The Economics of Attribute-Based Regulation: Theory and Evidence from Fuel-Economy Standards

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What is an “attribute-based regulation”?

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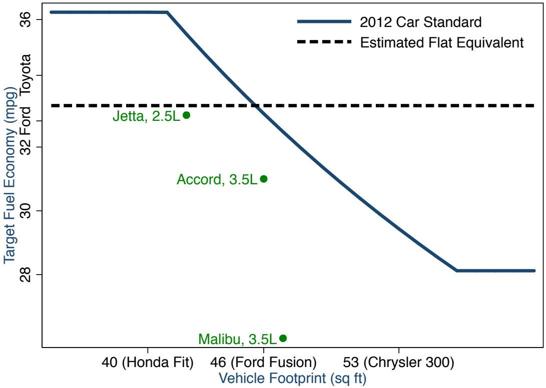
- An ABR is a regulation that targets some characteristic of a product or firm, but which takes some secondary attribute into consideration when determining compliance

Fuel Economy Standards in the U.S. since 2012



MPG standard (regulation) depends on footprint (attribute)

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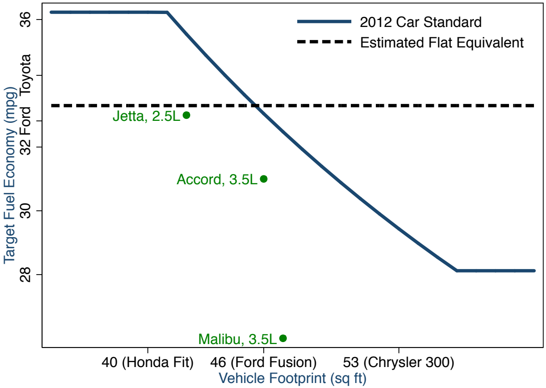
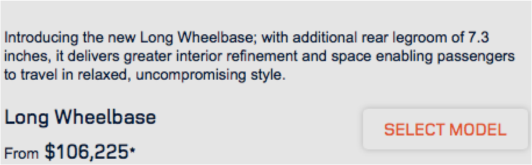


MPG standard (regulation) depends on footprint (attribute)

- **Potential cost:** secondary attribute may be distorted in response to the regulation; cars may get larger

Anecdotal evidence of the "up-sizing" incentive

- The New Range Rover advertises its **"Long Wheelbase"** (footprint = wheelbase $\times$ trackwidth)



Introducing the new Long Wheelbase; with additional rear legroom of 7.3 inches, it delivers greater interior refinement and space enabling passengers to travel in relaxed, uncompromising style.

Long Wheelbase

From $106,225*

SELECT MODEL

Hat tip: Catie Hausman

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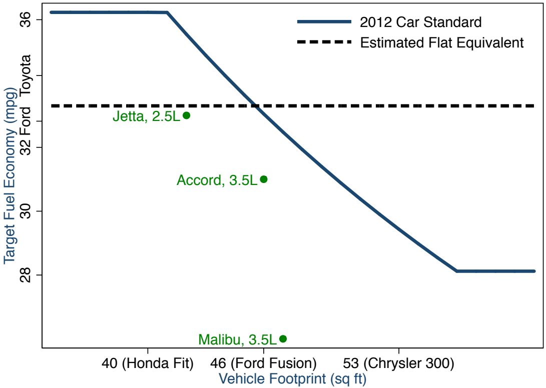

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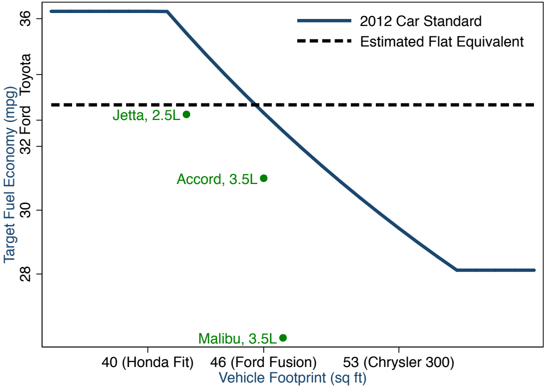

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- **Efficiency benefit?** equalize marginal cost of compliance

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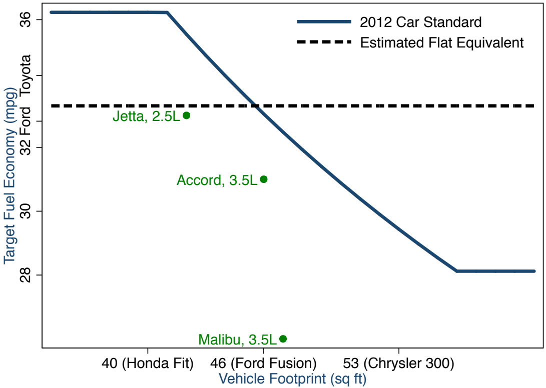

MPG standard (regulation) depends on footprint (attribute)

- **Efficiency benefit?** equalize marginal cost of compliance
- **Other possible benefits:** incidence, "fairness", safety, technology, targeting/tagging, imperfect competition

Attribute-based regulation is ubiquitous

- Attribute-based regulation (ABR):
  - Consider regulation on **e**
  - Stringency of regulation (**s**) depends on attribute (**a**)

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- Firm liability **s** for worker safety depends on firm size **a**
- Affordable Care Act **s** depend on firm size **a**
- Power plant emissions rules **s** depend on plant vintage **a**
- Income tax schedule **s** depends on marital status **a**

In this paper, we examine theory and evidence of ABR

Research question:

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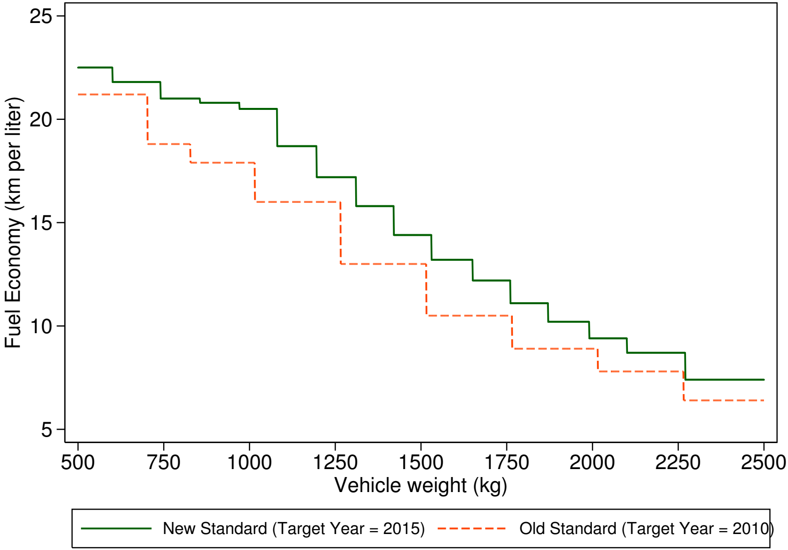
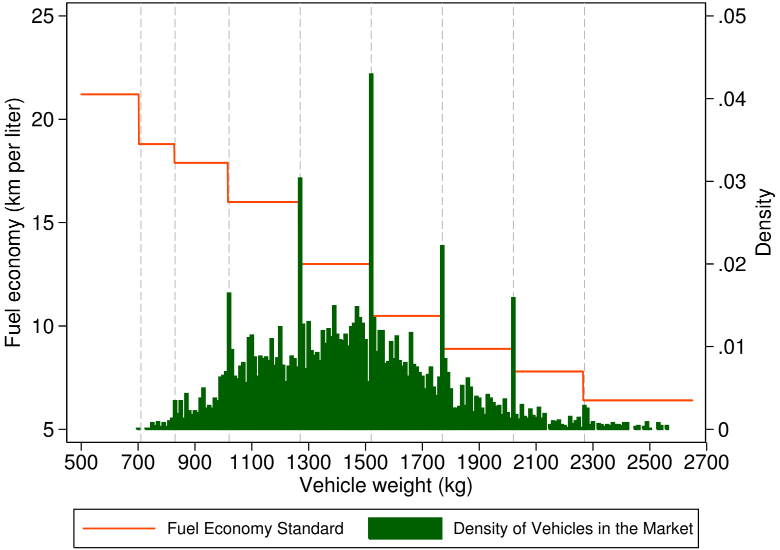
   - Empirical evidence from the Japanese auto market

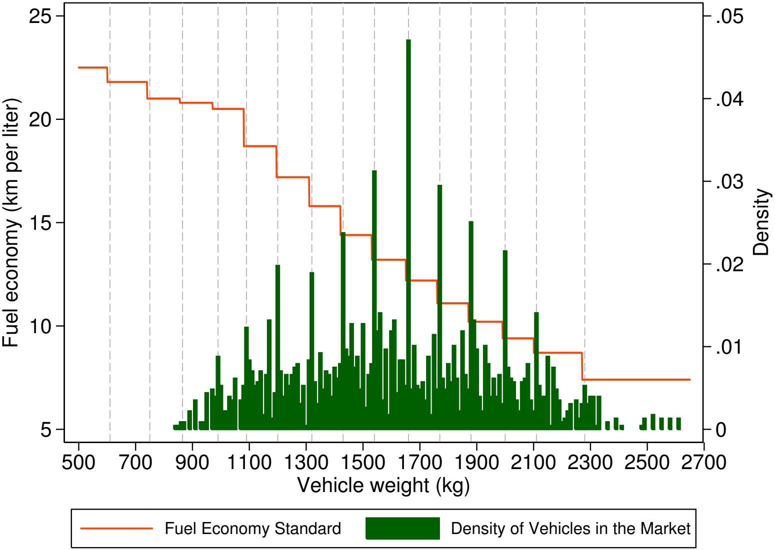
- “Notched” Fuel Economy Standard Schedule in Japan



- Use “bunching” to estimate firm’s responses to policy



- Use a policy change to test if bunching moved accordingly



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Road Map

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Sketch of the theory to get intuition (details in paper)

- Suppose fuel economy **e** creates (positive) externality ϕ

- Non-attribute-based Pigouvian subsidy for fuel economy **e** is:

$$\text{Subsidy } = S(e) = s \cdot e$$

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- Essentially, ABR creates an implicit extra subsidy for weight **a**

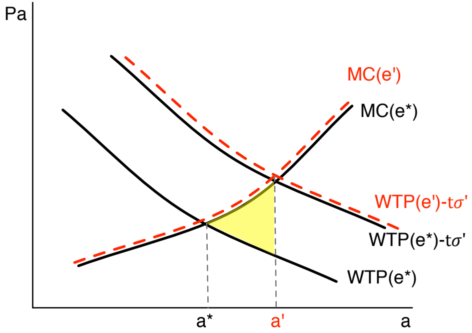
ABR creates two incentives

- ABR creates two subsidy incentives for **a** and **e**:

$$\frac{\partial S(a,e)}{\partial e} = s$$
$$\frac{\partial S(a,e)}{\partial a} = -\sigma'(a) \cdot s$$

- 1st incentive is sufficient to correct externality (by $s =$ Pigou)
- 2nd incentive creates unnecessary distortions in **a**

Proposition 1: Optimal policy $\to$ No ABR: $\sigma'(a) = 0$



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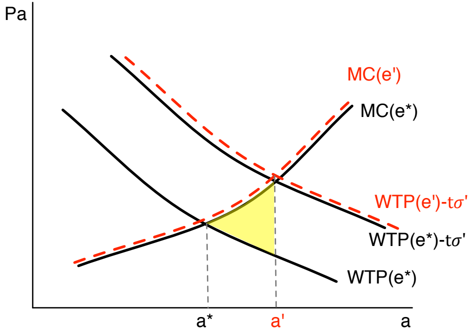

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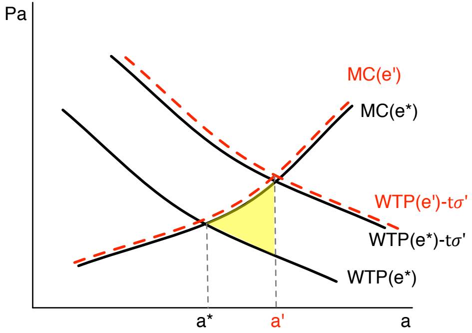

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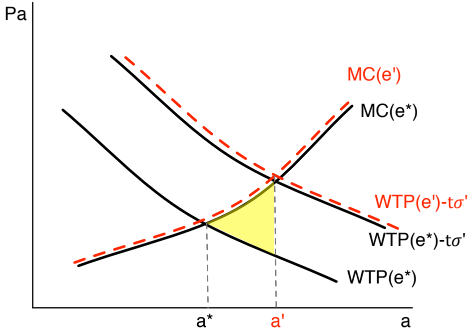

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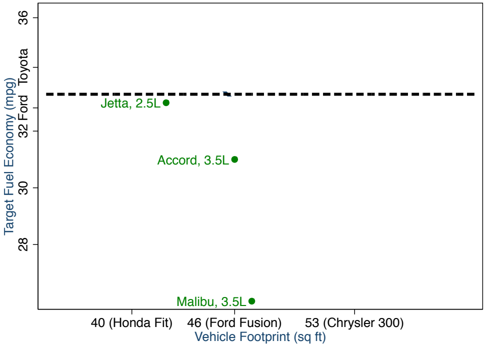
- Does ABR help equalizing marginal costs of compliance?
- "No" in this case. Tax/subsidy equalizes MC of abatement

Corollary 1: Regulation with "compliance trading" $\rightarrow$ Equivalent result to the tax/subsidy case



- Firms can trade their "compliance"
- Compliance trading equalizes MC of compliance
- A shadow price of compliance = Pigouvian subsidy

Proposition 3: ABR attenuates corrective subsidy

- What is the optimal subsidy level when we have to do ABR?
- For illustration, consider linear AB subsidy: $s \cdot (e - \hat{\sigma} a)$, where $\hat{\sigma}$ is a constant

- **Proposition 3:** Suppose $\hat{\sigma}$ fixed. Then SB s is:

$$s^{SB} = \frac{\phi}{1 - \hat{\sigma}\left(\frac{(\sum_n \frac{\partial a}{\partial s})/n}{(\sum_n \frac{\partial e}{\partial s})/n}\right)} \leq \phi$$

- ABR **attenuates** corrective subsidy
- Response to policy tilted towards **a** $\rightarrow$ attenuation greater

Under alternative assumptions, can ABR be useful?

- How about if compliance trading is unavailable?
  - I'll talk about this in the final part of this talk
- Incidence ▸ More
  - Regulators may use ABR to redistribute compliance burdens
  - Our new theory section incorporates this possibility
  - Note: efficiency loss from distortions still exists
- Targeting/tagging ▸ More
  - Suppose that "actual externality" cannot be regulated
  - In theory, an optimal ABR can be designed
  - However, observed ABR policies are not created in this way

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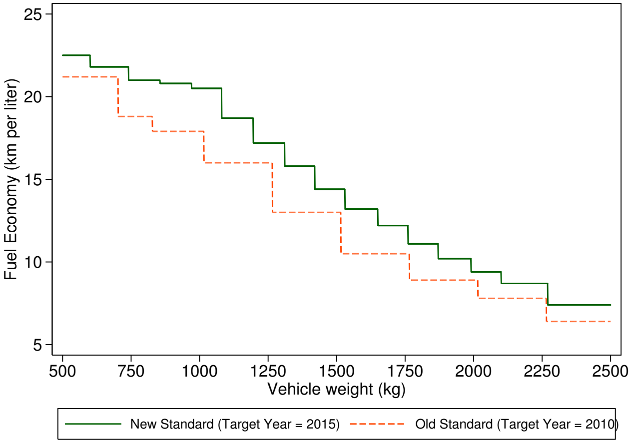
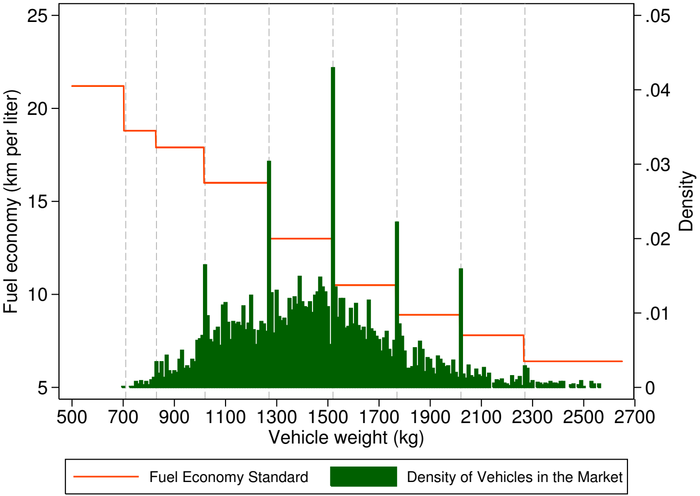
Japan's fuel economy regulations provide three advantages



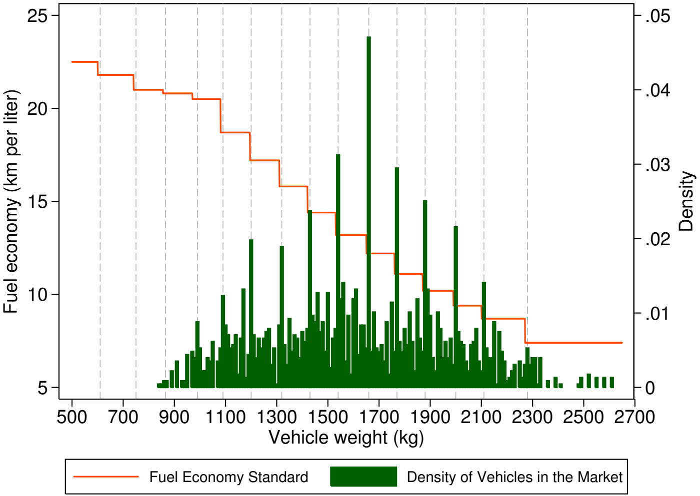
1. Notched schedule in vehicle weight
2. A policy change of the notched schedule
3. Long analysis window (policy started in 1970's)

A histogram of raw data reveals substantial bunching



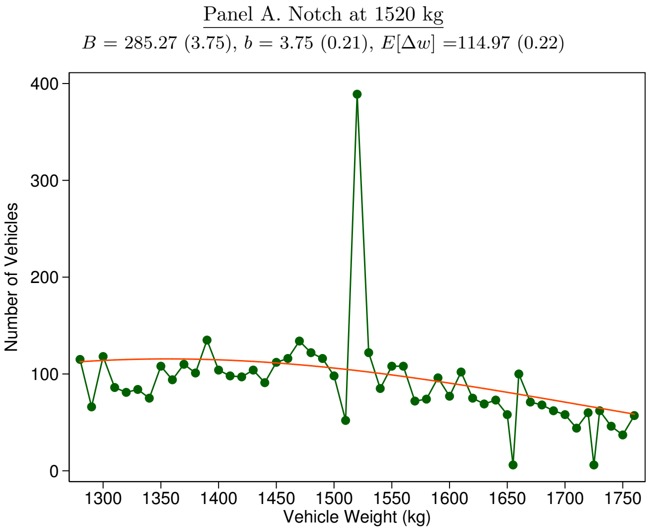
- Data: 2001-2008
- Bunching of vehicles at notches in vehicle weight

After a policy change, bunching moved accordingly



- Data: 2009-2013 (new fuel economy standard)
- Bunching at "new" notches in vehicle weight

We econometrically estimate excess bunching



- Estimate a counterfactual density to estimate excess bunching (Chetty et al. 2011 and Kleven and Waseem 2013)

How to estimate the counterfactual density?

$$c_j = \sum_{s=0}^{S} \beta_s^0 \cdot (w_j)^s + \sum_{k=1}^{K} \gamma_k^0 \cdot d_k + \varepsilon_j,$$

- c_j = the number of vehicles in a 10 kg bin
- w_j = weight (kg) for bin j
- First summation is a polynomial; we use $S = 7$
- Second summation is a dummy variable for each notch point k
- Fit the polynomial to the distribution, excluding notch points

- Counterfactual distribution: $\hat{c}_j^0 = \sum_{s=0}^{q} \hat{\beta}_s^0 \cdot (w_j)^s$
- Excess bunching of cars at notch k is $\hat{B}_k^0 = c_k - \hat{c}_k^0 = \hat{d}_k^0$

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- This **initial estimate** overestimates excess bunching
- Because it does not satisfy "integration constraint"

How to satisfy the integration constraint?

$$c_j + \sum_{k=1}^{K} \alpha_{kj} \cdot \hat{B}_k = \sum_{s=0}^{S} \beta_s \cdot (w_j)^s + \sum_{k=1}^{K} \gamma_k \cdot d_k + \varepsilon_j,$$

- Our method is an extension of Chetty et al. (2011 QJE)
- Estimate this equation by iteration until we reach a fixed point
- **We make an important (conservative) assumption:**
- Bunching comes only from the immediate left weight bins
- Potentially, firms respond more to reach a further right notch
- Our method provides **lower bounds** of firms' responses

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- Two methods to specify α_{kj}
  - Uniform assumption
  - Estimate α_{kj} from the observed & counterfactual distribution

How should we interpret counterfactual distribution?

- Counterfactual: policy with same shadow price λ, but no attribute-basing ($\sigma' = 0$)

- For illustration, consider a notched tax policy with only one notch:

$$t(a,e) = \begin{cases} t \cdot e & \text{if } a < \bar{a} \\ t \cdot e + \tau & \text{if } a \geq \bar{a}. \end{cases}$$

- For all non-bunchers ($a \neq \bar{a}$):
  - Incentive for $t : \partial t(a,e)/\partial e = t$
  - Incentive for $a : \partial t(a,e)/\partial a = 0$
  - τ is lump-sum $\Rightarrow$ choice of a and e independent of τ

- Therefore, non-bunchers choose as though $t(a,e) = t \cdot e$

Bunching Estimation Results

- First, we report results for 2001-2008 (old fuel econ. standard)
- Bootstrapped S.E. (Chetty et al. (2011 QJE) and Kleven and Waseem (2013 QJE))

Notch Point	Fuel Economy Standard below & above the Notch (km/liter)	Main Estimates: Excess Bunching (# of cars)	Main Estimates: Excess Bunching (ratio)	Main Estimates: E[Δweight] (kg)
(1)	(2)	(3)	(4)	(5)
830 kg	18.8	16.46	2.13	51.57
	17.9	(7.91)	(0.49)	(3.21)
1020 kg	17.9	87.18	2.41	103.77
	16	(8.05)	(0.16)	(0.49)
1270 kg	16	163.48	2.47	146.89
	13	(7.92)	(0.11)	(0.62)
1520 kg	13	285.27	3.75	114.97
	10.5	(8.21)	(0.21)	(0.22)
1770 kg	10.5	143.93	3.52	129.44
	8.9	(8.93)	(0.30)	(0.57)
2020 kg	8.9	127.07	8.51	120.77
	7.8	(9.04)	(1.55)	(0.15)
2270 kg	7.8	15.67	2.52	137.86
	6.4	(6.40)	(0.66)	(4.48)

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Summary of bunching estimation results

- Substantial excess bunching at each notch point
  - $b = 2.1$ to 8.5 in the old fuel economy standard (2001-2008)
  - $b = 1.6$ to 4.1 in the new fuel economy standard (2008-2013)
- Weight manipulation is economically significant
  - $\approx$ 10% of vehicles have manipulated weight
  - Average weight increase of those vehicles is $\approx$ 110 kg
  - Implies empirical evidence of distortion in a (attribute)
- What is the welfare loss from the weight increase?
  - Heavier vehicles increase fatality for other cars
  - DWL $\approx$ \$1 billion per year for the Japanese auto market

Welfare loss from safety externality

- Externality of heavier vehicles
  - Increase probability of fatality of other cars
  - Anderson and Auffhammer (2012) and Jacobsen (2013)

- Deadweight loss (DWL)
  - DWL $\approx \Delta kg * \partial Fatalities / \partial kg * VSL$
  - Anderson and Auffhammer (2012): 1000 lb increase raises probability of fatality by 0.09%
  - DWL $\approx 110 * 2.2/1000 * .0009 * 9,300,000 =$ **\$2026 per manipulated car**
  - **DWL $\approx$ \$1.0 billion** in the Japanese market per year

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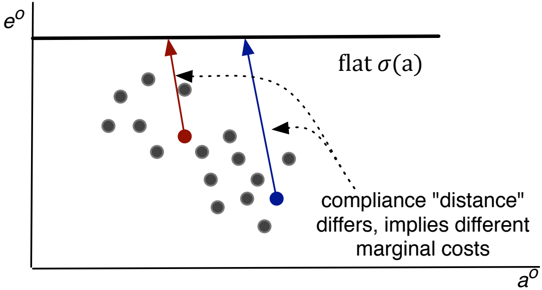
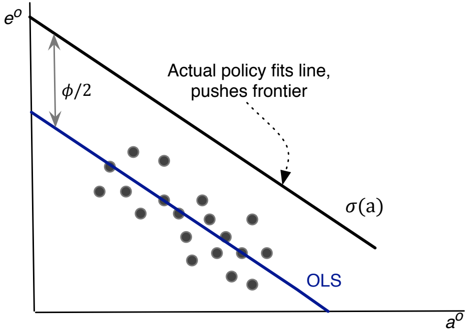
   - Develop new "double notch" method

What if compliance trading is not available?

- With no compliance trading, a flat standard creates different marginal costs of abatement across products ⇒ inefficiency

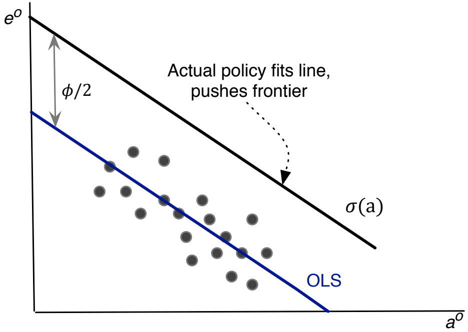


- Potentially, ABR may help equalizing marginal costs?



Proposition 4 from theory section

- Benefit: ABR can *partially* equalize the MC of abatement



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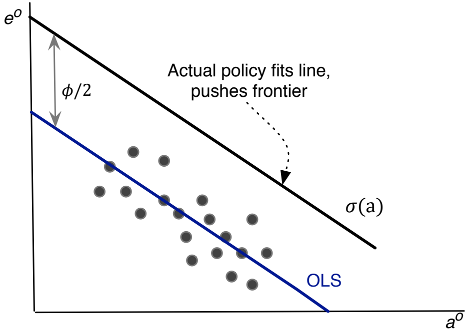
- Cost: ABR distorts attributes



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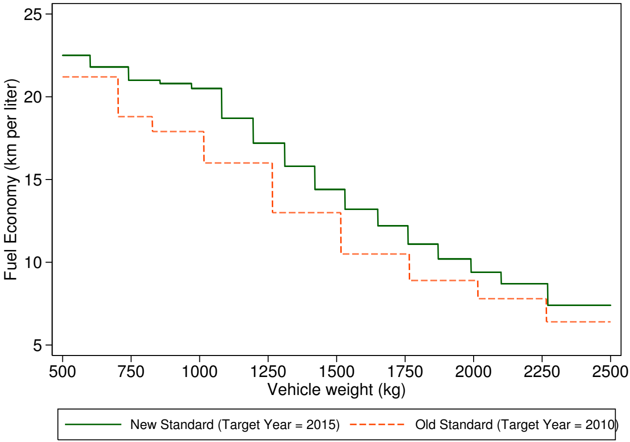
Empirically investigate this welfare implication

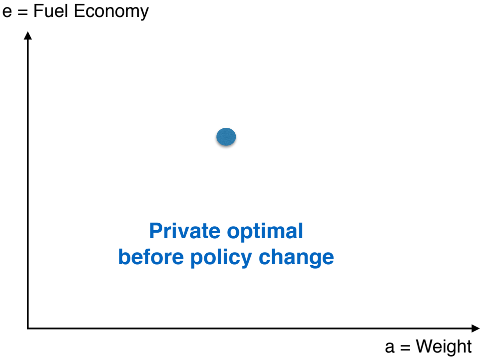
- Leverage panel data on vehicle redesigns in a "double notched" policy

Policy change: a new subsidy for each specific vehicle

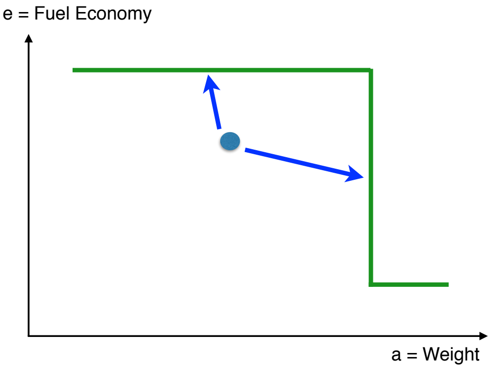


- New policy
  - Changes in the notched schedule
  - Subsidy (about $1,500) per car sale if car meets the standard

Consider a vehicle before the policy change

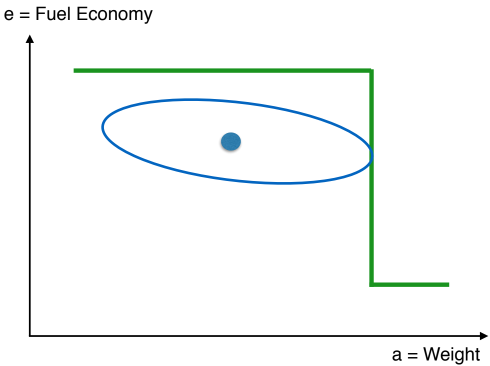


This policy change creates a <u>double notch</u> problem



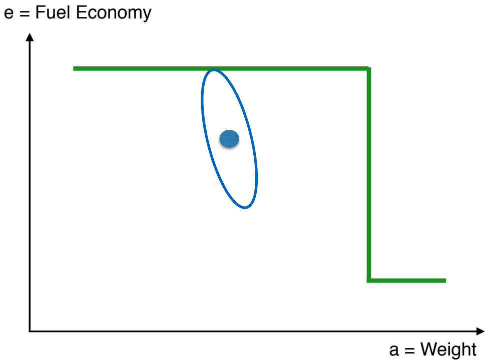
- Subsidy if $(a, e) \in$ upper-right areas
- But, deviation from the initial optimum creates loss in surplus
- What is the optimal choice of Δa and Δe?

Consider a level set of a loss function



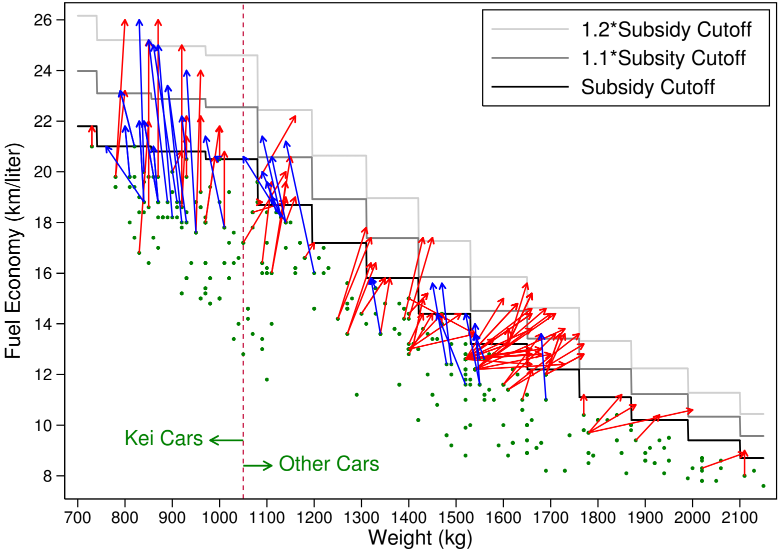
- This example shows the case where Δa creates smaller loss

This example shows the case where Δe creates smaller loss



- This loss function determines responsivness of a and e wrt t
- This is key for welfare and policy analysis
- Goal is to recover this loss function from revealed preference

Raw panel data reveal each car's "path" to the subsidy



Estimate adjustment cost function from revealed choices

- For each vehicle j, the data tell us their $Choice(a_j, e_j)$
- Discrete choice model for Δa_j and Δe_j

$$Choice_j = \alpha \Delta a_j^2 + \beta \Delta e_j^2 + \gamma \Delta a_j \Delta e_j + \tau Subsidy_j + \varepsilon_j$$

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- Estimate by Logit. More results are in Table 4.

$$Choice = -1.24 \cdot \Delta_a^2 - 1.15 \cdot \Delta_e^2 + 0.13 \cdot \Delta_a \Delta_e + 0.77 \cdot Subsidy$$

- This function tells us the relative cost of changing a and e
- We use this adjustment cost function for policy simulation

Compare three policies by policy simulation

Three policy alternatives to correct externality **e**

1. ABR
2. Flat standard with NO compliance trading
3. Efficient (= flat standard with compliance trading)

What is each policy's welfare cost in order to achieve the same welfare benefit by improving **e**?

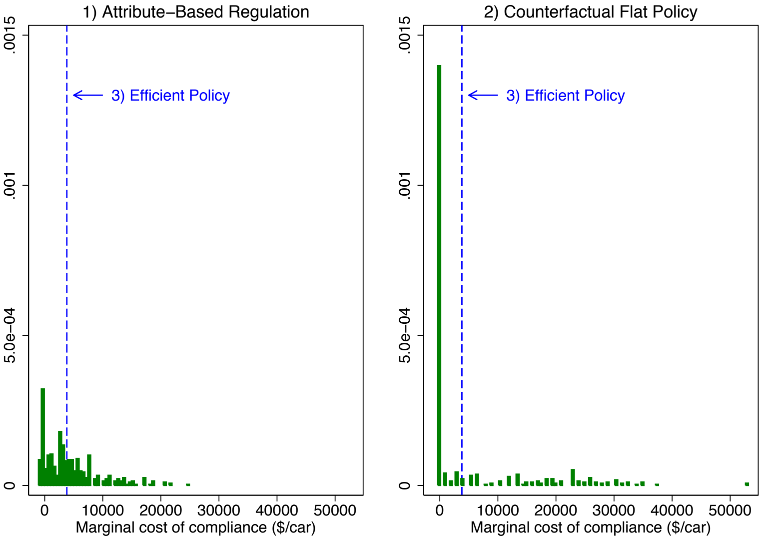
Compare three policies by policy simulation

	Δe: Fuel consumption (liter/100km)	Δa: Weight (kg)	Cost from Δe (\$/car)	Cost from Δa (\$/car)	Welfare cost (\$/car)	Cost relative to ABR
Panel A) Based on the Loss Function without Controls for Compliance Regulation						
ABR	-0.76	33.28	-1319	-524	-1843	1.00
Flat	-0.76	0.00	-3590	0	-3590	1.95
Efficient	-0.76	0.00	-731	0	-731	0.40

Three policy implications:

1. Efficiency $\rightarrow$ 1) Efficient policy $>$ 2) ABR $>$ 3) Flat
2. **Cost of ABR**: Attribute distortions (Δa)
3. **Benefit**: Equalize marginal compliance costs (only partially)

Histogram of marginal costs of compliance



Planned empirical extension

- Our DCM estimates "reduced-form" adjustment cost
- Under perfect competition, adjustment cost = social cost

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- Use method of Berry, Levinsohn and Pakes (1995) to estimate welfare for observed products
- To model counterfactual policy, need to allow price, weight and fuel economy to respond; BLP endogenizes only price
- We could:
  1. Use BLP, but endogenize all three with instruments
  2. Use our DCM approach to establish counterfactual products

Planned empirical extension: algorithm

1. Estimate BLP on actual data (with actual policy)
   - Yields consumer and producer surplus
2. Estimate DCM in 3-dimensions: price, weight, fuel economy
3. Marginally change policy (e.g., flatten $\hat{\sigma}$)
4. Use DCM to predict counterfactual set of products
   - DCM predicts new price, weight, fuel economy
   - Assume other attributes are unchanged
   - Focus on marginal change justifies no entry/exit assumption
5. Calculate new consumer and producer surplus, using BLP coefficients

- If DCM delivers counterfactual price, need only demand system
- FOC conditions allow us to infer product cost and thus profits

Conclusion

- **Attribute-based regulation is widespread**
  - Tools/insights developed here can be used elsewhere

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  2. DWL from safety externality ≈ $ 1 billion per year

- **Results from policy simulation**
  - The most efficient policy is No ABR with compliance trading
  - ABR is an imperfect substitute for the efficient policy
  - **Cost**: ABR creates attribute distortions
  - **Benefit**: ABR (*only partially*) equalizes MC of compliance

Thank you!

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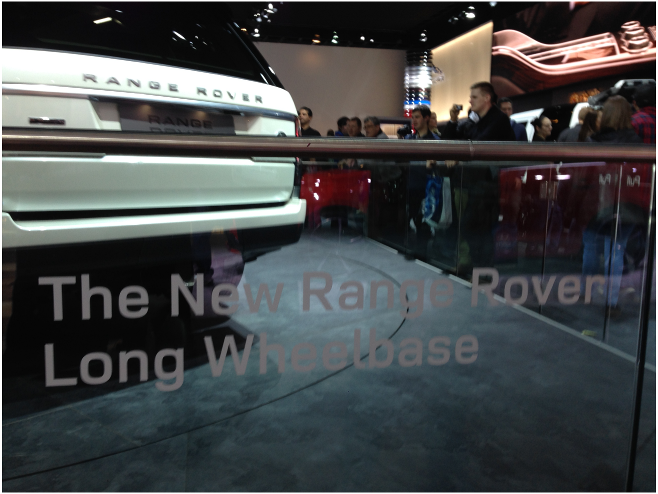
James M. Sallee (sallee@uchicago.edu)

Backup Slides

Data from the Japanese Ministry of Transportation

Year	N	Fuel Economy (km/liter)		Vehicle weight (kg)		Displacement (liter)		CO2 (g-CO2/km)	
2001	1441	13.53	(4.58)	1241.15	(356.63)	1.84	(0.98)	195.40	(66.72)
2002	1375	13.35	(4.33)	1263.52	(347.00)	1.86	(0.97)	196.72	(66.26)
2003	1178	13.78	(4.53)	1257.15	(356.28)	1.85	(1.03)	191.88	(68.08)
2004	1558	14.20	(4.78)	1255.37	(364.69)	1.82	(1.03)	184.33	(66.67)
2005	1224	13.30	(4.66)	1324.81	(380.62)	2.00	(1.13)	198.14	(71.62)
2006	1286	13.08	(4.59)	1356.56	(391.13)	2.08	(1.17)	201.78	(72.67)
2007	1298	13.24	(4.78)	1369.41	(399.45)	2.09	(1.22)	200.35	(75.07)
2008	1169	13.38	(4.82)	1390.09	(405.77)	2.14	(1.29)	198.58	(76.27)
2009	1264	13.49	(4.93)	1396.40	(413.76)	2.15	(1.30)	197.73	(76.67)
2010	1300	13.50	(5.04)	1428.27	(438.06)	2.21	(1.30)	198.32	(77.34)
2011	1391	13.95	(5.06)	1437.21	(426.23)	2.19	(1.28)	190.15	(71.60)
2012	1541	14.50	(5.21)	1446.50	(411.87)	2.16	(1.24)	182.05	(67.26)
2013	1706	14.43	(5.40)	1476.79	(400.31)	2.24	(1.24)	183.67	(67.37)

- Fuel economy, model, manufacturer, engine description, transmission, drivetype, weight, and other characteristics



- Anecdotal evidence from the Detroit Auto Show 2014
- "The New Range Rover Long Wheelbase"
  - Photo: Catie Hausman, University of Michigan

Back

What if e does not directly generate externality?

- Suppose externality is $g(a, e)$; e.g., $g = \frac{-m(a)}{e}$
- Planner's maximand is $U(a, e) - C(a, e) + g(a, e)$
- Consumer's maximand is $U(a, e) - P(a, e) + t(a, e)$
- Set $t(a, e) = g(a, e)$
- In example, $\frac{\partial g}{\partial a} = \frac{-m'}{e} < 0$ (empirically)

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- Intuition: size/weight positively correlated with mileage, so optimal attribute-basing will penalize size/weight
- Limitation: with heterogeneity in $g(a, e)$, will need second best calculations

Back

What if there is imperfect competition? Markups

- Imperfect competition implies pricing above marginal cost
- Not obvious that imperfect competition will lead to misallocation of a and e—may only distort $P(a,e)$
- If $P(a,e) - C(a,e)$ correlated with a, then might justify attribute-basing
- Empirically, think $P(a,e) - C(a,e)$ positively correlated with a, implies subsidy to a optimal

- Could justify attribute-basing, but definitely not what regulators were intending

Back

What if there is imperfect competition? Exit and Entry

- With fixed costs, limited set of vehicles on market, need not be efficient portfolio
- Attribute-basing will alter vehicle set
- Certainly possible that new set of vehicles more efficient

- Competition concerns definitely not what regulators were intending

Back

Result 1) First-best solution - No attribute-basing

- Consumer's FOC for the optimal tax:

$$\text{FOC for } a \qquad \frac{\partial U(a,e)}{\partial a} - \frac{\partial C(a,e)}{\partial a} = \sigma' t$$

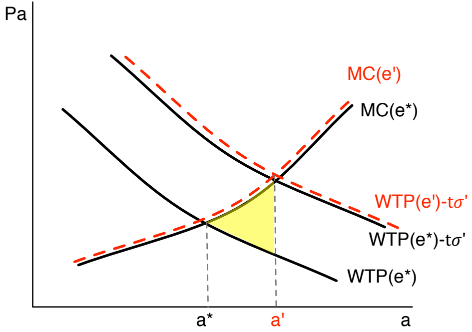
$$\text{FOC for } e \qquad \frac{\partial U(a,e)}{\partial e} - \frac{\partial C(a,e)}{\partial e} = -t$$

- Matches planner's FOC iff $\sigma' = 0$ (no attribute-basing) & $t = \phi$ (Pigou)
- Attribute-basing ($\sigma' \neq 0$) creates distortion

- Important, but not surprising (Pigou, Kopczuk 2003, etc.)
- Regulation with compliance trading identical if $\lambda(\kappa) = t$

Back

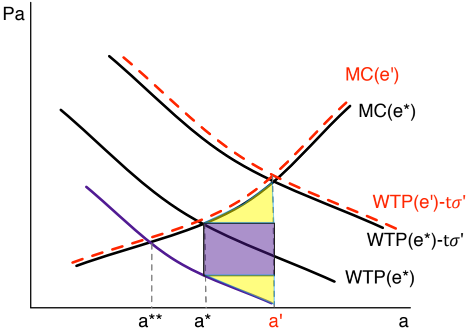
Result 2) Welfare loss from Harberger triangle of *a*



- Attribute-basing induces welfare loss of Harberger triangle (yellow), tax wedge is size $\sigma' t$
- Welfare loss (size of triangle) rises as a more elastic

Back

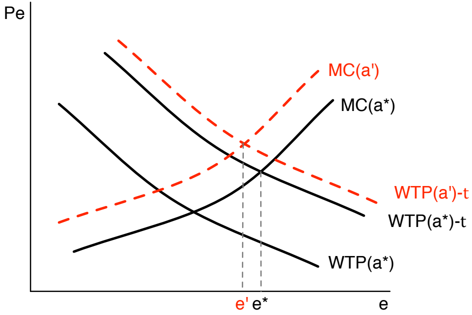
Result 3) Welfare loss from the externality in a



- For vehicles, footprint/weight correlated with safety externality
- If a also causes externality, attribute-basing exacerbates that externality (purple rectangle)
- Welfare loss linear in tax wedge
- This effect dominates if tax wedge is small

Back

Result 4) Welfare loss from general equilibrium in "e"



- Change in $a \Rightarrow$ general equilibrium effect for e
- e' could be above or below or equal to e^*
- We expect a resulting DWL (deadweight loss) in e
- However, this DWL is likely to be smaller than the DWL in a

Back

Model with Incidence Concerns

- Model can accommodate incidence via welfare weights θ_n
- With revenue-recycling, net subsidy to type n is

$$S_n = s(e_n - \hat{\sigma} a_n) - \underbrace{s(\bar{e_n} - \hat{\sigma} \bar{a_n})}_{\text{Demogrant}}$$

Back

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- Changing s and $\hat{\sigma}$ have different incidences:

$$\frac{\partial S_n}{\partial s} = \underbrace{(e_n - \hat{\sigma} a_n) - (\bar{e} - \hat{\sigma} \bar{a})}_{\text{``Lump-sum transfer''}} + \underbrace{s\left(\frac{\partial e_n}{\partial s} + \frac{\partial \bar{e}}{\partial s}\right) - \hat{\sigma} s\left(\frac{\partial a_n}{\partial s} - \frac{\partial \bar{a}}{\partial s}\right)}_{\text{``Behavioral response''}}$$

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$$\frac{\partial S_n}{\partial \hat{\sigma}} = \underbrace{-s(a_n - \bar{a})}_{\text{“Lump-sum transfer”}} \underbrace{+ s\left(\frac{\partial e_n}{\partial \hat{\sigma}} + \frac{\partial \bar{e}}{\partial \hat{\sigma}}\right) - \hat{\sigma} s \left(\frac{\partial a_n}{\partial \hat{\sigma}} - \frac{\partial \bar{a}}{\partial \hat{\sigma}}\right)}_{\text{“Behavioral response”}}$$

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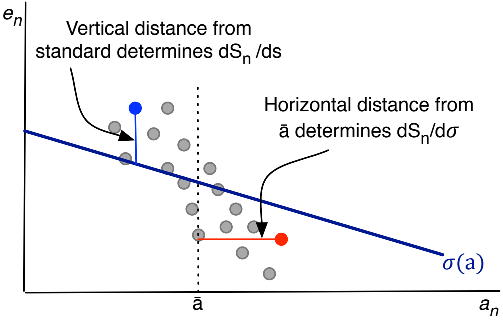

- If θ_n correlated with a_n, ABR may be useful in targeting; likely explains some real-world examples
- **New Proposition (in progress):** optimal ABR features:

$$\hat{\sigma}^{INC} \approx \frac{s \cdot \text{cov}(\theta_n, a_n)}{(\sum_n \frac{\partial a}{\partial \hat{\sigma}})/n}$$

- Denominator is negative $\Rightarrow \hat{\sigma} < 0$ with positive covariance
- Approximation assumes $s \approx \phi$ and that derivatives of e and a w.r.t. $\hat{\sigma}$ are not correlated with θ_n Back

Model with Imperfect Targeting

- Our model assumes that e causes externality
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- Taxing *energy-efficiency* never first-best
- In general, all flexibility useful in second-best policy design ("tagging", Akerlof 1978)

$\Rightarrow$ Optimal policy will involve some attribute-basing, except in special cases

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- But, such considerations very unlikely to rationalize observed policies Back

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- In JKSvB, second-best linear ABR would be OLS fit:
  1. Estimate $\phi_n = \alpha + \beta e_n + \gamma a_n + \varepsilon$
  2. Set $s = \hat{\beta}$ and $-\hat{\sigma} s = \hat{\gamma}$
  - Efficiency gain from ABR proportional to increase in R^2 from adding a_n to regression (instead of only e_n)
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- Actual policies do not maximize possible gains
  - Want attribute with maximal information about ϕ that is orthogonal to e; but policymakers explicitly pick a that is tightly correlated with e
  - Policies choose $\hat{\sigma}$ based on correlation of a and e; amounts to inefficient restriction on OLS Back

- Possibility 2: Important special case is $\phi_n = \gamma_n e_n$
- Marginal benefit of e_n varies across consumers
  - Consumers drive different amounts
  - Local air pollution damages vary by location
- If a_n correlated with γ_n, ABR can improve targeting
- Optimal policy will approximate $S(a, e) = s(a) \times e$; let marginal incentive to e_n vary across types

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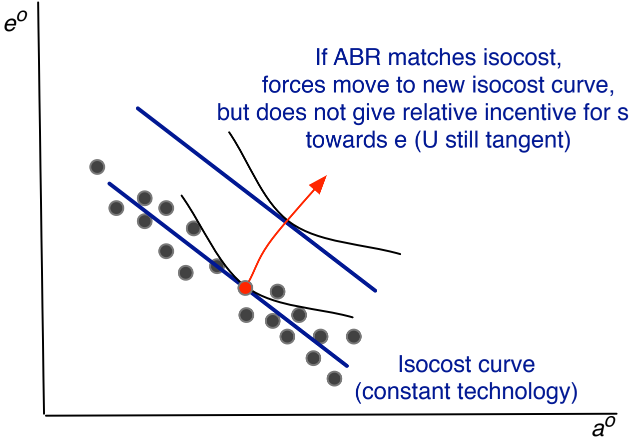
- Optimal $\hat{\sigma} \neq 0$ in general case, but actual policy ill suited to address this problem Back

Technology

- Firms can comply with flat standard by:
  1. Downsizing
  2. Adding technology
  3. Mix shifting
- Advocates of ABR claim that we want to spur technology and avoid downsizing

- Prefer technology only if there is some additional market failure; perhaps spillovers from technology. But...
  - Many technologies are patentable, not clear there are big spillovers not captured by market incentives
  - Many technologies deployed for compliance already available, widely known
- Downsizing is efficient, unless people undervalue their own safety; ABR advocates seem confused about private versus social safety effects

Back



- Actual policy "fits" data; eliminates downsizing
- This induces technology; but (incorrectly) preserves relative price of a and e
- Might even lead to reduction in e ▸ Back

Technology

- Actual policy "fits data"; eliminates downsizing
- Model extension: assume technology externality, size γ, from any product that extends beyond frontier

- **Proposition:** Optimal attribute slope for vehicles on frontier, when there is a technology spillover is:

$$\hat{\sigma}^T = \frac{\gamma \frac{\partial C}{\partial a}}{\phi + \gamma \frac{\partial C}{\partial e}}$$

- When $\gamma/\phi \to 0$, $\hat{\sigma}^T \to 0$; i.e., if energy externalities dominate technology spillovers, then want no ABR
- When $\phi \to 0$, $\hat{\sigma}^T \to \frac{\partial C}{\partial a} / \frac{\partial C}{\partial e}$; this is actual policy

- Actual policy right when there is no energy externality; only technology market failure
- At most, a modest ABR could be justified, but not clear there are spillovers in real world Back