ECOCEP - Energy and Climate Economic Modeling,
Prague, 3-4 November

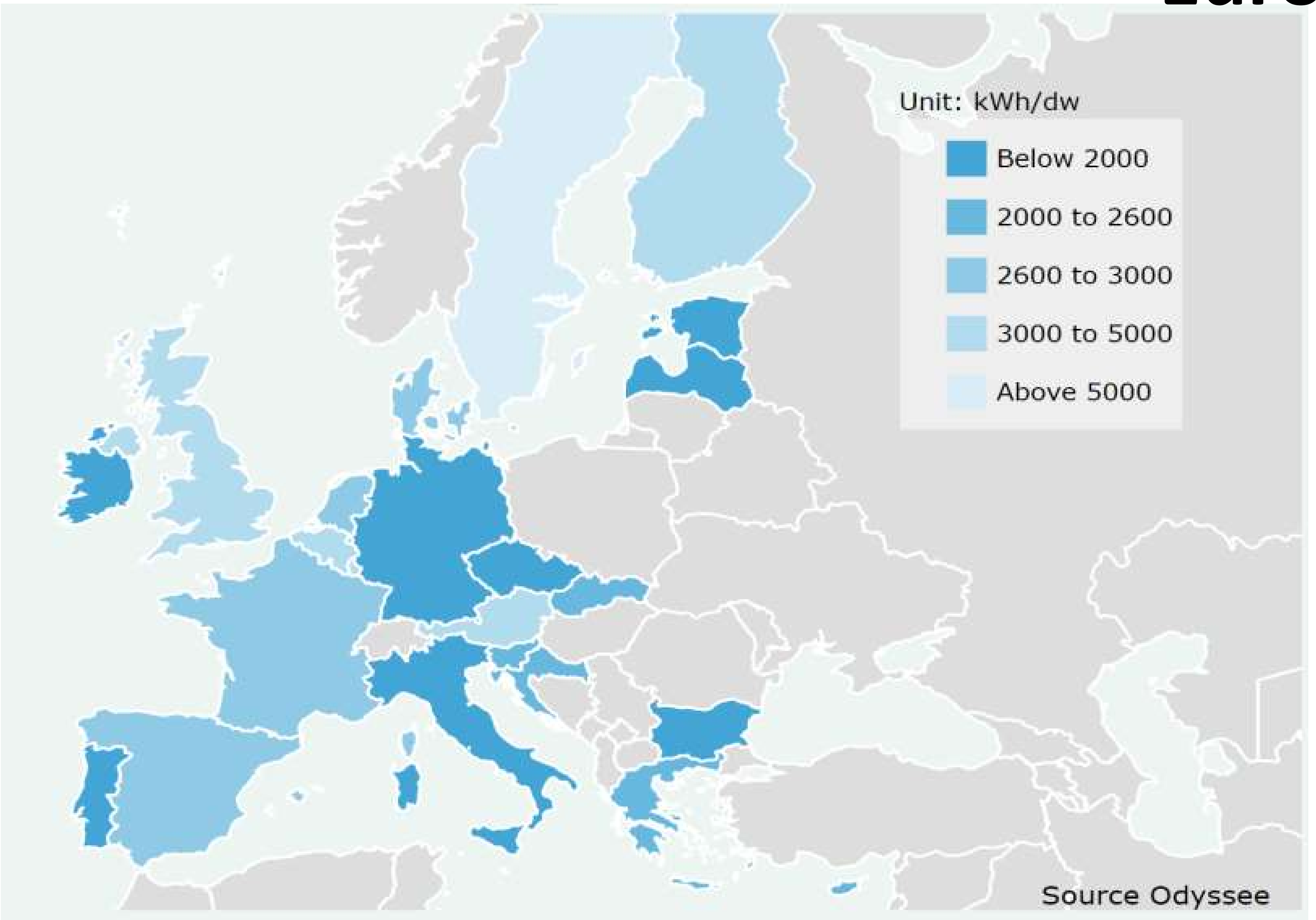
Household Energy Use, Energy Efficiency, Emissions and Behaviors

Anna Alberini
AREC, University of Maryland

Focus of this presentation

- Direct household energy use and associated emissions
  - Residential energy consumption (electricity, natural gas or other heating fuel)
    - 39% of energy use and CO_2 emissions
  - Private motor transportation (cars)
    - Road transport accounts for 20 – 30% of CO_2 emissions
    - CO_2 emissions $\propto$ (inverse) fuel economy
- Advances in empirical work seeking to assess the effects (potential pitfalls) of policies

Electricity used for lighting & appliances Europe, 2014



Basic Theoretical Model

- Household production function
- Household uses energy inputs (e.g., gas, electricity, motor fuel) and energy-using capital (boilers, lightbulbs, cars) to produce energy services (a warm home, lighting, driving), from which it derives utility

$$U(X, ES(E)) \qquad y = X + p * E$$

- Derive a demand function for energy inputs or energy services

But…

- Traditional models assume that consumers are perfectly aware of prices paid and quantities consumed

- Energy a strange good: you often buy in advance, get bill much later

- Difficult to monitor usage and adjust it (smart monitors, IHDs)

- Energy efficiency gap

Empirical Model (1)
Energy Input Demand

$$\ln E_{it} = \alpha_i + \beta \ln P_{it} + \gamma \ln P_{it}^{A} + \mathbf{X}_{it}\boldsymbol{\delta} + W_{it}\boldsymbol{\lambda} + \varepsilon_{ij}$$

Household characteristics, including income; stock of energy-using capital

Weather, time controls

Empirical Model (2)
Demand for Energy Services

$$\ln VMT_{it} = \alpha_i + \beta \ln(PGAS_{it} / MPG_{it}) + \mathbf{X}_{it}\boldsymbol{\delta} + W_{it}\boldsymbol{\lambda} + \varepsilon_{ij}$$

Price per liter / kilometers per liter = price per unit of energy service (kilometer driven)

In other words, the dep. variable in your regression is what is easiest to measure/best measured (electricity or gas bills from the utilities, individually or aggregated to state level, VMT because easier to keep a track than volume of gasoline used)

What do policies seek to do?

GOALS

- Reduce energy use and emissions
- Steer consumers towards energy from renewables
- Align demand and supply, infrastructure (peak load, capacity)

INSTRUMENTS

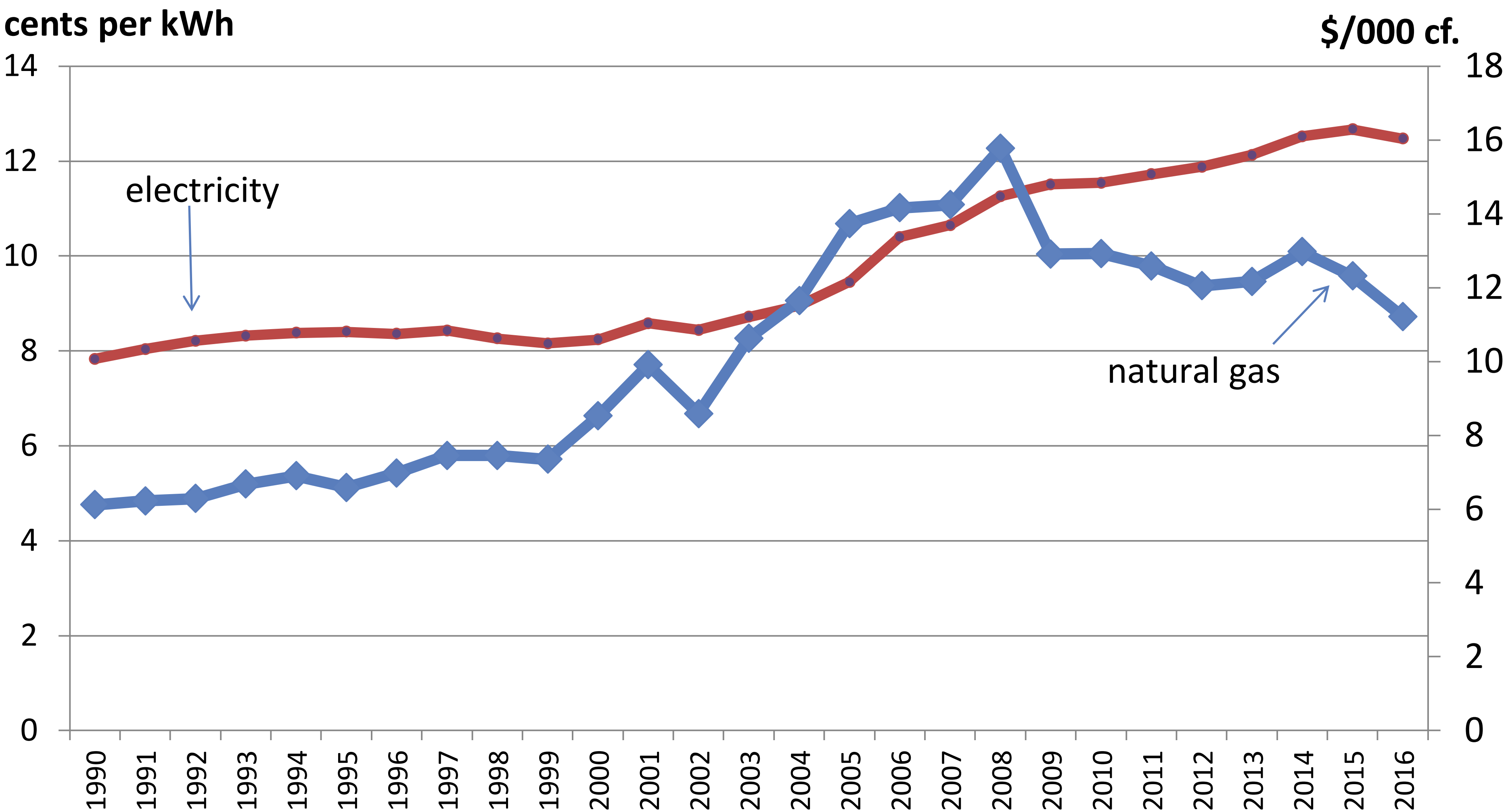
- Taxes on energy inputs (incl. carbon tax, other pricing schemes)
- Energy efficiency policies (standards, incentives)
- Renewables policies (standards, incentives)

Super Important: the Price Elasticity of Demand

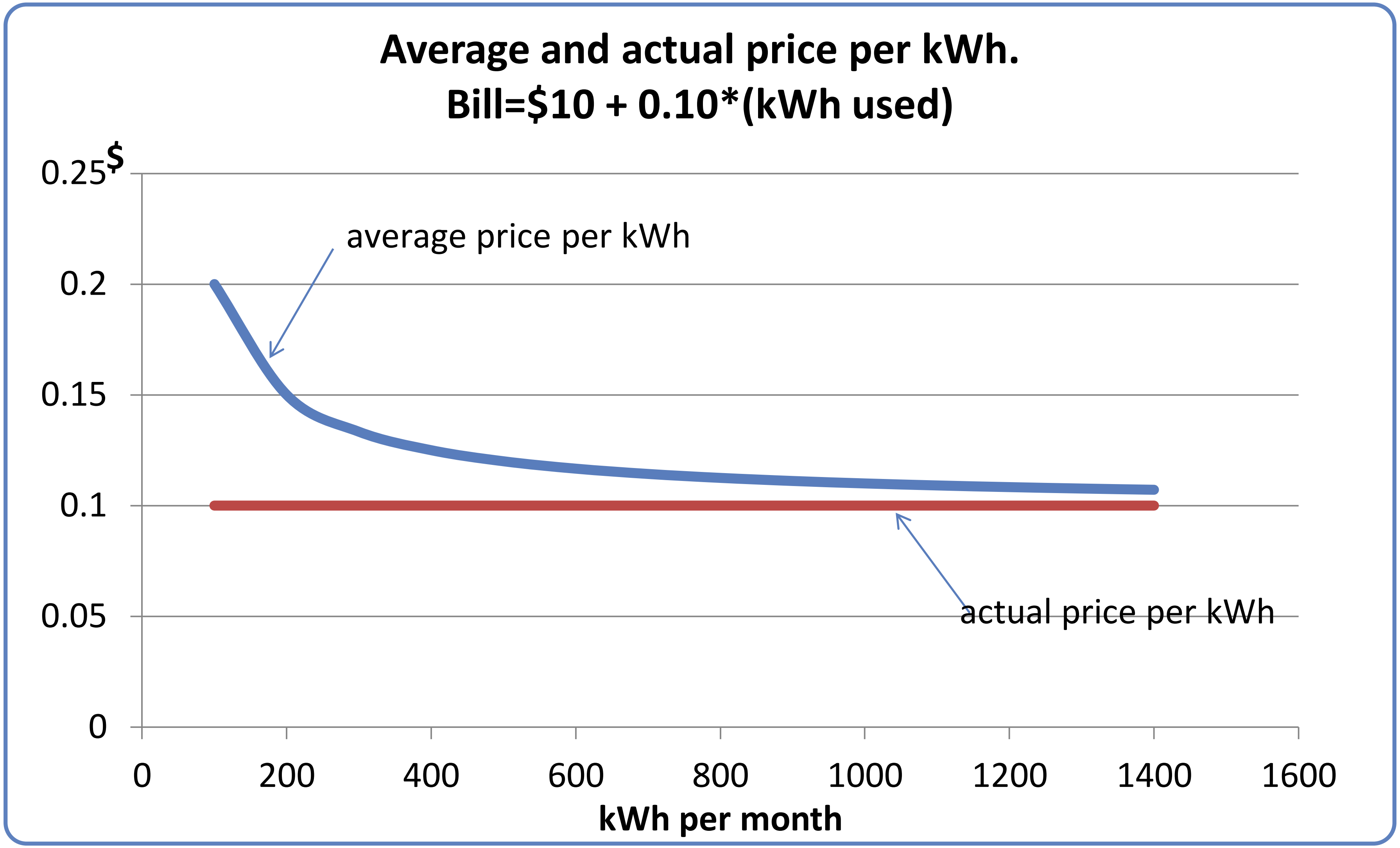
- Responsiveness to price is estimated from variation over time and across units
- Wide range of estimated elasticities (0 to -2, but generally low) (Miller and Alberini, 2016)

- Measurement error in prices
  - Average price in the state or area v. individual price
- Price is endogenous w/ quantity
  - if average price used and there is a two-part tariff
  - with block pricing
- Which price?
  - Is marginal price really what matters?

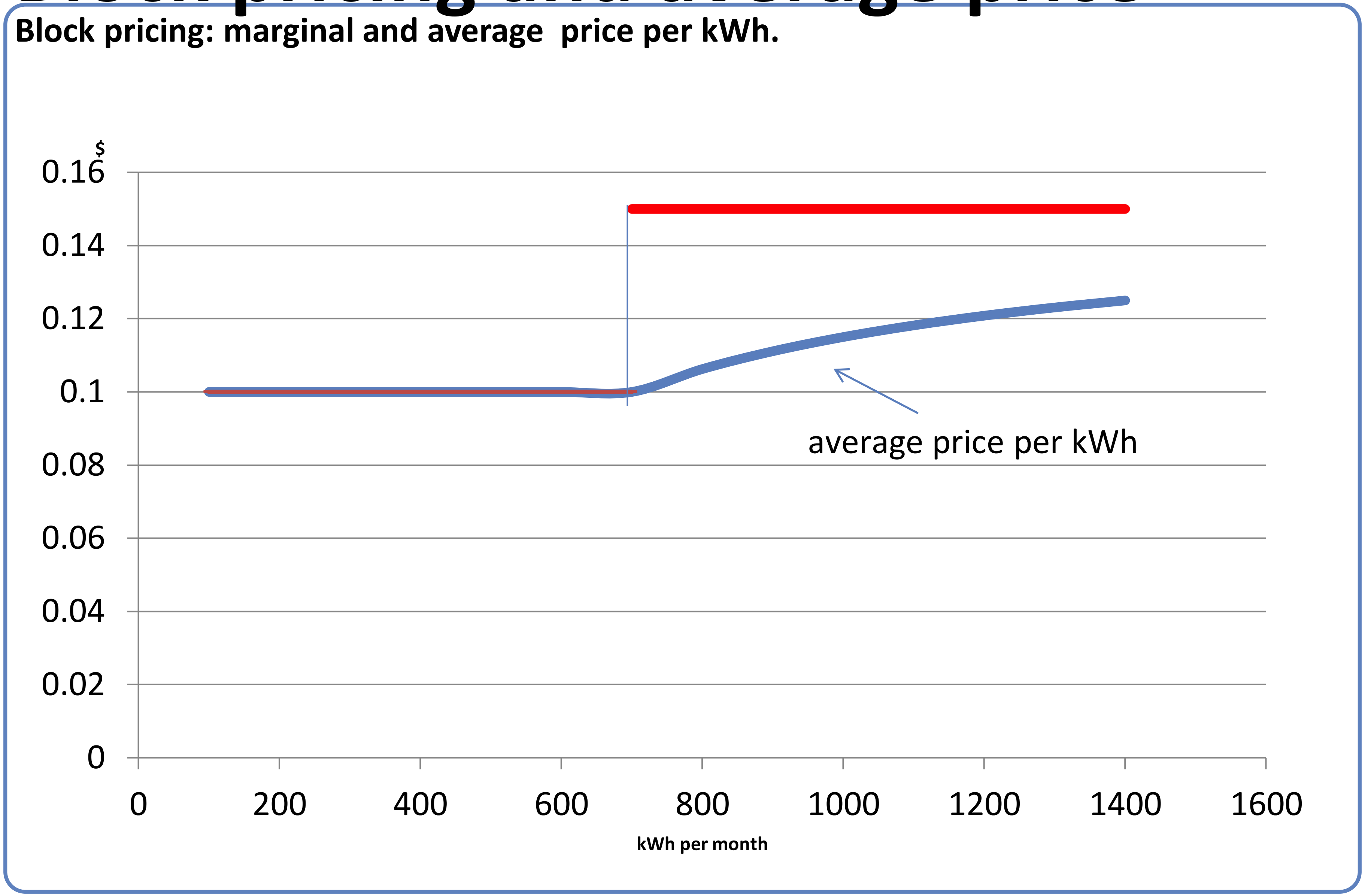
Residential electricity and natural gas prices in the US (nominal)



Two-part tariffs and average price



Block pricing and average price



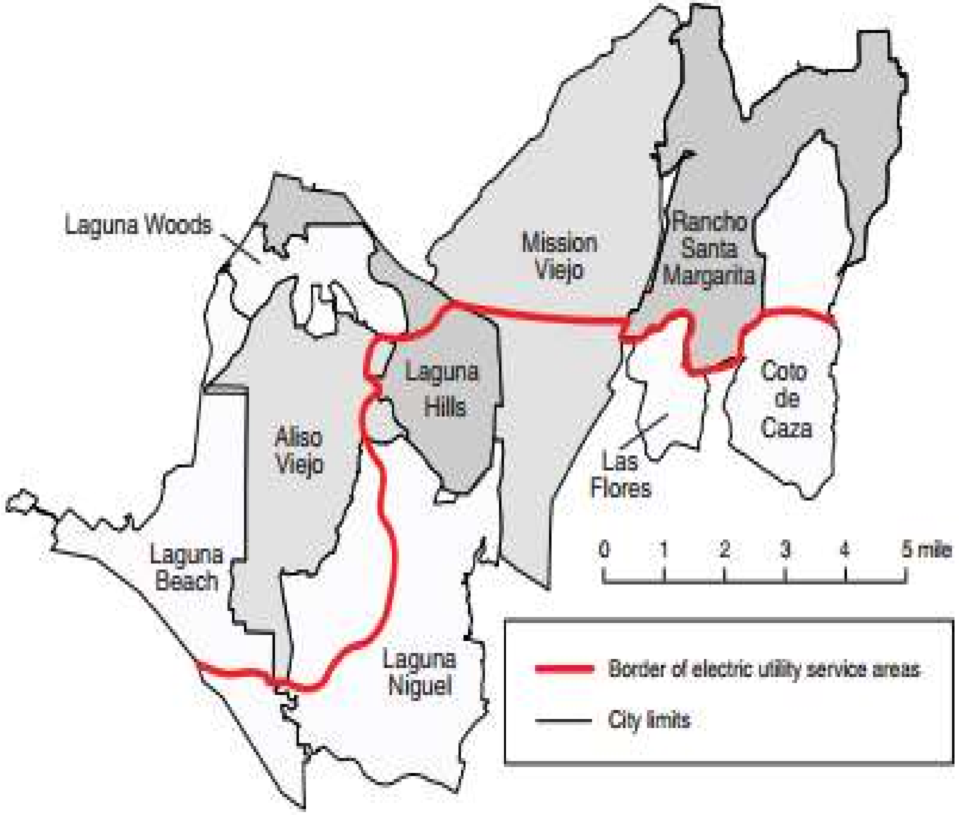


FIGURE 2. BORDER OF ELECTRICITY SERVICE AREAS IN ORANGE COUNTY, CALIFORNIA

Notes: The border of electricity service areas lies within city limits in six cities. SCE serves the north side of the border and SDG&E serves the south side of the border.

Ito (2014)

- Takes advantage of within-city variation in electricity providers in Orange Co., So. Cal., and in their tariffs
- Both providers use increasing block tariff but the rates are different and change differently over time
- The residents are very similar across utility boundaries
- 1999-2009, monthly bills and usage records

Ito (2014) Block structure

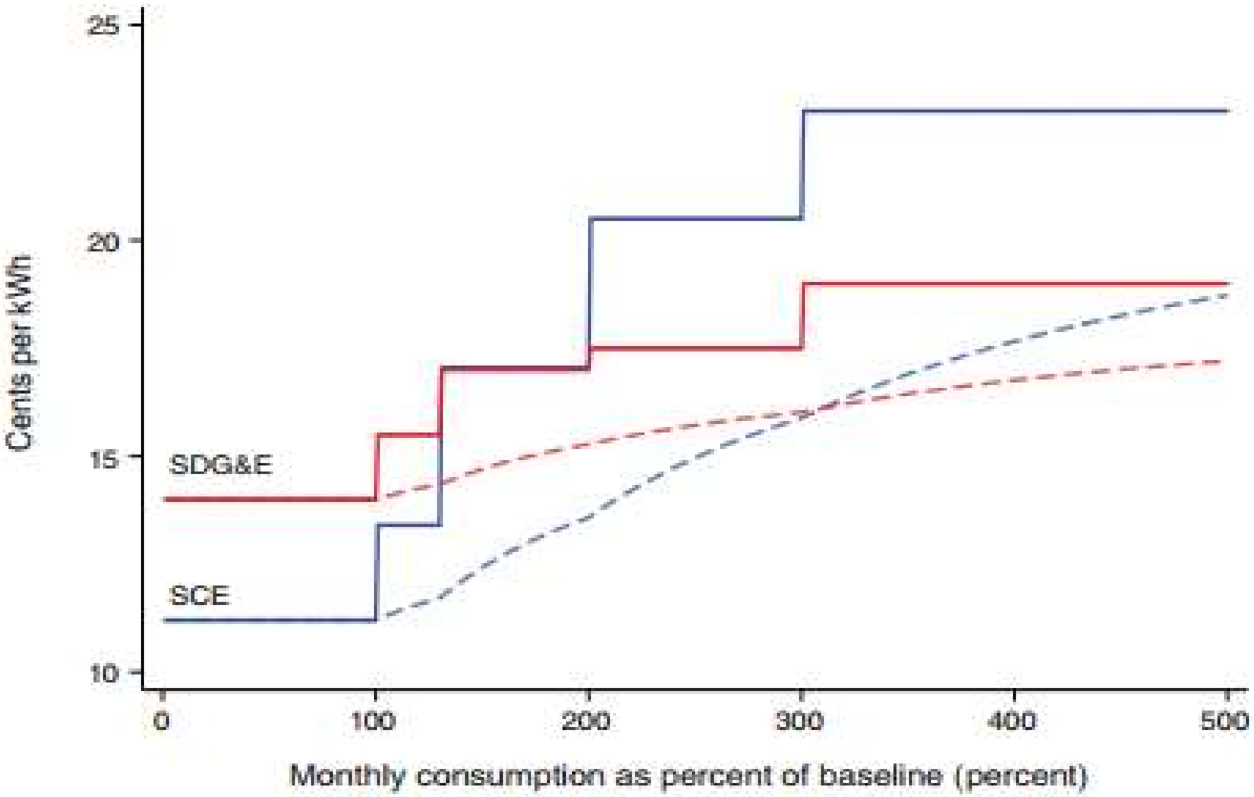


Figure 3. An Example of Cross-Sectional Price Variation in Nonlinear Electricity Pricing

Note: To show an example of cross-sectional price variation, this figure presents the marginal price (solid line) and the average price (dashed line) for SCE and SDG&E in 2002.

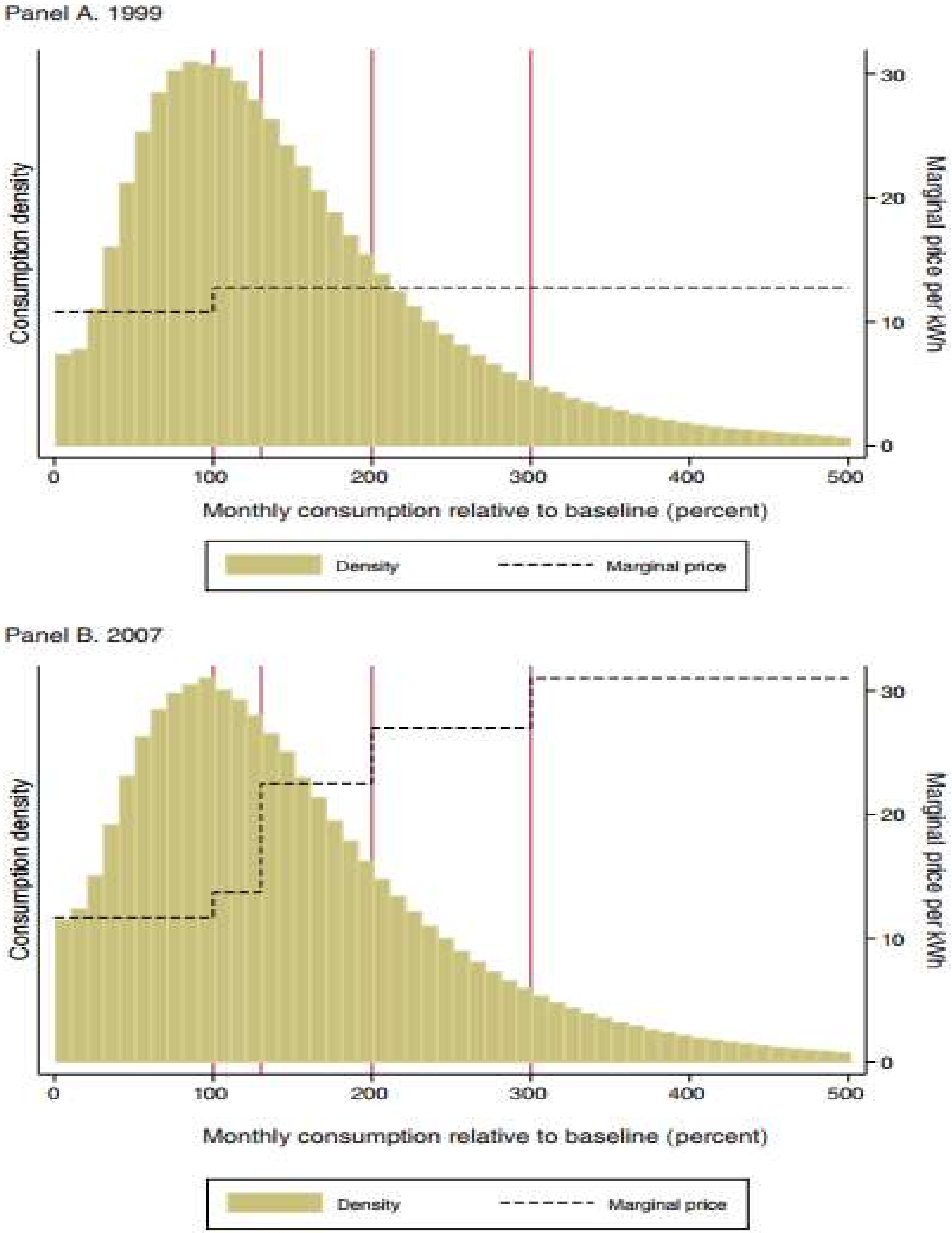


FIGURE 5. CONSUMPTION DISTRIBUTIONS AND NONLINEAR PRICE SCHEDULES

Notes: The figure shows the histogram of household-level monthly electricity consumption for SCE in 1999 (panel A) and in 2007 (panel B). The figure also shows the nonlinear price schedule for each year. The vertical solid lines show the kink points of the nonlinear price schedule.

- Theory predicts that if people respond to the marginal price, there should be bunching at the end of each block
- No such evidence
- Demand function: evidence shows that once you control for the average price, the coefficients on marginal price and expected price are no longer significant
- Graphical analysis and prediction from the econometric model show that people **consume more** than they would if they responded to the marginal price (b/c average price is lower than marginal price once we depart from the first block)
- **Conclusion**: block pricing **does** not promote conservation if people respond to average price instead.

Jessoe and Rapson (2014)

- Critical peak pricing works much better when combined with IHD
  - Price only treatment: 0-7% reduction in electricity usage (compared to control)
  - Price + IHD: 8-22% reduction
- Randomized control trial in Connecticut
- Six critical peak events on v. warm summer days
- Jessoe and Rapson find that the reductions in electricity use extend to non-peak times and off-summer days

Salience

- What part of the total price of something you take notice of, respond to, and adjust your demand with respect to?
- Posted prices in the United States typically do not include the sales tax. The sales tax is added at the cash register.
- Chetty et al. (2009)
  - Experiment at supermarkets
  - The demand for the goods that had the new tax inclusive price tags decreased by 8% when the new tags were posted. If consumers had been taking the sales tax into account to begin with, there would have been no change in demand.

Experiment with tax in Chetty et al. (2009)

← Original tag

← Experimental tag

Salience - 2

- How you offer an incentive to fuel economy matters!
- Gallagher and Muehlegger (2008) compare the impact of sales and income tax rebates on hybrid vehicle purchases.
  – Sales tax rebates are received at the time of the purchase and are thus highly salient and visible. Income tax rebates are received later, and so tax credits are less transparent at the time of purchase.
  – The sales tax rebate has seven times as large an effect on the number of hybrid cars sold as an equivalent-sized income tax rebate

Habit Formation

Scott (2012)

- Intertemporal utility maximization problem
- In each period, utility depends on current gasoline consumption (g_t) and gasoline habit stock (s_t)
- The habit stock decays in each period and is replenished with each period consumption:

$$s_t = \alpha g_{t-1} + (1 - \alpha) s_{t-1}$$

- α=1 means short memory, $\alpha \neq 1$ a habits-as-durables model (persistence – HAD)

Habit Formation - 2

- Demand function depends on past consumption of gasoline and future gasoline prices
- Model explains why…
  - you start reducing consumption now if you expect a permanent increase in prices in the future
  - Consumption doesn't adjust to price increases that are thought to be just temporary
  - Allcott and Wozny (2013) find that car markets respond to changes in gasoline prices with up to a six-month delay.

Are there non-price instruments that get people to change their energy use?

Feedback about consumption

- more frequent bills, clearer bills, IHDs)
- 0-16% reduction
- slight increase for poor people
- Gans et al. (2013) uses a natural experiment in Northern Ireland; Darby, 2008, 2012
- Relied upon by Energy Union directive

Norms

- OPower: a company based in the Wash. DC area that sends out “customized” or “modified” utility bills
-  “you are using less/more energy than your neighbor” (Allcott, 2011; Allcott & Wozny, 2014)
- Modest and temporary decrease in consumption

The Rebound Effect

Direct rebound effect

- energy-efficient equipment lowers the price of energy services, even if the price of electricity or gasoline stays the same.
- People demand more energy services (use dishwasher more often, drive more miles) and this erodes the savings in energy inputs
- Really? How big?
- Sorrell et al. (2009)
  - 17 studies
  - Range of effects 3 – 87%
  - Most credible range 10 – 30%

The Rebound Effect – 2

Most studies…

- Assess the rebound effect using the price elasticity of the demand for gasoline, which is generally low
- Treat periods of falling energy prices as symmetric with respect to periods with rising prices (only the former have an effect comparable to that of increasing energy efficiency)
- Use aggregate data
- Use single cross-sections
- Suffer from selection bias – for example, don't account for the fact that people buy fuel-efficient cars *because* they need to drive a lot

The Rebound Effect - 3

- Proper analysis?
  - Panel data
  - Sufficient car turnover
  - fuel economy of cars change (some people buy more fuel-efficient cars, others don't)
  - the price of fuel changes
- Linn (2013)
  - Single cross-section from 2009
  - Allows for different response of VMT to changes in gasoline prices and car fuel economy
  - Instruments for the choice of fuel economy
  - Finds that people respond more to changes in fuel economy than prices
  - 20% - 40% rebound effect
- Grosche and Vance (2013)
  - Germany Mobility Panel 1997-2009
  - Sample of people who kept the same cars
  - Gasoline price changes
  - Rebound effect 46 – 70%
- Gillingham et al. (2013)
  - … Note that the rebound effect (direct or indirect, or overall) is overrated
  - … We don't really know how the various types of effect will reinforce or offset each other
  - … Likely to be small overall (no more than 30%)

The Rebound Effect - 4

- Gillingham et al. (2016) on the rebound effect and energy efficiency policy
- They distinguish between

1. Zero-cost breakthrough

   - An innovation allows a product manufacturer to increase energy efficiency costlessly holding all other attributes of the product the same
   - The resulting consumer responses are a pure rebound effect

2. Policy-induced ("bundled") improvement

   - A policy requires manufacturers to energy efficiency of a product. The policy may induce or even necessitate changes in other attributes of the product, such as size, weight or capacity.

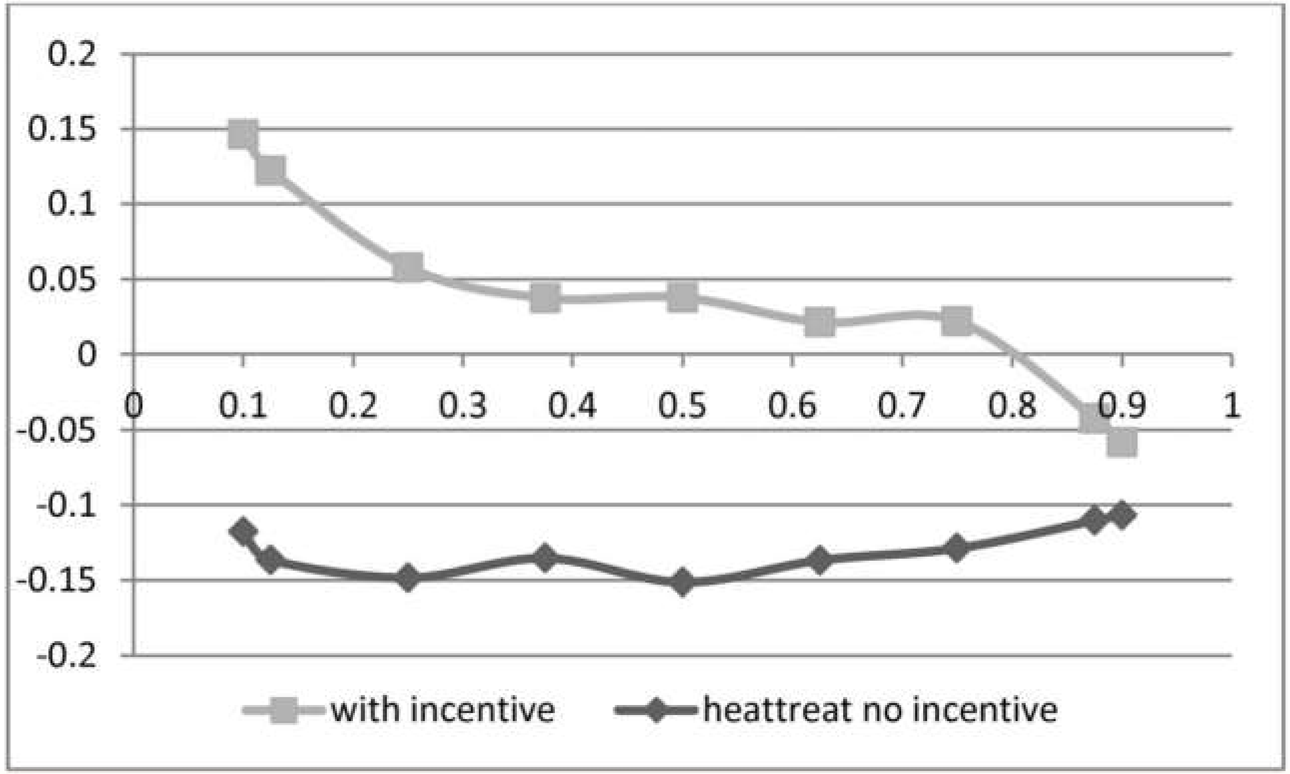
- Analysis must distinguish between these two
- Indirect effects rarely estimated
- Macroeconomic effects v. difficult to estimate

Own findings (Alberini and Towe, 2015)

- Look at MD households who use exclusively heat pumps for heating and cooling
- Heat pumps are heavy electricity users and are subject to EE standards (effective 2006)
- Detailed monthly usage records
- Diff-in-diff
- Those who changed heat pump reduced electricity use by 8%
    - People who received rebates and tax credits = 0% reduction
    - All other changers: 16% reduction
- Most likely rebates and tax credits financed an upsized system – difficult to disentangle energy efficiency with change in capital stock

Average Treatment Effect of Changing the Heat Pump: Quantile Regressions

Figure 4: Average Treatment Effect on the Treated from Fixed Effects Quantile Regression. Model with Interaction between Heat Pump Treatment Dummy and Incentive Dummy.



Energy Efficiency Gap? Really?

- Metcalf and Hassett (1993)
- Allcott and Greenstone (2012)
- Fowlie et al. (2015)
  - Randomized controlled trial
  - Michigan low-income households
  - Enhanced effort to encourage participation in the Weatherization Assistance Program (WAP) (6% v. 1% control group)
  - WAP EE investments reduced monthly energy usage by 10-20% (actual) v. 25-50% (engineering projections)
  - Upfront investment twice as expensive as the realized energy savings
  - → people don't make EE investments because they don't make financial sense

Suppliers' Responses

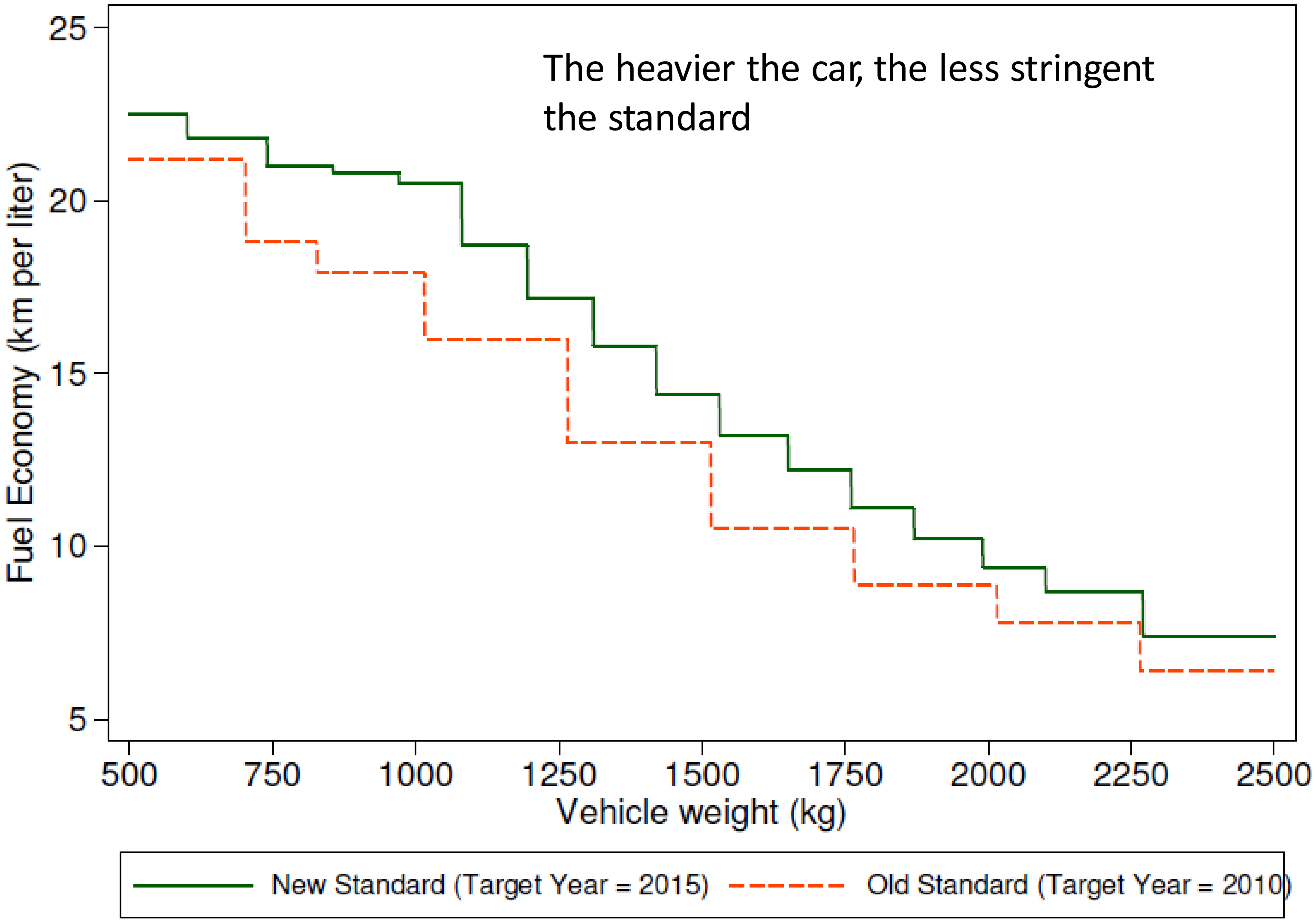
- Get around regulations
  - Example: automakers
- Raise prices and target products to take advantage of consumers who care about fuel economy, emissions, etc.
  - Example: Swiss auto importers, US appliance mfrs.
- At the same time, technological advances may imply that energy efficient products are not necessarily more expensive than their less efficient counterparts
  - Example: US appliance mfrs.

#1. Automakers overstate the cost of meeting fuel economy standards

- Anderson and Sallee (2011)
- Alternative Motor Fuels Act (1993)
  - Credits vehicles with flex-fuel capability (can run on gasoline and E85 [ethanol-gasoline mix]) with 2/3 more of the MPG fuel economy than they actually achieve
- AS show that US automakers did in fact exploit this loophole at very low cost to them

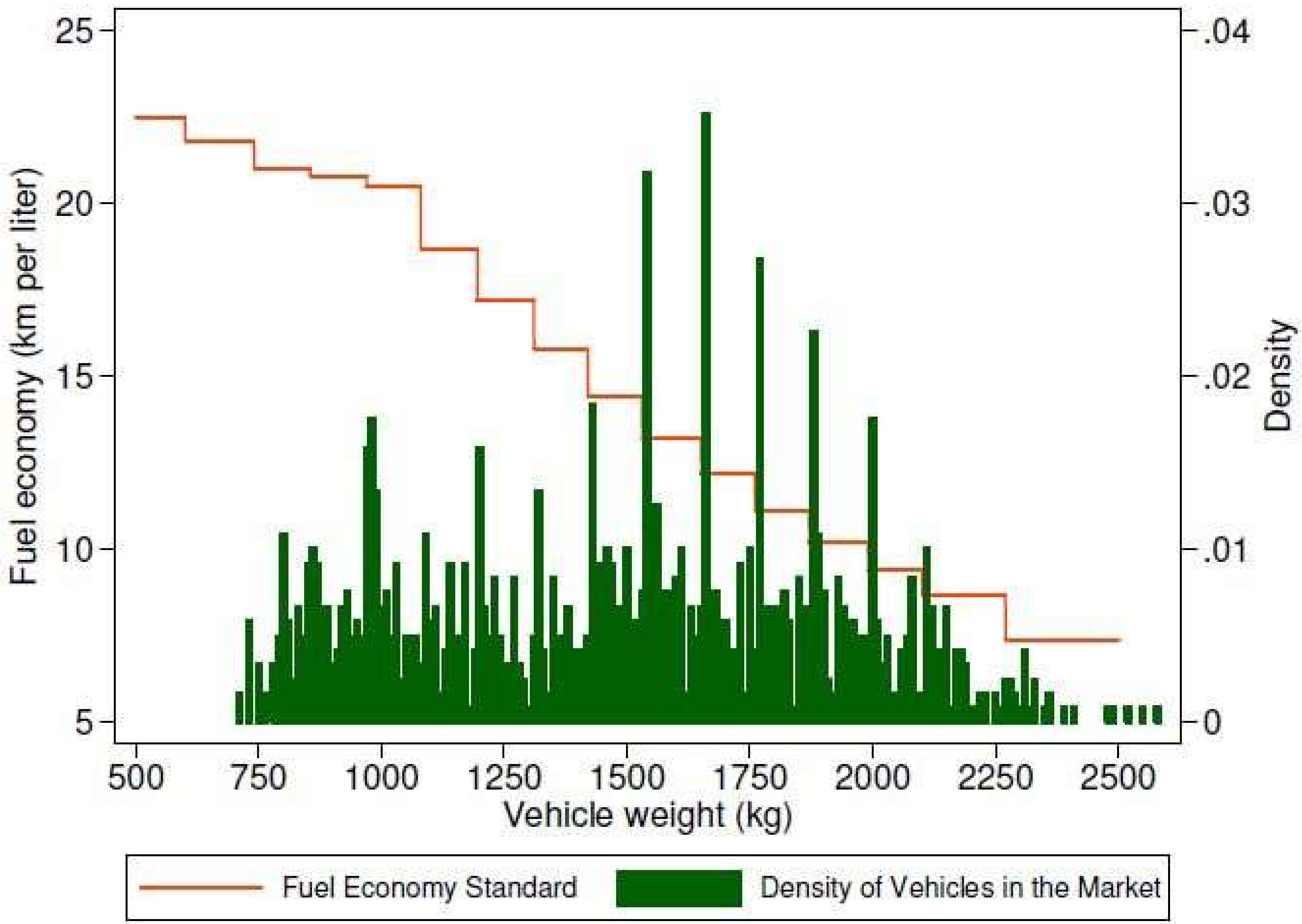
- Flex-fuel vehicles were sold at the same price as regular gasoline vehicles (to people that did not value flex-fuel capability)
- Consumers who bought flex-fuel vehicles often didn't even know!
- Flex-fuel vehicles were sold to consumers located very far away from H85 refueling stations
- Cost of producing flex-fuel: $9 – 27 per car
- The marginal costs of meeting fuel economy standards is really now as high as the automakers would like you to believe!

Figure 3: Fuel Economy Standard in Japan



#2. Bunching at the notches (Ito and Sallee, 2013)

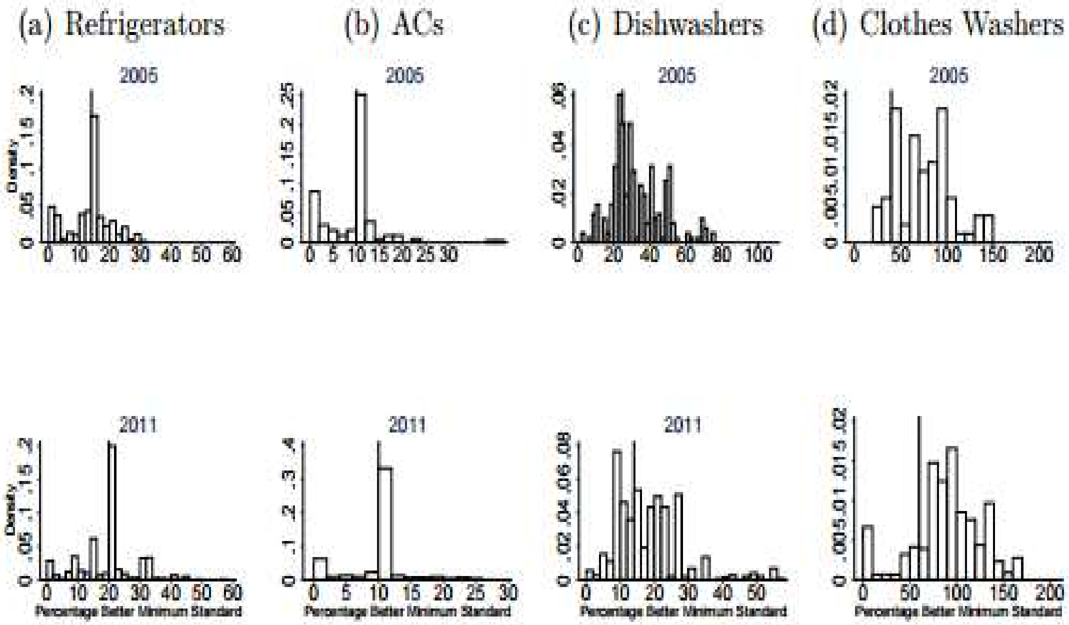
Panel B. Year 2013 (New Fuel Economy Standard Schedule)



Ito and Sallee (2013)

Charge higher prices when you can…

#3. Bunching at the Notches *and* Charging Higher Prices



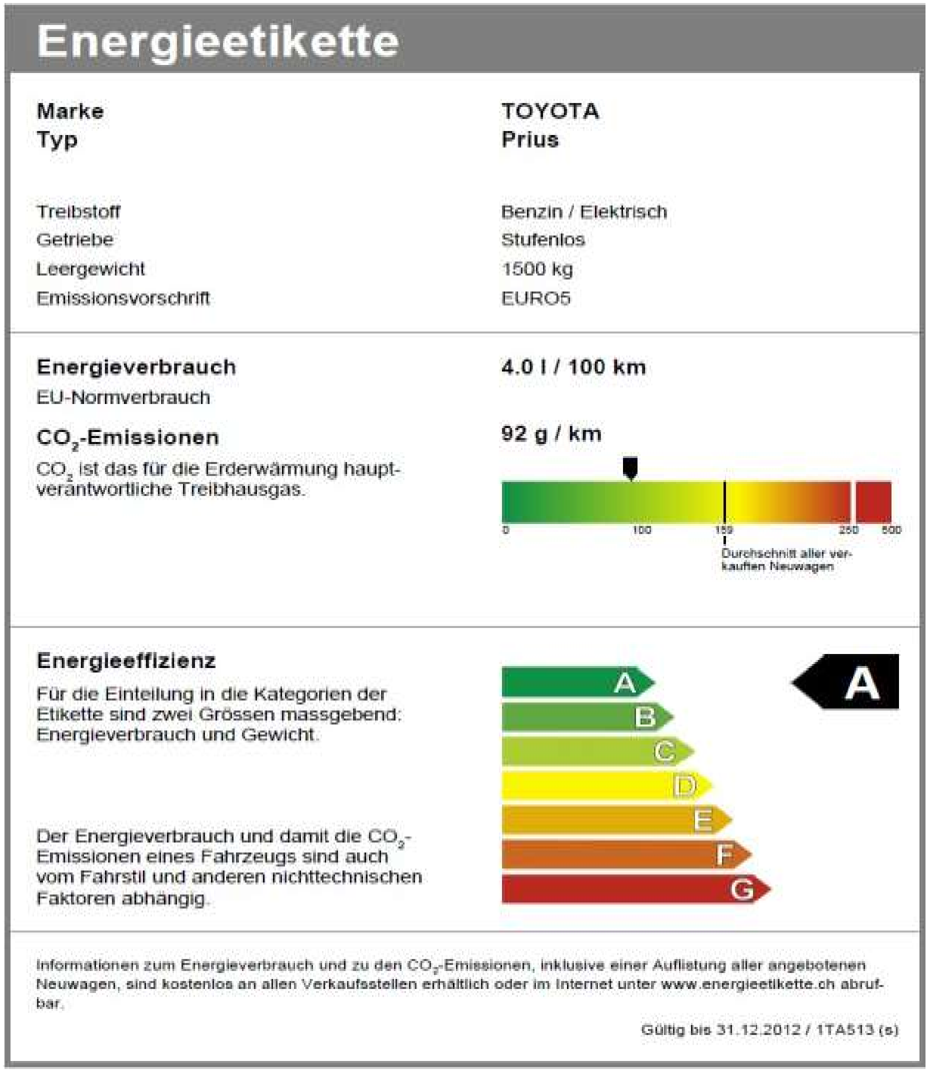
Houde (2014): Producers bunch up at EE standards and charge more for appliances that meet EE standards

#4. Seeking to Extract Higher Prices from Consumers

- Alberini et al. (2016): Fuel economy label system in Switzerland
- Car fuel consumption and CO_2 emissions rate in CH among the highest in Europe
- Reasons?
  - Topography
  - High disposable income of the Swiss
  - Fuel slightly cheaper than in neighboring countries
- System of fuel economy/CO_2 emissions labels – in place since 2003

The Swiss Fuel Economy Label for Passenger Cars

- Provides information about fuel efficiency and CO_2 emissions
- Comparison between this car and the average new car sold in CH
- A car is assigned to a label class based on a rating score
- Rating score = weighted average of absolute and relative fuel efficiency (60:40).
- Absolute: fuel consumption in liters per 100 km
- Relative: fuel consumption per 100 km per 1000 kg



Source: BFE

Rating Score Cutoffs used by Swiss BfE

Year	Threshold for A label
2003	20.3
2004	18.9
2005	18.9
2006	26.54
2007	26.54
2008	26.22
2009	26.22
2010	24.72
2011	24.72

Key Research Question

Does the label have an additional effect on price, above and beyond that of fuel efficiency alone?

- Cfr. labels and environmental certification on housing values (Brounen and Kok, 2011), office buildings (Eichholz et al., 2010), appliances (Houde, 2013)
- Cfr. Social norms (Allcott, 2011 – the OPower paper)

The Swiss Car Fleet and Market

- No car manufacturing in CH: All cars are imported
- ≈ 4.2 million cars
- Every year about 300,000 new cars sold
- Average CO_2 emissions in 2012:
  - fleetwide: 184 g/km
  - New cars: 151 g/km

- Importers – BFE negotiations
- Market dominated by German automakers
- Bestsellers in 2012:
  - VW, Audi, Renault, Ford, BMW, Skoda, Opel, Peugeot, Mercedes, Citroen
  - VW group: 18% of new car sales

Hedonic price model

$$\ln P_{imt} = a_m + \tau_t + \mathbf{x}_{imt}\boldsymbol{\lambda} + \beta \cdot DIESEL_{imt} + \gamma \cdot FE + \sum_{j=A}^{F} LABEL_{imt,j} \cdot \delta_j + \varepsilon_{imt}$$

Make-model fixed effect (e.g., BMW 3-Series or Toyota Corolla)

Year fixed effect

Car characteristics + polynomials in weight, hp_weight

Continuous fuel economy measure

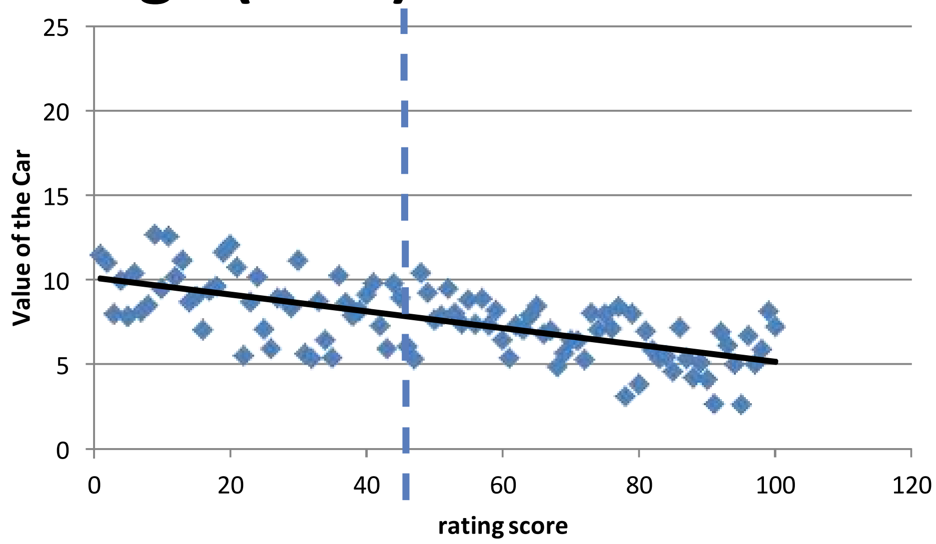
Label dummies

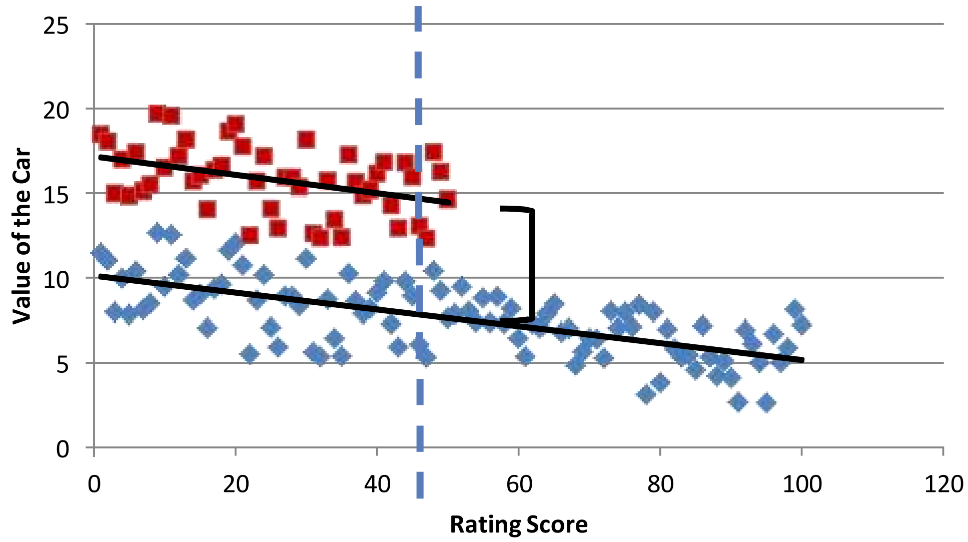
Regression Discontinuity Design (RDD)

- Units (cars) are assigned to treatment if an observed “driver” variable is below (above) a specified threshold

- Here, cars gets A if RN ≤ cutoff T

- Cars very close to the cutoff are very similar and so the jump in price is attributed to the treatment – as long as individual cannot precisely manipulate the driver variable





RDD Approach

- Sharp RDD (Imbens and Lemieux, 2008)
- Bandwidth $\pm$ 0.5 from cutoff for A label
- Fit:

$$\ln P_i = a + b \cdot A_i + c \cdot (RN_i - T) + d \cdot A_i \cdot (RN_i - T) +$$

$$+ f \cdot (RN_i - T)^2 + g \cdot A_i \cdot (RN_i - T)^2 +$$

$$+ \text{higher order terms} + \eta_i$$

ATT of making the A label

Threshold for A class

RDD Approach – cont'd

- If f, g and the coefficients on the higher order terms are zero, the model is simplified to a local linear regression with rectangular kernel
- Also fit a local linear regression with a triangular kernel (Hahn et al., 2001)

Data - 1

- List of all passenger cars approved for sale in Switzerland 2000 – 2011 (N = 51,206)
- Price (manufacturer-suggested retail price)
- Different attributes of the vehicles, such as…
  - Make, Model, Trim, Variant
  - Energy Label
  - Fuel consumption rate*
  - CO_2 emissions
  - Engine Size
  - Weight*
  - Horsepower
  - Doors
  - Vehicle Class
  - Body Type
  - Gearshift
  - Fuel type

* Used to compute rating and label

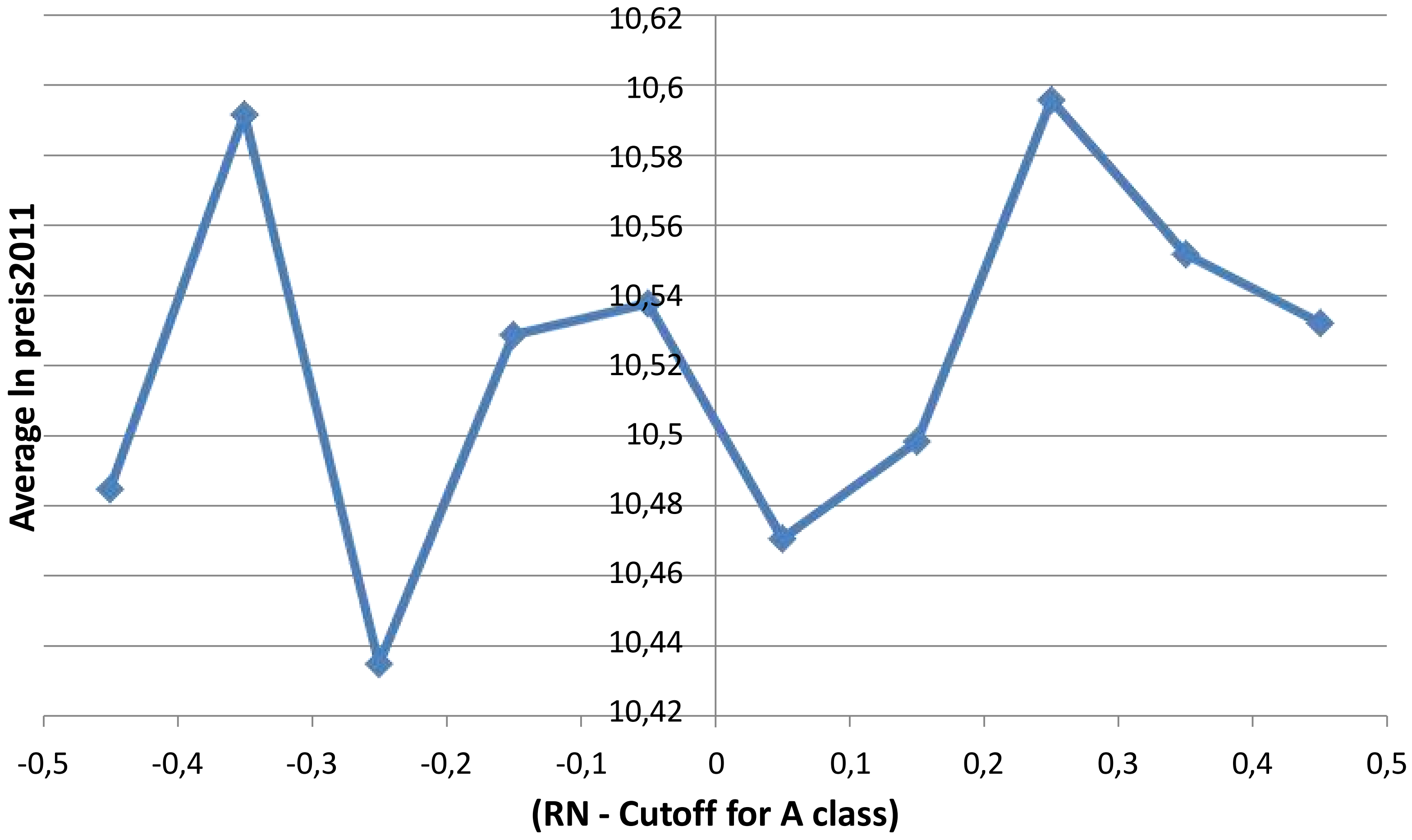
Data – 2

Price and Fuel Efficiency Descriptive Statistics

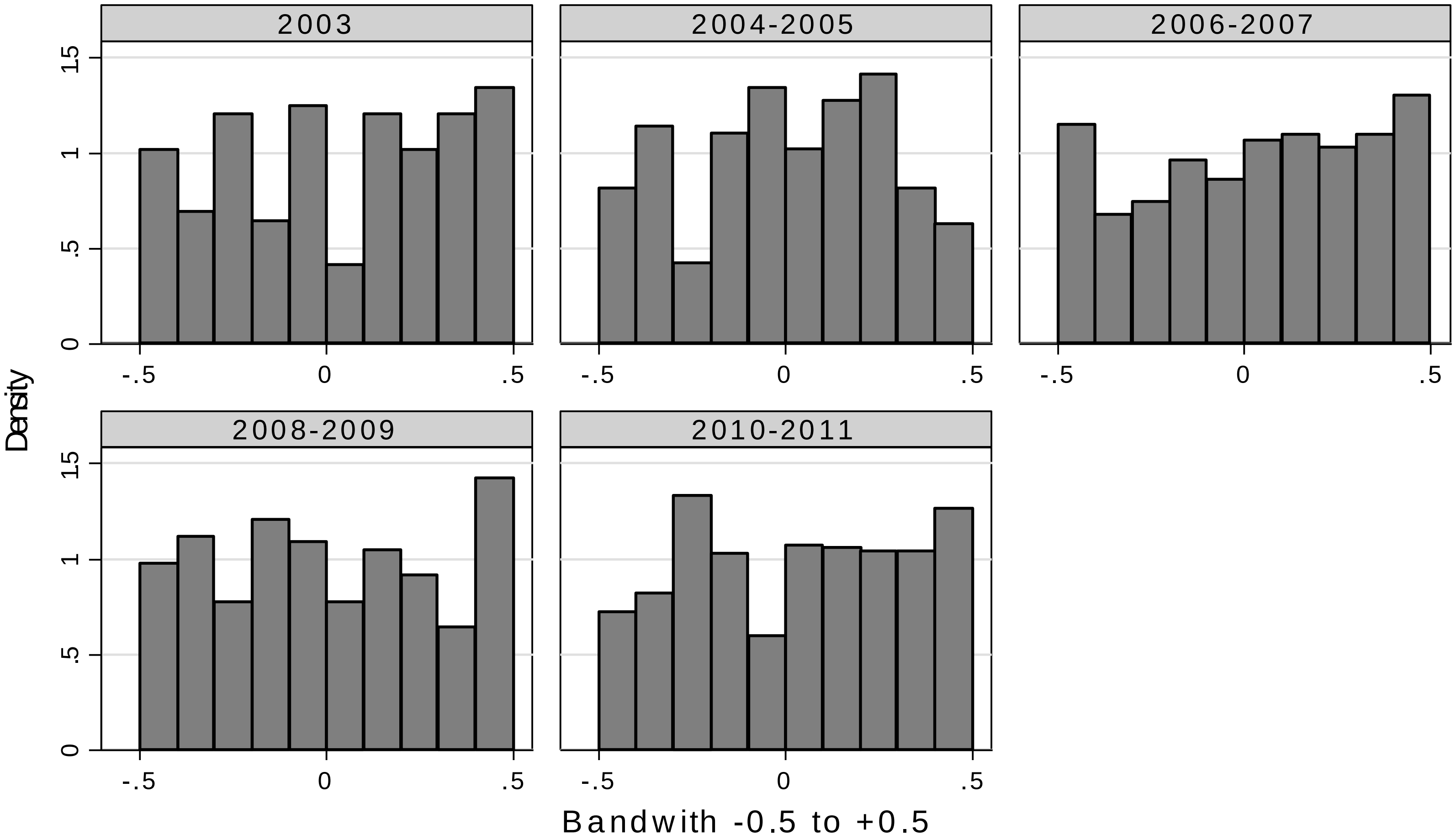
Variable	Description	Mean	Std. Dev.	Min	Max
preis2011	Price in 2011 CHF	43,422	18,723	10,278	270,000
fuelequi	fuel per 100 km in gasoline equivalent	7.70	1.70	3.36	12.10
fuel_weight	fuelequi/1000 kg	5.14	0.93	2.71	12.97
A label		0.22		0	1

Cleaned sample

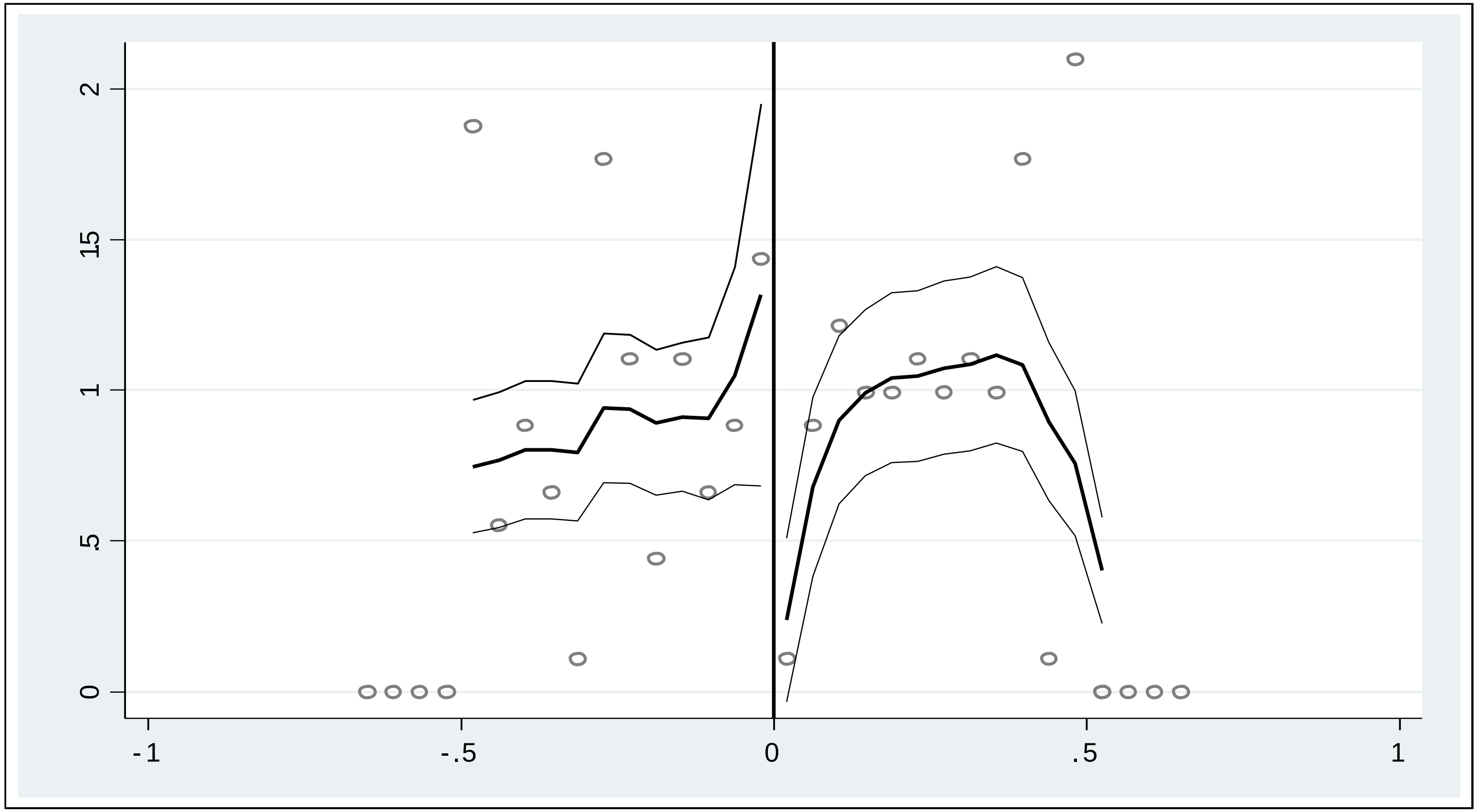
Evidence of Discontinuity Across the Threshold



Check: Driver variable is continuous across the cutoff

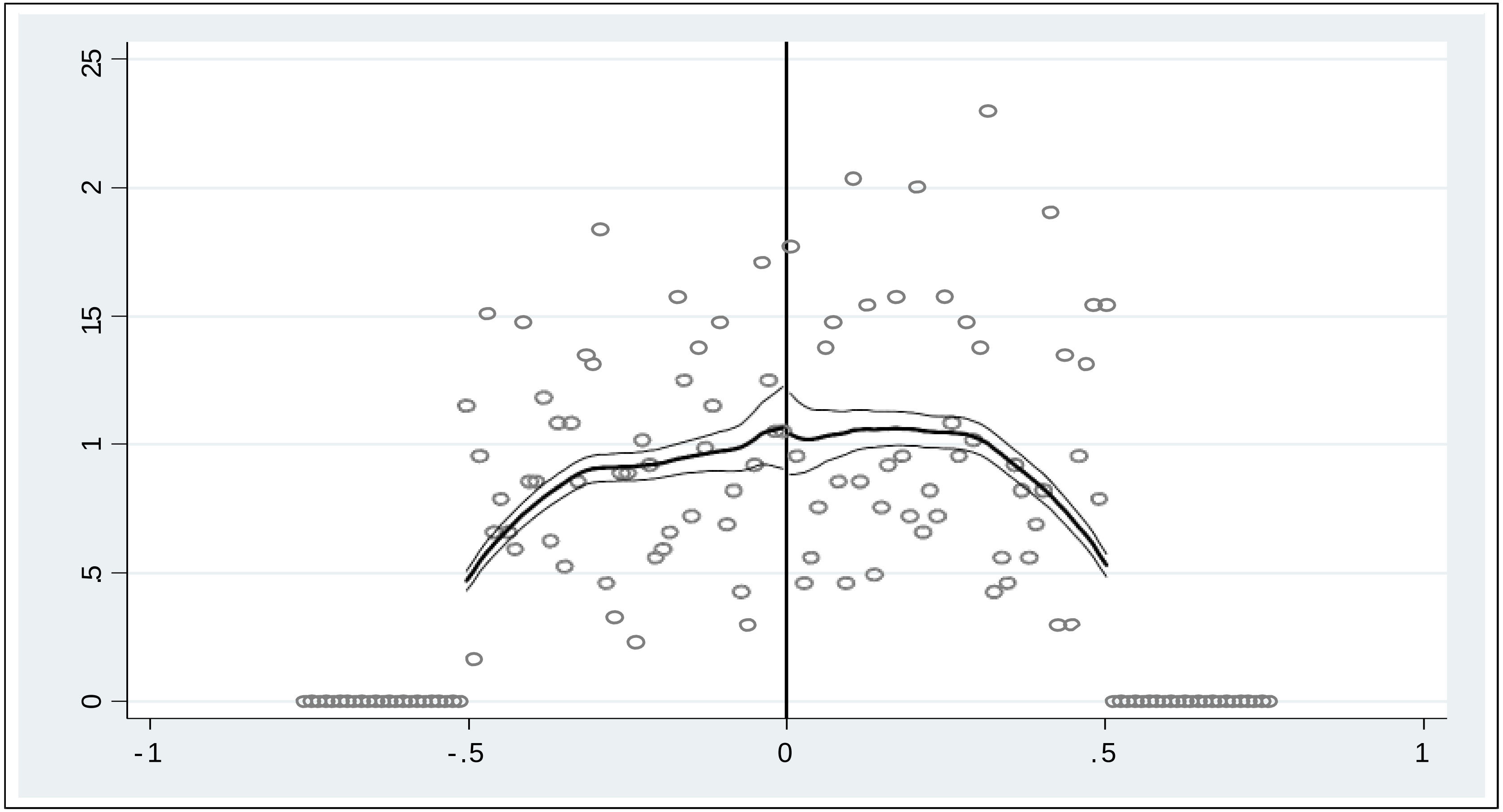


McCrary (2007) density test



2003 only

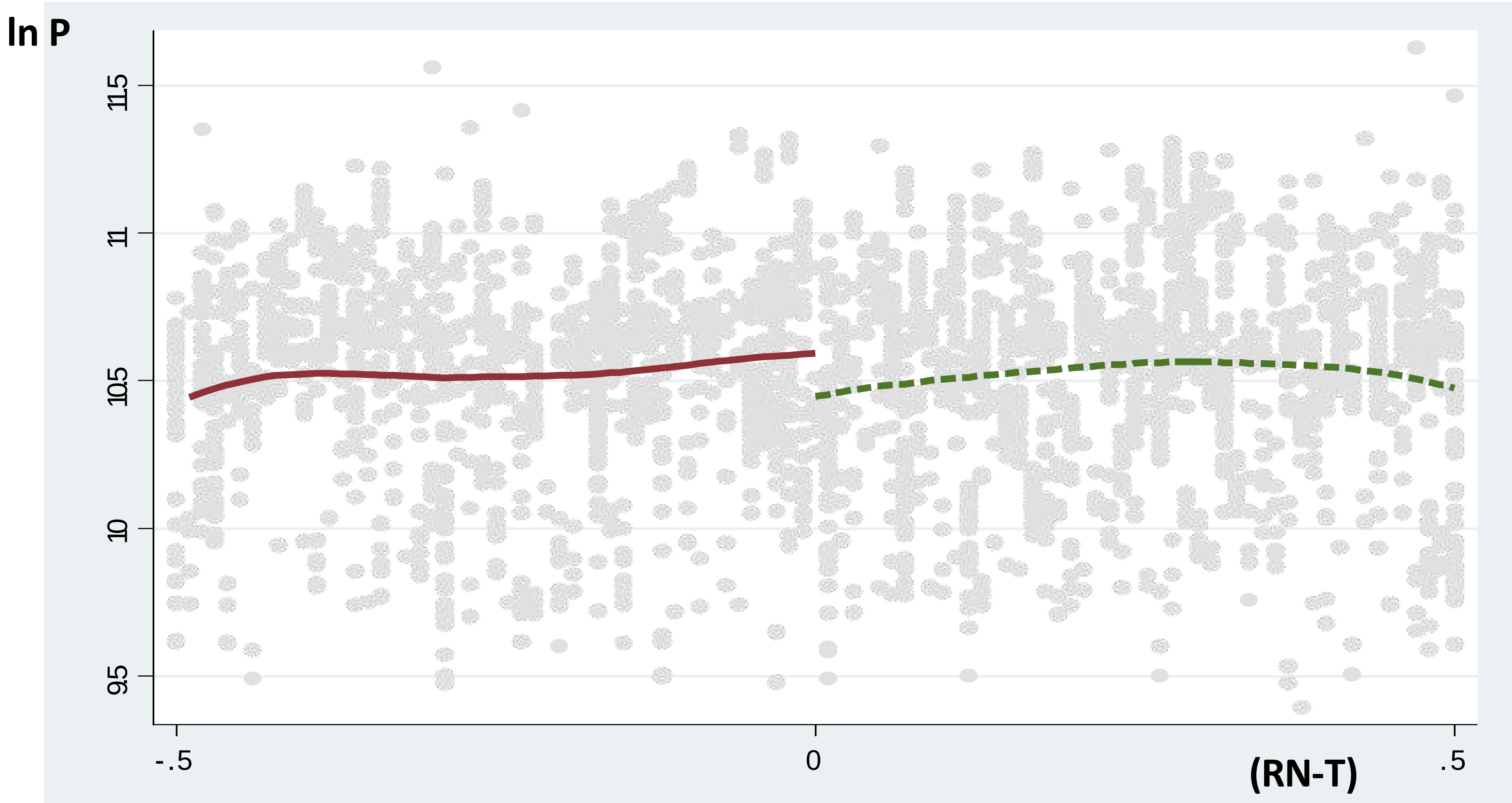
McCrary (2007) density test



2004-2011

Results from RDD

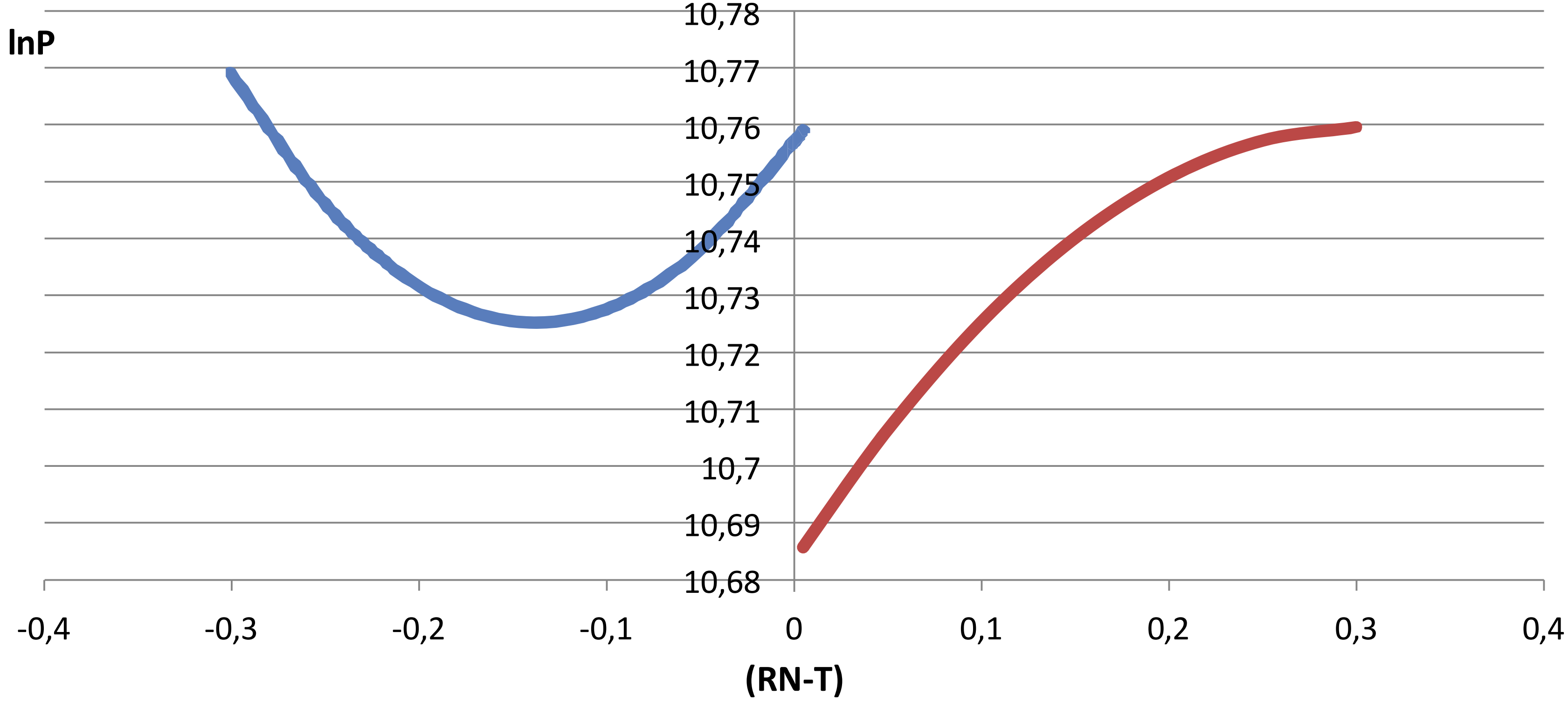
(local linear polynomial with triangular kernel)



- Same as previous slide
- Local linear regression with triangular kernel

ATT: 8.17% effect on price (t stat 3.12)

Results from RDD
(Quadratic with rectangular kernel)



- Model controls for car size, body type, transmission, AWD, Diesel, # doors
- Local quadratic polynomial in (RN-T)
- 2004 and later years

ATT: 7.60% effect on price (t stat 2.25)

Additional Checks

- Bandwidth
- Order of the polynomial
- Falsification tests
- B v. C: The RDD estimates the effect to be 3 – 4% and statistically insignificant (t stat never greater than 1.11)
- C v. D: The RDD estimates the effect to be less than 1% and statistically insignificant

But EE technologies change…

Houde and Spurlock (2015)

- Use extensive dataset from the largest sellers of domestic appliances in the US (Sears)
- Find that more energy efficient equipment is not necessarily more expensive:
- Once you control for quality, the more energy efficient equipment is actually *less* expensive
- Document instances in which the more EE equipment was offered at a lower price and people still chose a more expensive piece with virtually the same attributes

Changing car ownership and driving habits: Recent policies

- Gasoline tax $\approx$ carbon tax
- One-time bonus or malus linked to CO_2 emission rates (Sitzing, 2015; Klier and Linn, 2014; Adamou et al., 2014)
- Bonus or malus on annual registration fee linked to CO_2 emissions rates (Alberini and Bareit, 2016; Cerruti et al., 2016)

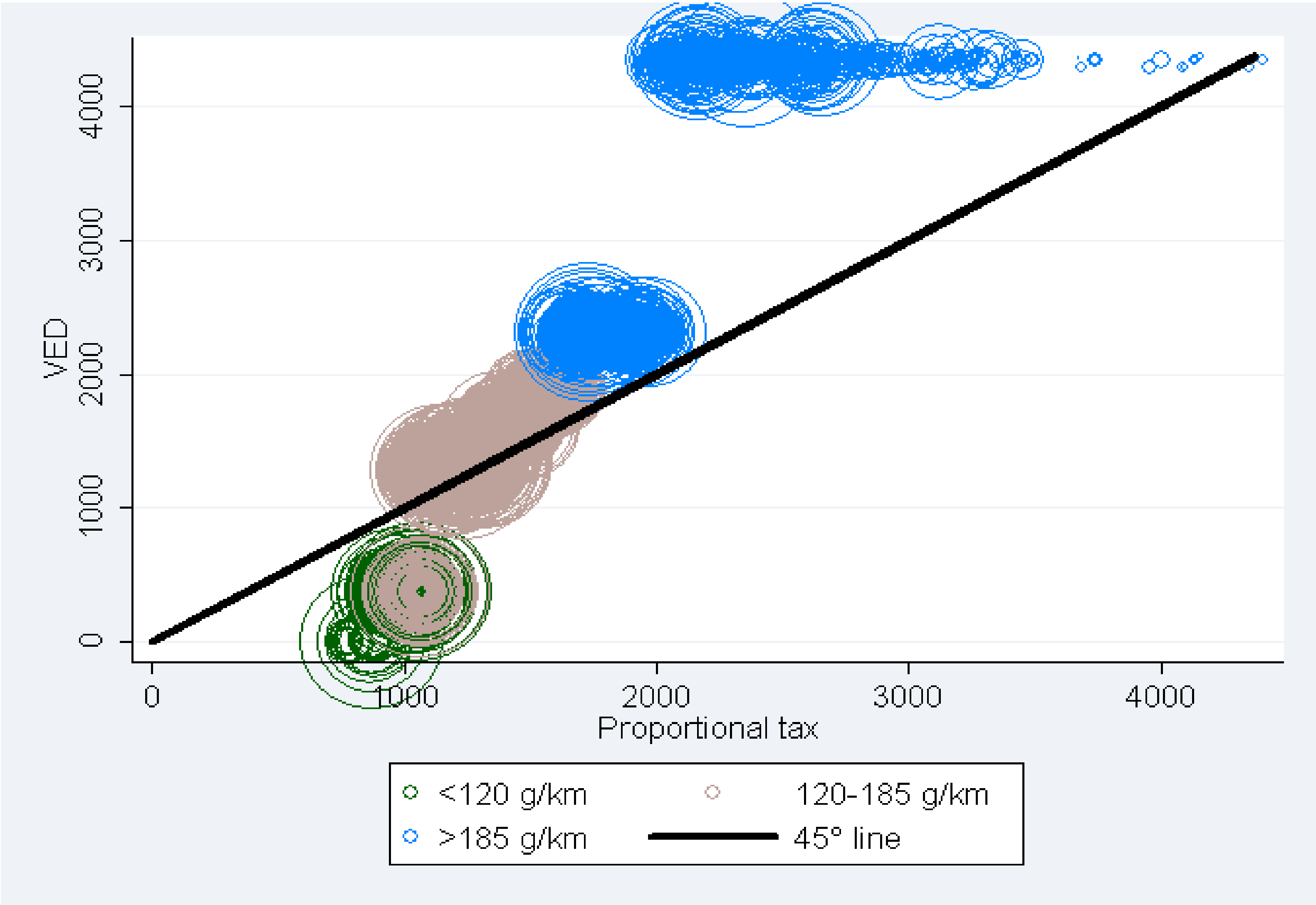
Registration fees linked to CO_2 emissions: The Vehicle Excise Duty (VED) in the UK

2001			2010		
VED Band	g CO2/km range	Annual registration fee (petrol) GBP	VED Band	g CO2/km range	Annual registration fee (petrol)* GBP
A	up to 150	100	A	up to 100	0
B	161 - 165	120	B	100 - 110	0
C	166 - 185	140	C	111 - 120	0
D	186+	155	D	121 - 130	0
			E	131 - 140	110
			F	141 - 150	125
			G	151 - 165	155
			H	166 - 175	250
			I	176 - 185	300
			J	186 - 200	425
			K	201 - 225	550
			L	226 - 255	750
			M	255+	950

Cerruti, Alberini and Linn (2016)

- Estimate a model of sales by make-model-trim-variant
- Berry (1994)
- Effect on total CO_2 emissions from
    - Changing the VED from the 2006 to the 2010 levels **(0.67% reduction in emissions)**
    - Imposing an annual tax is that is strictly proportional to a car's CO_2 emissions rate (the VED is a step function of the CO_2 emissions rate) **(0.11% increase in emissions)**
    - Imposing a carbon tax (carbon emissions depend on the car's emissions rates and how much one drives) **(2.88% reduction in emissions, due mostly to adjustment in driving)**

Actual VED v. annual fee proportional to the CO2 emissions rate (holding the revenue the same)



Alberini and Bareit (2016)

- Exploit the variation in annual registration fees across Swiss cantons and over time
- In 2005, Cantons started linking the annual registration fee to CO_2 emissions rates or fuel economy (bonus/malus)
- Not all of them did. For example, Zürich stayed with the old system.
- Berry (1994) type of model
- Sales respond to bonus/malus, but not much
- A 50% malus to emitters of 200+ g/km in Zürich changes sales and reduces emissions by 3%, at a cost of some 800 CHF per ton.

Other effects of the registration fees in CH – Martinez-Cruz et al. (2016)

- Q: Do emissions-linked registration fees cause earlier or later scrappage of old and highly polluting vehicles?
- Geneva – 2010 – malus applies only to new high emitting cars (200+ g/km)
- Obwalden – 2009 – malus applies to all “G” cars (existing and new)

- Survival analysis
- Geneva: policy *lengthens* lifetime of existing vehicles by 5 – 8 months
- That defeats the purpose of the policy!
- Obwalden: high polluters retired sooner (by 7 – 11 months)

Conclusions

- Review of research that assesses effectiveness, costs and benefits of policies
- Strategic responses by suppliers
- Consumer Behaviors
- Examined reasons why you should/shouldn't trust results from empirical models (in some cases)
- Creative econometrics needed to get around data challenges
- Assessing policies is difficult…let alone coming up with good ones!

Thank you!

Questions, suggestions, etc.?

aalberin@umd.edu