.1448]	1.1259 [0.1944]
Therms	35.4626 [33.7995]	37.7541 [36.0107]	31.8135 [29.5791]	33.8273 [30.7697]	50.9544 [35.2487]	17.7311 [11.5803]	33.1136 [28.7629]	34.4204 [32.3306]
Days	30.3992 [1.4275]	30.4282 [1.2667]	30.3530 [1.6505]	30.3994 [1.3038]	30.5876 [1.3843]	30.2225 [1.1966]	30.4040 [1.2761]	30.3955 [1.3263]
Total bill	36.8703 [39.5758]	42.3938 [44.0564]	28.0747 [29.0445]	34.9508 [33.8812]	52.0750 [39.8973]	18.8573 [14.0069]	30.3135 [27.2567]	38.8040 [38.1017]
(Percent) CARE	27.43%	26.35%	29.15%	45.38%	45.00%	45.74%	100%	0%

Notes: Unbracketed values provide the variables' means; bracketed values denote the variables' standard deviations. The *5% sample of California* is based upon 5% of PG&E's and SoCalGas's natural gas bills from 2010–2014, sampling at the 5-digit zip code. The *border-discontinuity sample* represents all bills from PG&E and SoCalGas for the 18 5-digit zip codes served by both utilities from 2010–2014. Back to data or map.

Balance on observables, Summer

	Non-CARE			CARE		
Variable	PG&E	SoCalGas	**Diff.**	PG&E	SoCalGas	**Diff.**
Therms consumed	17.61 [10.8]	17.29 [11.7]	0.32 [11.3]	19.35 [11.3]	18.00 [11.3]	1.34 [11.3]
Days in bill	30.31 [1.16]	29.97 [1.36]	0.34 [1.28]	30.29 [1.16]	29.96 [1.36]	0.33 [1.22]
Allowance	14.17 [0.805]	17.22 [8.05]	–3.05 [6.14]	14.14 [0.851]	17.11 [8.17]	–2.96 [4.33]
Total bill	21.58 [14.8]	16.45 [12.4]	5.14 [13.8]	19.03 [12.4]	13.52 [9.35]	5.51 [11.9]
HDDs *(thousands)*	0.16 [0.309]	0.25 [0.407]	–0.08 [0.367]	0.14 [0.267]	0.26 [0.418]	–0.12 [0.315]
N	810,949	961,824	1,772,773	973,063	320,082	1,293,145

Notes: Unbracketed values provide the variables' means; bracketed values denote the variables' standard deviations. The standard deviations below the difference column (*Diff.*) are pooled across utilities.

Balance on observables, Winter

	Non-CARE			CARE		
Variable	PG&E	SoCalGas	**Diff.**	PG&E	SoCalGas	**Diff.**
Therms consumed	51.40 [33.8]	54.07 [35.7]	–2.67 [34.8]	49.60 [31.1]	49.94 [33.1]	–0.34 [31.6]
Days in bill	30.55 [1.31]	30.78 [1.8]	–0.24 [1.59]	30.57 [1.31]	30.83 [1.81]	–0.26 [1.45]
Allowance	46.70 [12.8]	49.07 [10.7]	–2.37 [11.8]	47.16 [12.4]	49.68 [10.4]	–2.52 [12]
Total bill	59.79 [41.8]	50.60 [36.4]	9.19 [39.4]	45.35 [30.3]	36.51 [26.5]	8.84 [29.7]
HDDs *(thousands)*	1.69 [0.467]	1.73 [0.437]	–0.04 [0.452]	1.70 [0.439]	1.75 [0.422]	–0.05 [0.435]
N	746,140	800,037	1,546,177	871,795	270,198	1,141,993

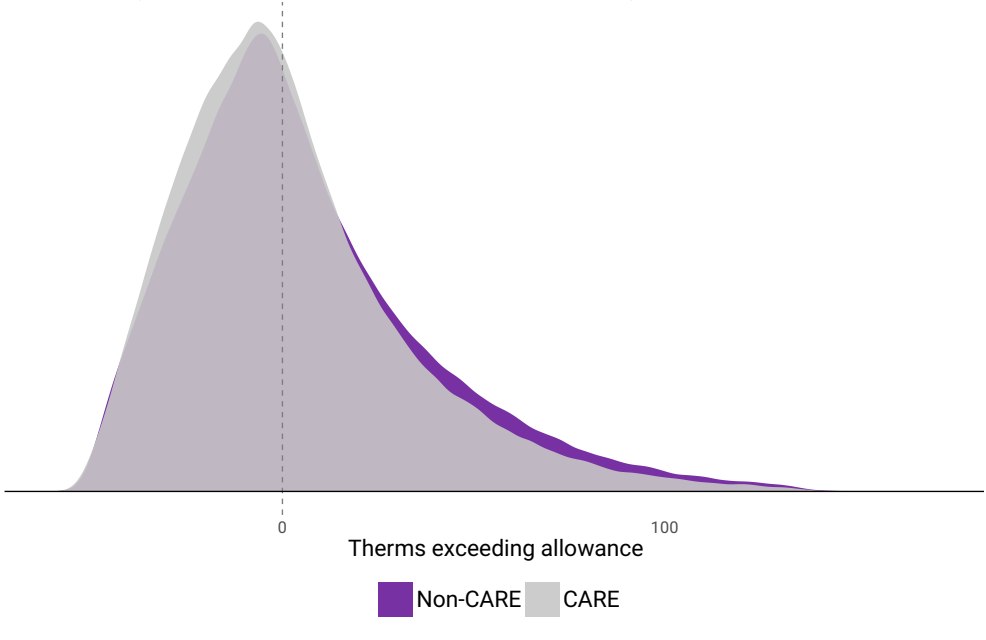
Notes: Unbracketed values provide the variables' means; bracketed values denote the variables' standard deviations. The standard deviations below the difference column (*Diff.*) are pooled across utilities.

Price correlation: Bivariate correlations between types of prices

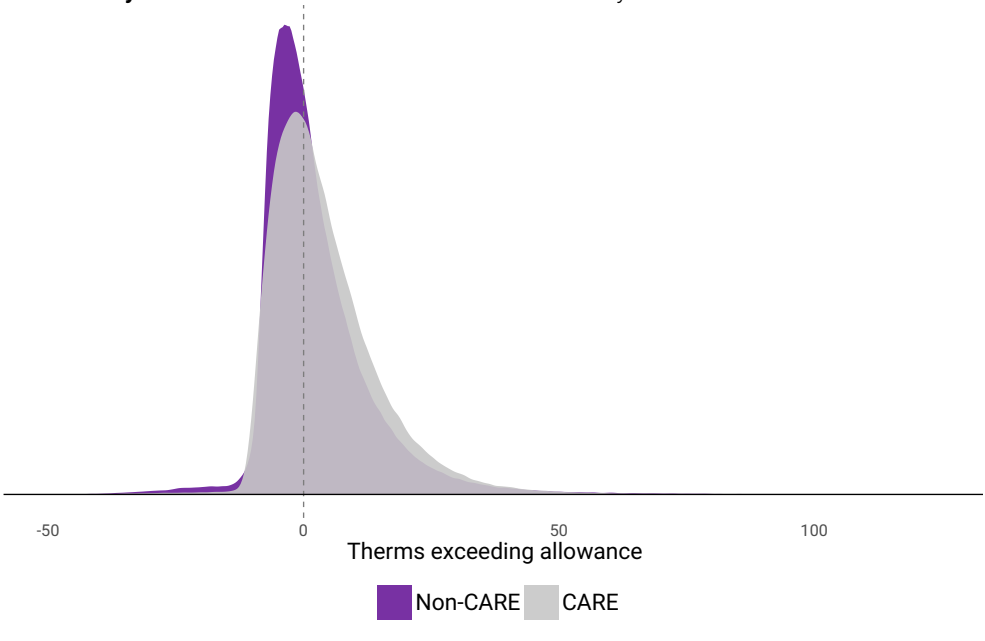
	Type of Price				
	Marginal	Average	Avg. Mrg.	Baseline	Sim. mrg.
Marginal	1				
Average	0.8898	1			
Avg. Mrg.	0.8628	0.9421	1		
Baseline	0.7901	0.942	0.9202	1	
Sim. mrg.	0.8503	0.849	0.8174	0.781	1

Notes: *Avg.* or *average* price is the total bill divided by quantity. *Avg. Mrg.* or *average marginal* price denotes the quantity-weighted average of the household's marginal price. *Base* or *baseline* price refers to the price the household pays for its first unit (*therm*) of natural gas. *Sim. Mrg.* or *simulated marginal* price is the household's marginal price (using the relevant pricing regime) as a function of the household's historical consumption patterns (lagged bills 10 through 14). Back

Density of bills' distances from first-tier allowance by CARE status in winter



Density of bills' distances from first-tier allowance by CARE status in summer



Institutional context

Decomposing residential rates: PG&E over time