

Do Consumers Respond to Marginal or Average Price?

Evidence from Nonlinear Electricity Pricing

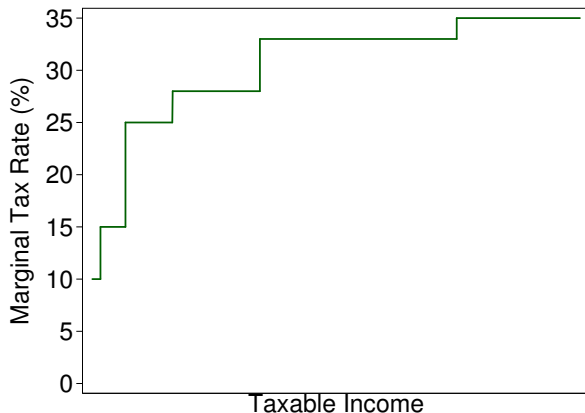
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Assistant Professor, Boston University School of Management (July 2013-)
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Nonlinear pricing is widely used in many important economic policies

- Example 1: Income taxation

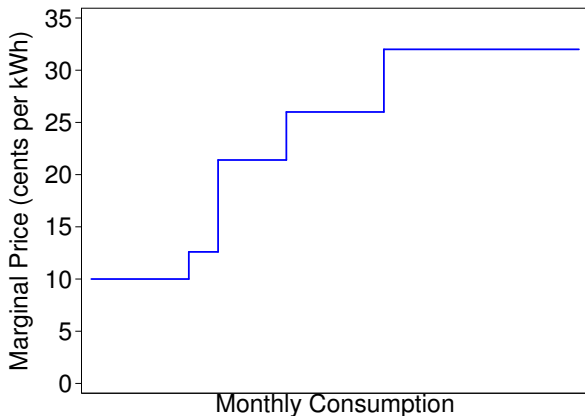
Marginal income tax rates (%) in 2010 in the US



Nonlinear pricing is widely used in many important economic policies

- Example 2: Electricity, cell phone, natural gas, and water pricing

Electricity prices (cents per kWh) in Southern California Edison in 2007



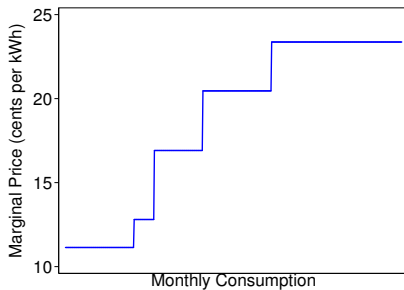
Research question: How do consumers respond to nonlinear price schedules?

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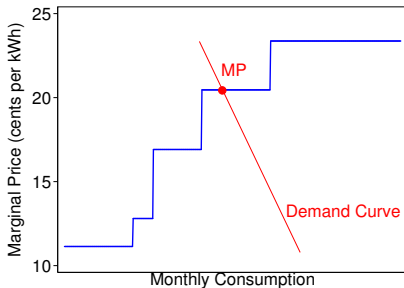


Research question: How do consumers respond to nonlinear price schedules?

- 1 Standard economic theory predicts:
 - Consumers respond to **Marginal Price**

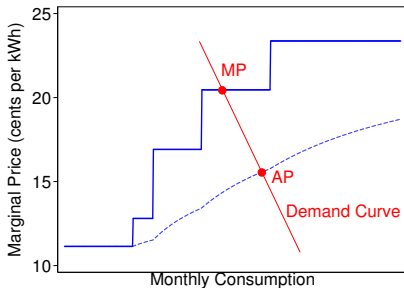
- 2

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Research question: How do consumers respond to nonlinear price schedules?

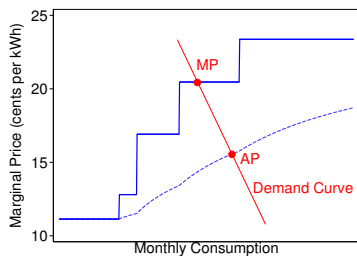
- 1 Standard economic theory predicts:
 - Consumers respond to **Marginal Price**
- 2 Laboratory experiments find:
 - Many individuals respond to **Average Price** = (Total payment / Quantity)



⇒ Standard theory and laboratory evidence provide different predictions

Why do we care about “Marginal price” vs. “Average price”?

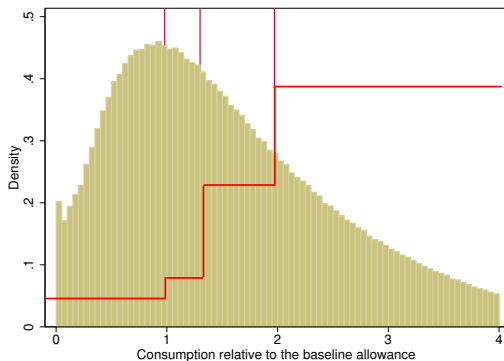
- It will change welfare implications of nonlinear taxation/pricing
 - “Schmeduling” by Liebman, Zeckhauser (2004)



- Existing literature analyzes welfare based on “marginal price response”
 - Optimal taxation (Mirrlees 1971)
 - Electricity pricing (Reiss and White 2005)
 - Water pricing (Olmstead, Hanemann, and Stavins 2007)

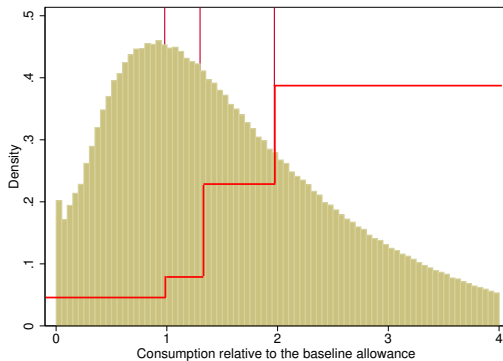
Why do we care about “Marginal price” vs. “Average price”?

- The mystery of “no bunching”
 - Bunching should be found if consumers/taxpayers respond to marginal price
 - Many studies find no bunching: Heckman (1982), Saez (1999, 2010)
 - Exception: Chetty, Friedman, Olsen, and Pistaferri (2011)



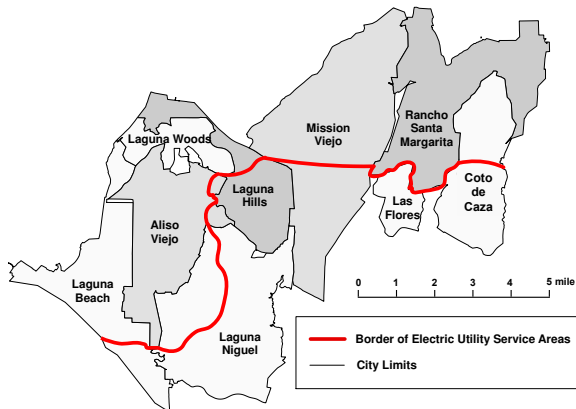
Why do we care about “Marginal price” vs. “Average price”?

- “No bunching” implies two possibilities:
 - Elasticity is nearly zero, or
 - Consumers respond to other perception of price rather than marginal price



I exploit a nearly ideal research environment in electricity markets in California

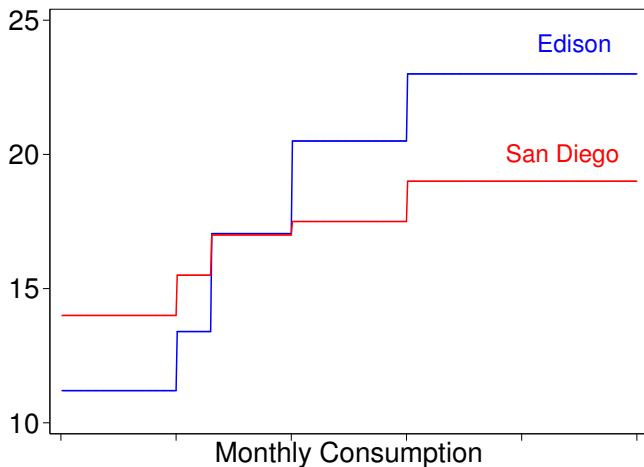
Edison (Southern California Edison) provides electricity for the north side



San Diego (San Diego Gas & Electric) provides electricity for the south side

Households experience substantially different nonlinear pricing

- Edison and San Diego: Cents per kWh in 2002



My research design addresses two challenges in previous studies

(1) Lack of clean counterfactual groups

- Comparable individuals usually face exactly the same tax/price schedule
- Difficult to find a clean control group \Rightarrow **Identification problems**
 - Noted by Heckman (1996), Goolsbee (2000)
- This study: **Nearly identical households experience different price schedules**

My research design addresses two challenges in previous studies

(2) Lack of sufficient exogenous price variation

- MP and AP are highly collinear in a typical nonlinear price schedule
- Multicollinearity problem \Rightarrow **Inconclusive results**
 - Liebman and Zeckhauser (2004), Borenstein (2009)
- This study: **Rich cross-sectional & time-series price variation**

My estimation results provide several key findings

- 1 Consumers respond to average price rather than marginal price
- 2 Consumers respond to lagged price rather than contemporaneous price
- 3 Short-run price elasticity wrt one-month lagged average price: - 0.14
- 4 This average price response changes welfare implications in two ways
 - It makes nonlinear pricing less successful in energy conservation
 - It changes the efficiency costs of nonlinear pricing

Average price response has key implications for energy and climate change policy

The cap-and-trade program proposed in 2009:

- 30% of permits will be given to electric utilities for free
- Concern: lowering electricity price may discourage conservation
- Existing proposal: distribute **a fixed credit to electricity bills**
- Rationale behind: a fixed credit does not change marginal price

However, if consumers respond to average price,

- The fixed credit may also discourage conservation because consumers see it as a price decline in average price (Burtraw 2009)

I begin with an overview of the research design

Road map

- 1 Introduction
- 2 **Research Design**
- 3 Estimation
- 4 Welfare Analysis
- 5 Conclusion

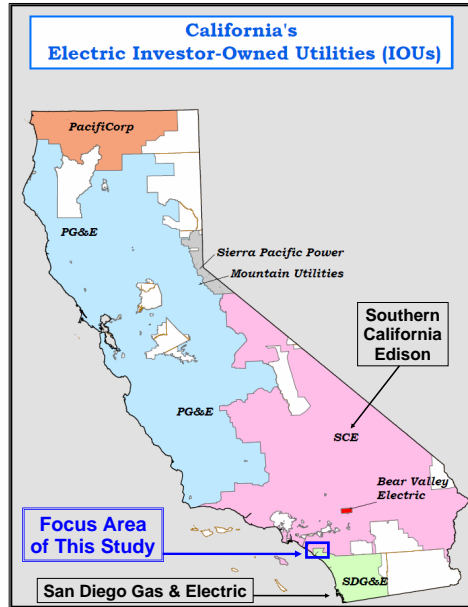
Research Design

Three key components:

- 1 The territory border of two electric utilities lies within city boundaries
- 2 I specifically focus on households within one mile of the utility border
- 3 The two utilities independently change their price schedules

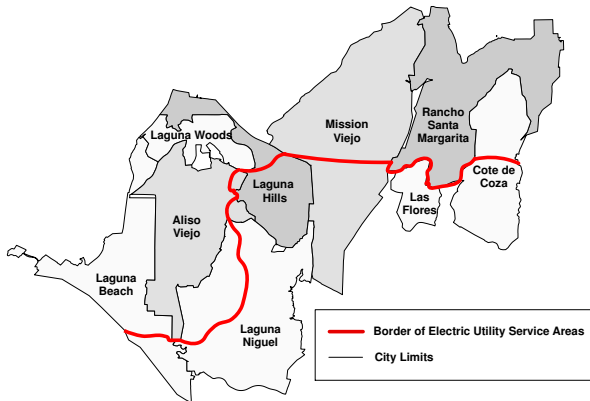


Nearly identical households experience different nonlinear price schedules



The territory border lies within city limits in several cities in Orange County, CA

Edison (Southern California Edison) provides electricity for the north side



San Diego (San Diego Gas & Electric) provides electricity for the south side

Why is the territory border here?

- It is because of the history of transmission line development
- In 1940's, Edison's and San Diego's transmission lines were connected here
 - Crawford and Society (1991)
 - Myers (1983)
- Most city boundaries in this area were established around 1980's

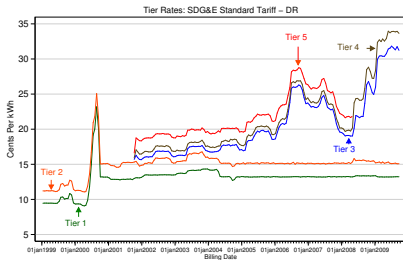
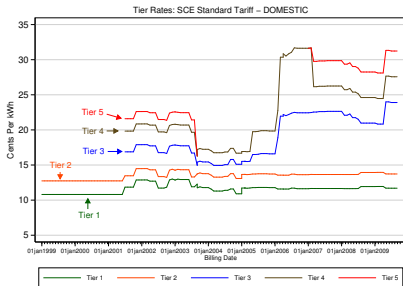
Data: A panel data set of household-level monthly billing records

- Main data: **Panel data of household-level monthly electricity billing records**
 - January 1999 to December 2007 (9 years)
- ① Customer ID
- ② Nine-digit ZIP code (e.g. 94720-5180)
- ③ Price schedules
- ④ Billing period (e.g. May15-Jun14)
- ⑤ Electricity consumption (kWh) during the billing period
- Additional data: **Demographic variables from Census 2000**

● Household characteristics are nearly identical at the territory border

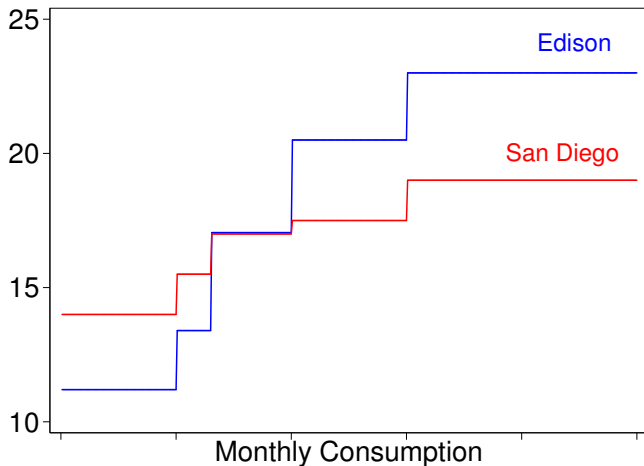
	SCE		SDG&E		Difference	
	Mean	(S.E)	Mean	(S.E)	Mean	(S.E)
<u>Data from Census 2000</u>						
Income per capita (\$)	40773	(1591)	40832	(1627)	59	(2261)
Median home value (\$)	391508	(19897)	404887	(19768)	13379	(27849)
Median rent (\$)	1364	(41)	1385	(62)	21	(74)
Population density/mile ²	6084	(362)	5423	(360)	-662	(508)
Household size	2.71	(0.07)	2.81	(0.05)	0.11	(0.09)
Median age	47.71	(1.23)	45.73	(0.55)	-1.98	(1.35)
% owner occupied housing	81.86	(1.65)	84.27	(1.93)	2.41	(2.53)
% male	49.12	(0.41)	48.65	(0.32)	-0.46	(0.52)
% employment of males	74.90	(2.14)	78.67	(1.13)	3.78	(2.41)
% employment of females	57.75	(1.83)	58.54	(1.22)	0.79	(2.19)
% college degree	50.31	(1.28)	52.96	(1.22)	2.65	(1.76)
% high school degree	35.25	(1.11)	32.27	(0.93)	-2.98	(1.44)
% no high school degree	4.28	(0.29)	4.07	(0.33)	-0.21	(0.44)
% white	85.53	(0.86)	83.74	(0.94)	-1.79	(1.27)
% hispanics	9.33	(0.58)	9.70	(0.74)	0.37	(0.93)
% asian	6.97	(0.61)	8.23	(0.66)	1.26	(0.90)
% black	1.19	(0.15)	0.86	(0.16)	-0.32	(0.22)
<u>Electricity Billing Data</u>						
Electricity use (kWh/day)	21.37	(0.07)	22.48	(0.09)	1.11	(0.12)
ln(Electricity use)	2.89	(0.00)	2.89	(0.01)	0.00	(0.00)
ln(Electricity use) in 1999	2.86	(0.00)	2.86	(0.01)	0.01	(0.01)

In contrast, households experience substantially different nonlinear pricing



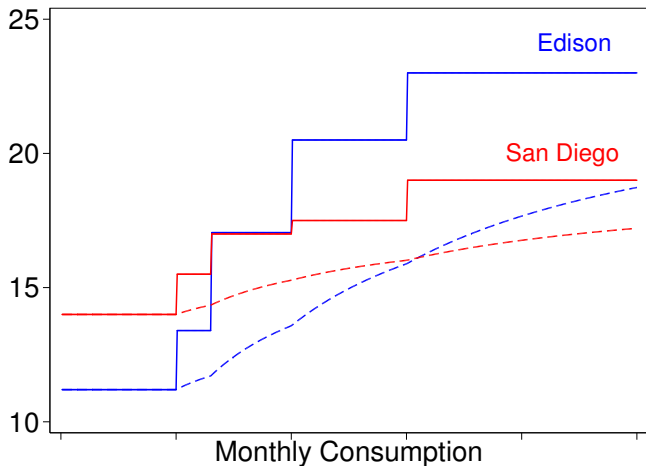
In contrast, they experience substantially different nonlinear pricing

- Edison and San Diego: Cents per kWh in 2002



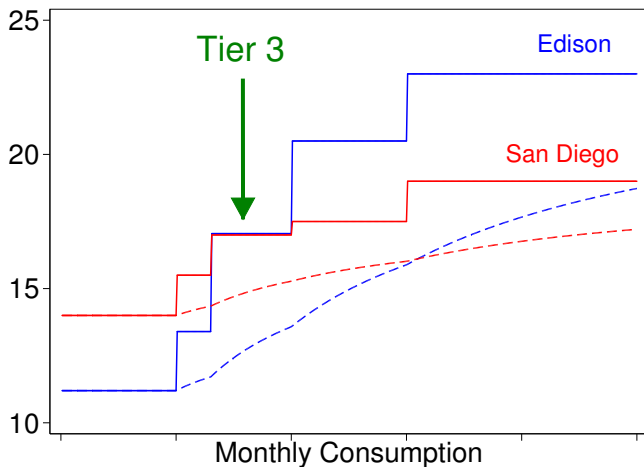
In particular, they experience different MP and AP

- Marginal price (solid) and average price (dashed): Cents per kWh



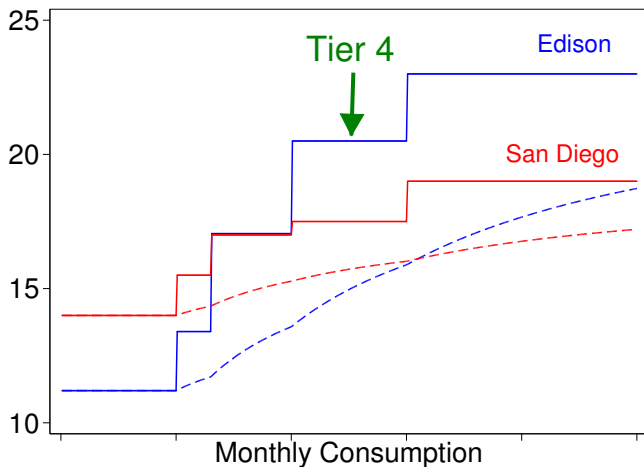
In tier 3, MP is similar, but AP is higher in SDG&E

- Marginal price (solid) and average price (dashed): Cents per kWh



In tier 4, MP is lower but AP is higher in SDG&E

- Marginal price (solid) and average price (dashed): Cents per kWh



I first explain my identification strategy and then present results

Road Map

- 1 Introduction
- 2 Research Design
- 3 Estimation**
 - 1 Identification strategy
 - 2 Results
- 4 Welfare Analysis
- 5 Conclusion

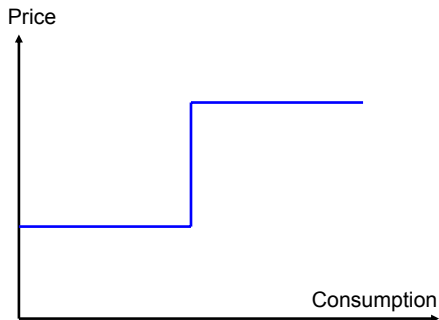
Four steps to explain my identification strategy

- 1 Price is a function of consumption \Rightarrow OLS estimates will be biased
- 2 Changes in price schedules can be used to estimate demand
- 3 Several studies show that identifying assumptions are violated in a conventional method
- 4 I use a spatial discontinuity to address this challenge

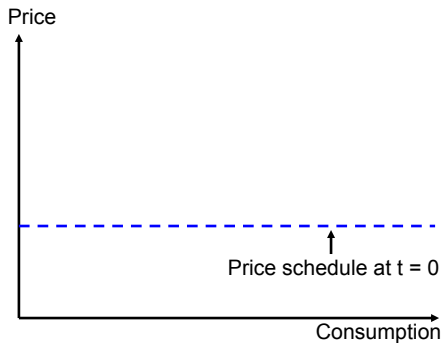
1) Price is a function of consumption \Rightarrow OLS estimates will be biased

$$\ln x_{it} = \alpha + \beta \ln p_{ut}(x_{it}) + \varepsilon_{it}$$

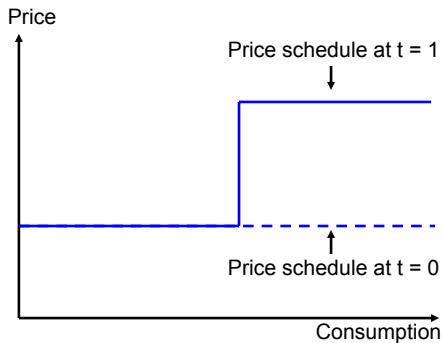
- x_{it} : consumption of household i at time t
- p_{ut} : price schedule in electric utility u at time t



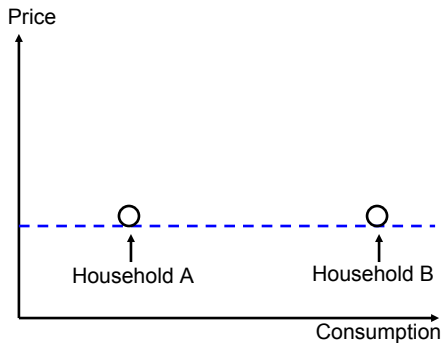
2) Changes in price schedules can be used to estimate demand



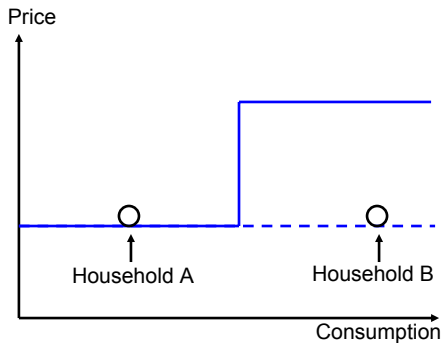
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2) Changes in price schedules can be used to estimate demand



2) Changes in price schedules can be used to estimate demand



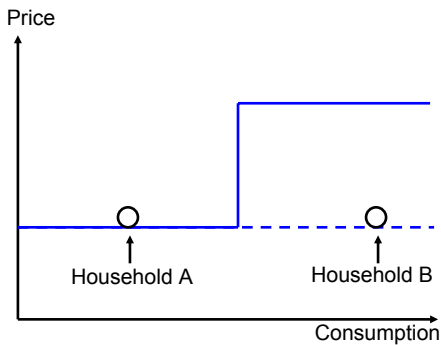
2) Changes in price schedules can be used to estimate demand

$$\Delta \ln x_{it} = \alpha + \beta \Delta \ln p_t(x_{it}) + \varepsilon_{it}$$

- Previous studies use simulated instruments (policy-induced price changes):

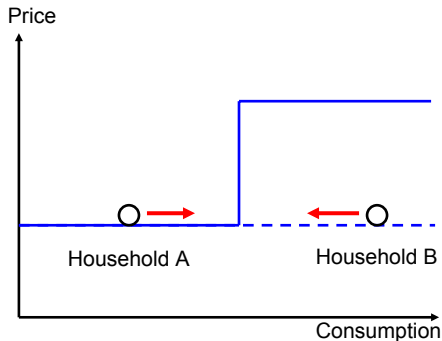
$$\Delta \ln p_t^{PI}(x_{it}) = \ln p_t(x_{it_0}) - \ln p_{t_0}(x_{it_0})$$

- Typically, the first stage is very strong
- An identification assumption: a parallel trend between A and B



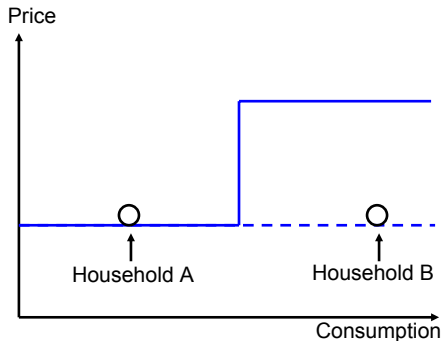
3) Several studies show that the parallel trend assumption is likely to be violated

- Reason (1) Mean reversion in consumption
 - Saez, Slemrod, and Giertz (2009)

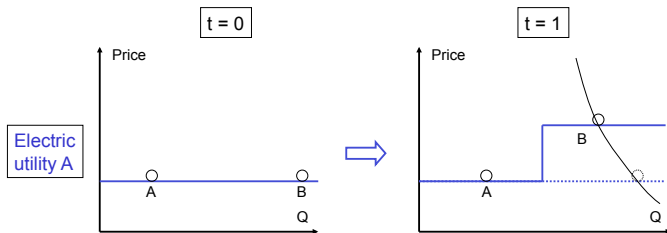


3) Several studies show that the parallel trend assumption is likely to be violated

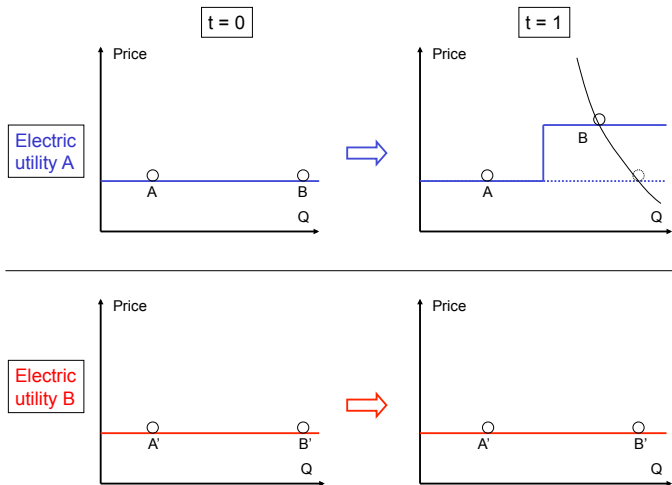
- Reason (2) Changes in the distribution of consumption
 - Heckman (1996), Goolsbee (2000)



4) I use a spatial discontinuity in electricity service areas to address this challenge



4) I use a spatial discontinuity in electricity service areas to address this challenge



- Parallel trend assumptions: between A and A', and between B and B'

Instrumental Variable Estimation

$$\Delta \ln x_{it} = \beta \Delta \ln p_{it} + \gamma_{ct} + \delta_{bt} + f_t(x_{it_m}) + \varepsilon_{it}$$

- IV: Policy-induced price change based on consumption in middle month ($t_m = t - 6$)

$$\Delta \ln p_t^{PI} = \ln p_t(x_{it_m}) - \ln p_{t_0}(x_{it_m})$$

- γ_{ct} = city-by-time fixed effects
- δ_{bt} = billing-cycle-by-time fixed effects
- $f_t(x_{it_m})$ = nonparametric controls for mean reversion and distributional changes
- Identification assumption:
 - Given the fixed effects and the controls for mean-reversion, the instrument (policy-induced price change) is not correlated with the error term

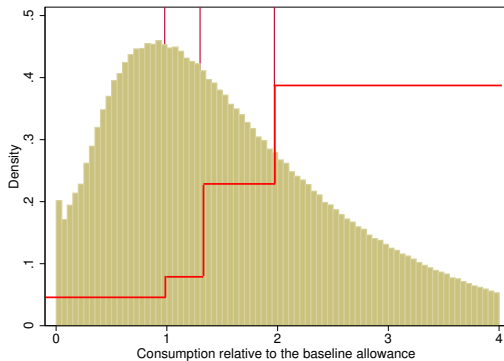
Now I present results

Road Map

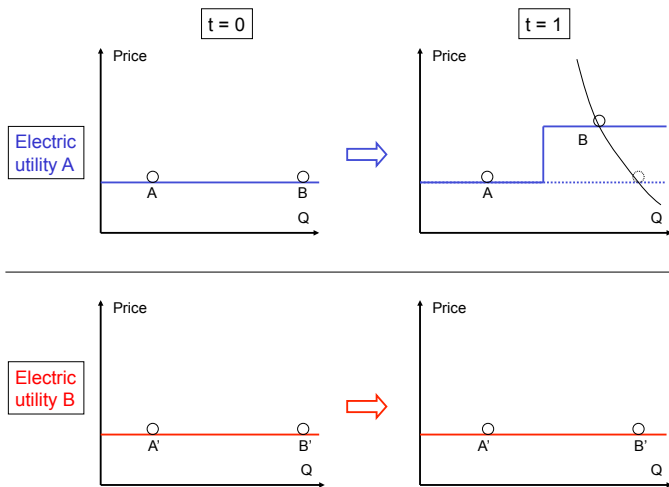
- 1 Introduction
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I find no bunching at any kink points of the nonlinear price schedules

- No bunching implies two possibilities
 - 1 Consumers respond to Marginal Price with nearly **zero elasticity**
 - 2 Consumers respond to **Alternative Price**

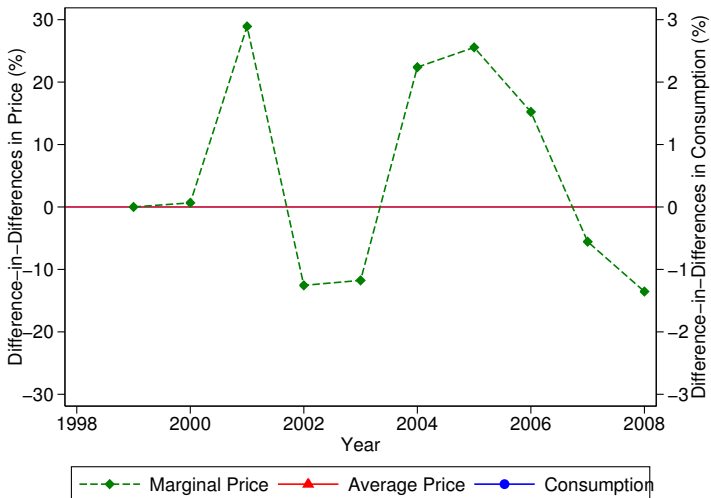


The difference-in-differences analysis



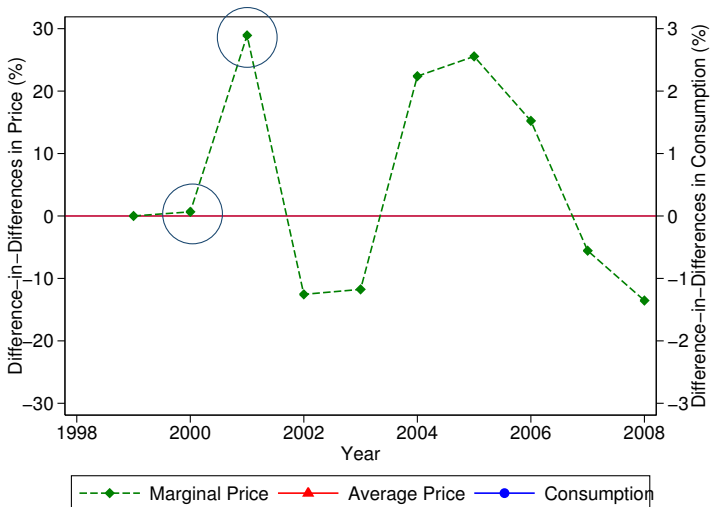
- Relative changes for SDG&E customers relative to SCE customers.
- January billing months

Panel A. Consumers whose previous year's consumption is on tier 4



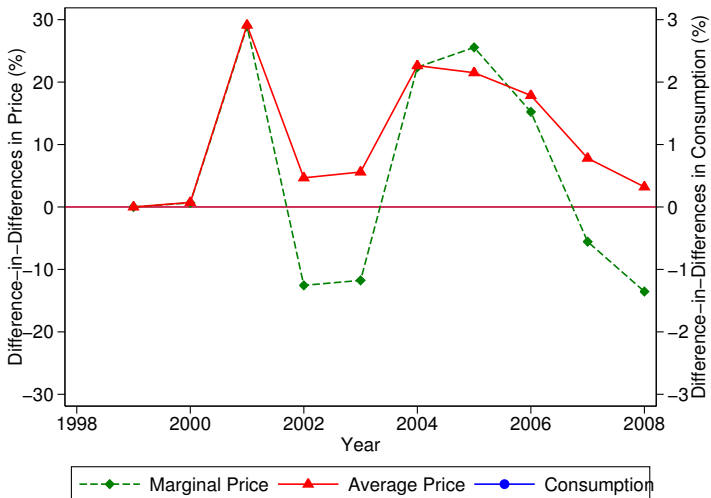
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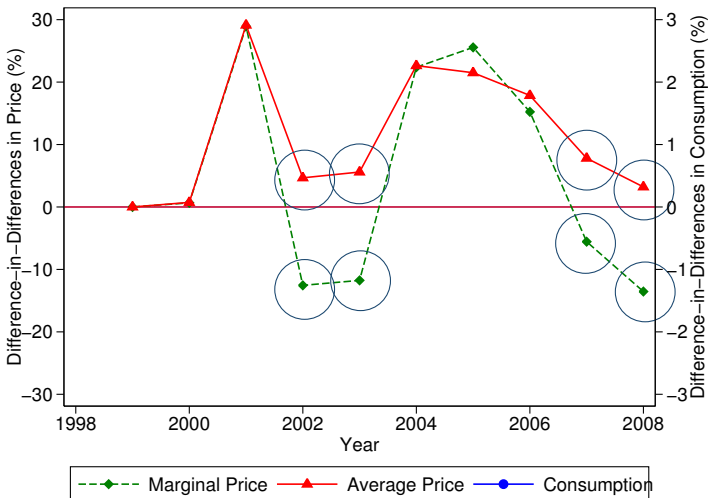
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Panel A. Consumers whose previous year's consumption is on tier 4



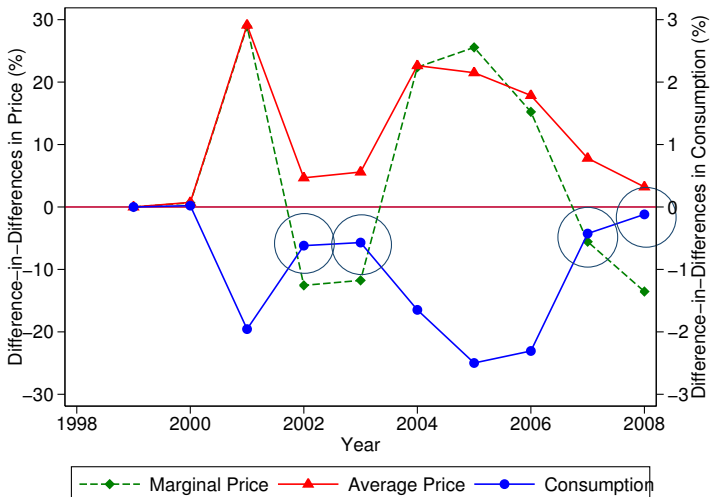
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Panel A: Consumers whose previous year's consumption was at tier 4



- Relative changes for SDG&E customers relative to SCE customers.
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Panel A: Consumers whose previous year's consumption was at tier 4



Estimation Results

- 1 Marginal price vs average price
- 2 Contemporaneous price vs lagged prices
- 3 Expected marginal price vs average price
- 4 A more general way of identifying consumers' perceived price

Estimation results: Marginal Price v.s. Average Price

IV Estimates: Marginal Price vs. Average Price

$$\Delta \ln x_{it} = \beta_1 \Delta \ln MP_{it} + \beta_2 \Delta \ln AP_{it} + \gamma_{ct} + \delta_{bt} + f_t(x_{it_m}) + \varepsilon_{it}$$

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(\text{Marginal Price}_t)$	-0.034					
	(0.004)					
$\Delta \ln(\text{Average Price}_t)$						
$\Delta \ln(\text{Marginal Price}_{t-1})$						
$\Delta \ln(\text{Average Price}_{t-1})$						

- Dependent variable: $\ln(\text{Electricity consumption})$
- Standard errors are clustered at the household level to account for serial correlation

Estimation results: Marginal Price v.s. Average Price

IV Estimates: Marginal Price vs. Average Price

$$\Delta \ln x_{it} = \beta_1 \Delta \ln MP_{it} + \beta_2 \Delta \ln AP_{it} + \gamma_{ct} + \delta_{bt} + f_t(x_{it_m}) + \varepsilon_{it}$$

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$\Delta \ln(\text{Marginal Price}_{it})$	-0.034					
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Estimation results: Marginal Price v.s. Average Price

IV Estimates: Marginal Price vs. Average Price

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	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(\text{Marginal Price}_{it})$	-0.034		0.002			
	(0.004)		(0.011)			
$\Delta \ln(\text{Average Price}_{it})$		-0.051	-0.054			
		(0.005)	(0.015)			
$\Delta \ln(\text{Marginal Price}_{it-1})$						
$\Delta \ln(\text{Average Price}_{it-1})$						

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Estimation results: Marginal Price v.s. Average Price

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	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(\text{Marginal Price}_{it})$	-0.034 (0.004)		0.002 (0.011)			
$\Delta \ln(\text{Average Price}_{it})$		-0.051 (0.005)	-0.054 (0.015)			
$\Delta \ln(\text{Marginal Price}_{it-1})$				-0.050 (0.004)		
$\Delta \ln(\text{Average Price}_{it-1})$					-0.074 (0.005)	

- Dependent variable: $\ln(\text{Electricity consumption})$
- Standard errors are clustered at the household level to account for serial correlation

Estimation results: Marginal Price v.s. Average Price

IV Estimates: Marginal Price vs. Average Price

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	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(\text{Marginal Price}_{it})$	-0.034 (0.004)		0.002 (0.011)			
$\Delta \ln(\text{Average Price}_{it})$		-0.051 (0.005)	-0.054 (0.015)			
$\Delta \ln(\text{Marginal Price}_{it-1})$				-0.050 (0.004)		0.006 (0.011)
$\Delta \ln(\text{Average Price}_{it-1})$					-0.074 (0.005)	-0.082 (0.015)

- Dependent variable: $\ln(\text{Electricity consumption})$
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Estimation Results

- 1 Marginal price vs average price
- 2 Contemporaneous price vs lagged prices
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Estimation results: Contemporaneous Average Price v.s. Lagged Average Prices

IV Estimates: Average Price vs. Lagged Average Price

	Lagged	Medium-Long Run Responses			
	Responses	1 month	2 month	3 month	4 month
	(1)	(2)	(3)	(4)	(5)
$\Delta \ln(\text{Average Price}_t)$	0.001 (0.002)				
$\Delta \ln(\text{Average Price}_{t-1})$	-0.049 (0.006)				
$\Delta \ln(\text{Average Price}_{t-2})$	-0.026 (0.007)				
$\Delta \ln(\text{Average Price}_{t-3})$	-0.011 (0.006)				
$\Delta \ln(\text{Average of Lag Average Prices})$		-0.071 (0.005)	-0.082 (0.005)	-0.087 (0.006)	-0.088 (0.006)

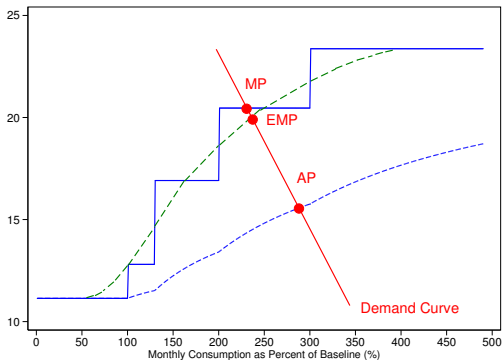
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Estimation Results

- 1 Marginal price vs average price:
- 2 Contemporaneous price vs lagged prices
- 3 Expected marginal price vs average price
- 4 A more general way of identifying consumers' perceived price

Do consumers respond to “expected marginal price?”

- I provide evidence that consumers respond to average rather than marginal
- However, it does not exclude other possibilities
 - e.g. Consumers may respond to **Expected Marginal Price** (Saez 1999)



Estimation results: Expected Marginal Price vs. Average Price

IV Estimates: Expected Marginal Price vs. Average Price

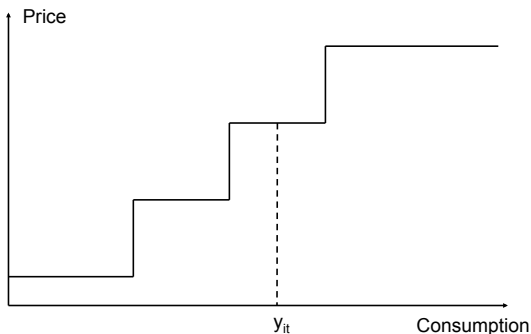
	(1)	(2)	(3)	(4)
$\Delta \ln(\text{Expected Marginal Price}_t)$	-0.036 (0.004)	0.004 (0.012)		
$\Delta \ln(\text{Average Price}_t)$		-0.056 (0.015)		
$\Delta \ln(\text{Expected Marginal Price}_{t-1})$			-0.053 (0.004)	0.009 (0.012)
$\Delta \ln(\text{Average Price}_{t-1})$				-0.086 (0.015)

Estimation Results

- 1 Marginal price vs average price:
- 2 Contemporaneous price vs lagged prices
- 3 Expected marginal price vs average price
- 4 A more general way of identifying consumers' perceived price

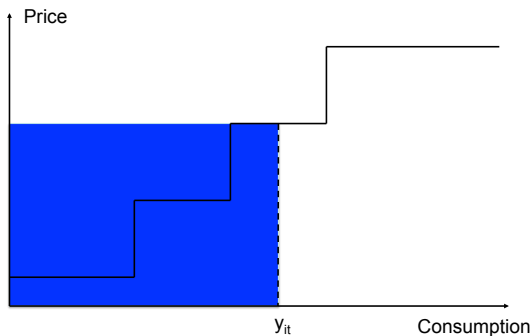
More generally, price perception can be modeled in the following way

- Consider consumer i with consumption y_{it}
- Consider that the consumer's perceived price can be modeled as **a weighted average of possible marginal prices for this consumer**
- Consumer i constructs her perceived price based on her weight distribution



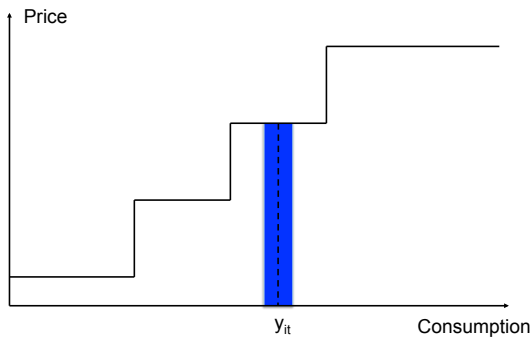
More generally, price perception can be modeled in the following way

- Perceived price = AP when the weight distribution is uniform $[0, y_{it}]$



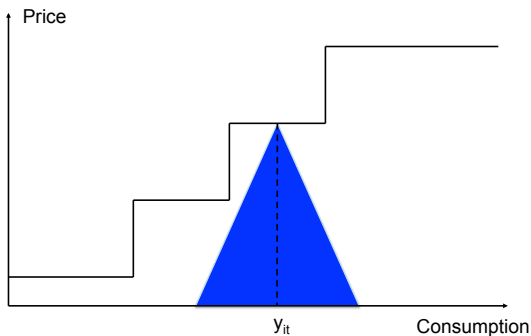
More generally, price perception can be modeled in the following way

- Perceived price = MP when the weight distribution is truncated locally around y_{it}



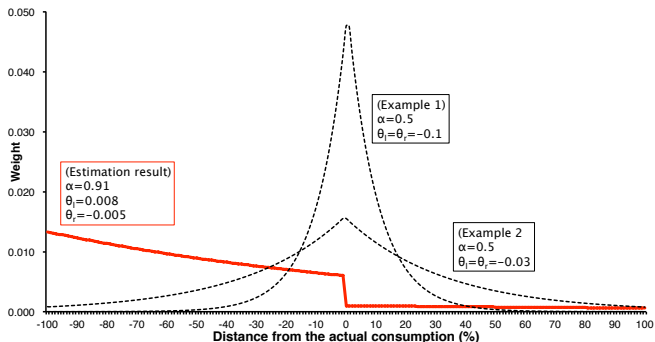
More generally, price perception can be modeled in the following way

- Perceived price = Expected MP when the weight distribution is symmetric and surrounded broadly around y_{it}



I model and estimate the weight distribution to recover consumers' perceived price

$$w_k(\alpha, \theta) = \begin{cases} \alpha \cdot \frac{\exp(-k \cdot \theta_l)}{\sum_{k \leq 0} \exp(-k \cdot \theta_l)} & \text{for } k \leq 0 \\ (1 - \alpha) \cdot \frac{\exp(k \cdot \theta_r)}{\sum_{k > 0} \exp(k \cdot \theta_r)} & \text{for } k > 0. \end{cases} \quad (1)$$



Joint estimation of price elasticity and price perception weighting parameters

$$\Delta \ln x_{it} = \beta \sum_{k=-100}^{100} w_k(\alpha, \theta) \cdot \Delta \ln p_{k,it} + f_t(x_{it_m}) + \gamma_{ct} + \delta_{bt} + u_{it}. \quad (2)$$

	Price Variable		
	Current month (1)	One-month lag (2)	Four-month average (3)
Weighting parameter α	0.911 (0.082)	0.896 (0.083)	0.883 (0.087)
Slope parameter θ_l	0.008 (0.013)	0.013 (0.014)	0.015 (0.014)
Slope parameter θ_r	-0.005 (0.015)	-0.009 (0.015)	0.001 (0.017)
Elasticity parameter β	-0.059 (0.005)	-0.086 (0.006)	-0.094 (0.006)
p-value for $H_0: \alpha = 0.5$	0.00	0.00	0.00
p-value for $H_0: \alpha = 1$	0.28	0.21	0.18

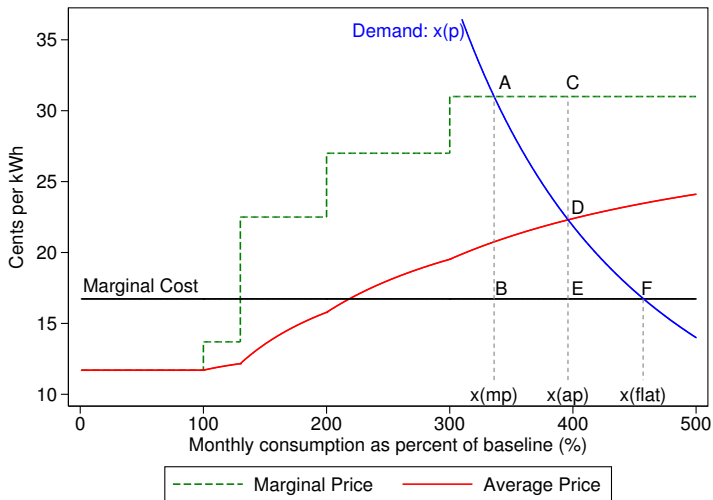
Does the sub-optimal response change welfare implications of nonlinear pricing?

Road Map

- 1 Introduction
- 2 Research Design
- 3 Estimation
- 4 **Welfare Analysis**
 - 1 The effects on energy conservation
 - 2 The effects on efficiency costs of nonlinear pricing
- 5 Conclusion

Welfare implication 1: The effects on energy conservation

- Many electric utilities introduce nonlinear pricing to reduce GHG emissions
- “Flat rate tariff” vs “Nonlinear tariff” for energy conservation



Welfare implication 1: The effects on energy conservation

Results: Compared to a flat rate design, the existing five-tier nonlinear pricing

- ① Reduces total consumption if consumers respond to **Marginal Price**
- ② Slightly increases total consumption if consumers respond to **Average Price**

	Flat rate tariff	Five-tier Tariff	
		MP response	AP response
Consumption (Gwh)	20,471	19,993	20,526
%Change from Flat Rate Tariff		-2.33%	0.27%
Standard Errors by Delta Method		(0.05%)	(0.02%)

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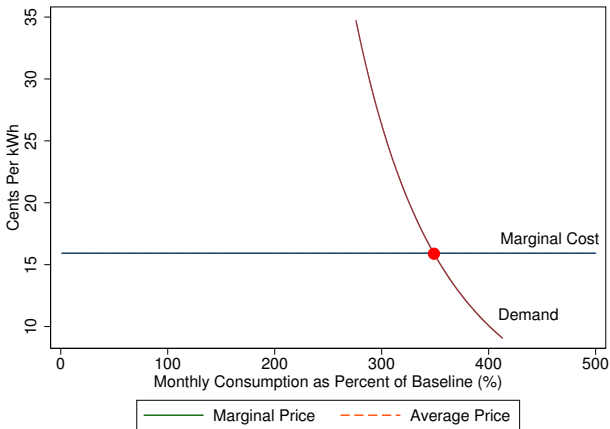
Welfare implication 2: The effect on the efficiency costs of nonlinear pricing

Road Map

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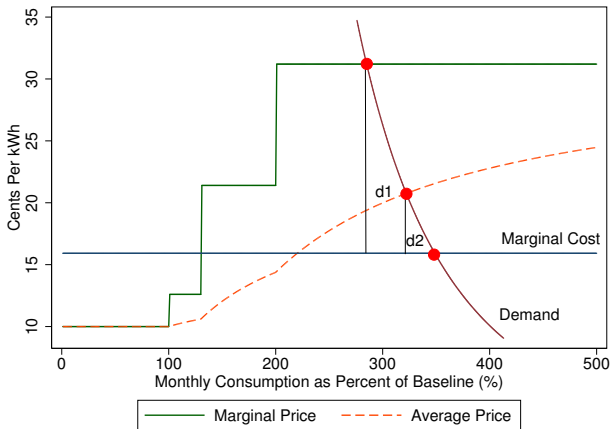
Welfare implication 2: The effect on the efficiency costs of nonlinear pricing

- Suppose that the MC of electricity:
 - Does not depend on the *level* of an individual household's monthly consumption
 - Minimum efficiency cost if $P = MC$



Welfare implication 2: The effect on the efficiency costs of nonlinear pricing

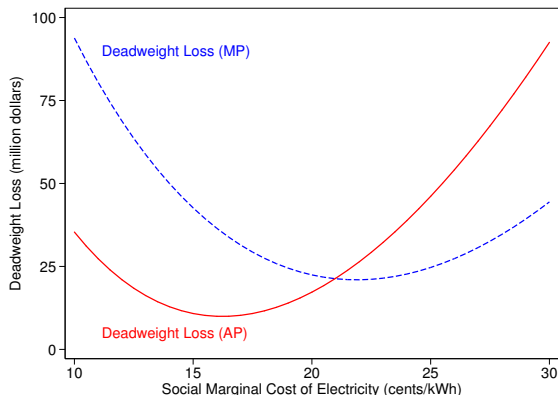
- Suppose that the MC of electricity:
 - Does not depend on the *level* of an individual household's monthly consumption
 - Nonlinear pricing creates efficiency costs



The sub-optimal response reduces the DWL if the social MC

Results: Average price response →

- 1 Reduces the DWL when the social MC of electricity ≤ 21 kWh
- 2 Increases the DWL when the social MC of electricity > 21 kWh



Summary

Road Map

- 1 Introduction
- 2 Research Design
- 3 Data
- 4 Estimation
- 5 Welfare Analysis
- 6 Conclusion**

Summary

This paper examines how consumers respond to nonlinear pricing:

- Exploit price variation across the territory border of two electric utilities

Key findings:

- 1 Consumers respond to average price rather than marginal price
- 2 Consumers respond to lagged price rather than contemporaneous price
- 3 This average price response changes welfare implications in two ways
 - It makes nonlinear pricing less successful in energy conservation
 - It changes the efficiency costs of nonlinear pricing

Discussion and Future Research

Why do consumers respond to average price?

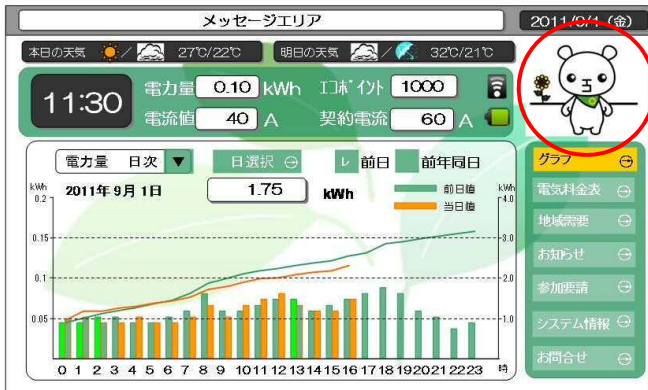
- Information costs are probably larger than the utility gain

Can information provision change consumer behavior?

- Chetty and Saez (2009): Teaching tax codes
- Similar research on residential electricity can help us to understand how to effectively inform consumers about economic incentives

An ongoing project: Randomized field experiments on Dynamic Pricing

- Consumers receive clear price information from their in-home-display
- We find clear responses to dynamic electricity prices in our experiment



Thank you

- Thank you for your attention!