Asa Watten

National Center for Environmental Economics, US EPA

January 23, 2024

Hi, I'm Asa

Now:
Postdoc at Yale School of Environment

Grad school/pandemic:
EPA Office of Transportation and Air Quality

PhD:
Michigan State University

Before:
University of Chicago
Biofuel co. in Braddock, PA
Carnegie Mellon

Themes

Technical change and light-duty vehicle policy

1. "Attribute Production and Technical Change in Automobiles"
2. "The Marginal Benefits of Electrification Policy"
3. Distributional impacts of standards

Household adoption of green technologies

4. "How is Rooftop Solar Capitalized in Home Prices?"
5. A battery storage field experiment
6. Solar and EV co-adoption

Policy and regulation under uncertainty

7. "Political Risk Reduces Solar Adoption in RPS"
8. "Technology Specific Subsidies and Policy Longevity"
9. Dynamic Intraseasonal Farming Investment, Abandonment, and Climate Change
10. Hedonic estimation under uncertainty

R&R; working paper; work in progress

Approach

Structural modeling

Theory motivated reduced form estimation

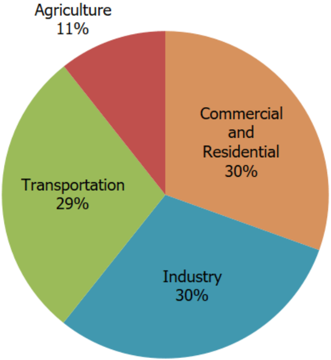
Dynamics, real options, simulations

Attribute Production and Biased Technical Change in Automobiles

Asa Watten[1] Soren Anderson[2] Gloria Helfand[3]

[1]Yale University
[2]Michigan State University
[3]University of Michigan

Multi-attribute durable goods are responsible for the majority of US GHGs



U.S. Environmental Protection Agency (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

Cars and trucks

- Fuel economy, size, acceleration

Buildings

- Energy consumption, size, natural light

Computing and server clusters

- Energy consumption, speed, number of operations, footprint

These attributes are physically co-determined

Economists have worried that regulation causes attribute trade-offs for a long time

Rand Journal of Economics
Vol. 16, No. 4, Winter 1985

The nonpecuniary costs of automobile emissions standards

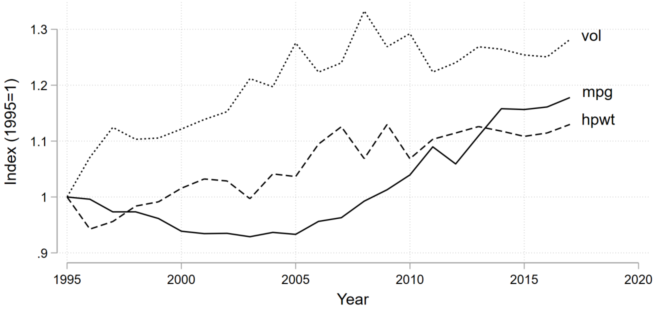
Timothy F. Bresnahan*

and

Dennis A. Yao**

An important component of the costs of automotive air-pollution control has been nonpecuniary: a decline in vehicle performance characteristics. This regulatory impact on what the auto industry calls "drivability" has never been quantified, although there is considerable reason to believe that it has been a major component of the costs of some of the auto emissions standards of the last decade. We develop a methodology for econometric assessment of such costs, and apply it to the automobile air pollution standards of 1972–1981. We find that these costs are important. For the first standards implemented in the 1970s, they exceeded the costs of pollution control equipment installed on the car and the costs of decreased fuel efficiency. Since then, however, advances in compliance technology have allowed increases in automobile quality so that incremental costs of recent standards are much lower than previously believed.

Yet, cars are bigger, faster, and more efficient



+38% MPG
+56%hp/wt
+7% vol.

Estimated cost of 2012-16 standards were overly pessimistic

Knittel (2011)

- Rate of technical change insufficient to meet standards
- Standards require size to rollback to 1980s levels

EPA TSD (2010)

- Expected shadow cost approx. \$20 per gram CO_2/mile
- Observed shadow cost approx. \$1-7 per gram CO_2/mile (Yeh et al. 2021)

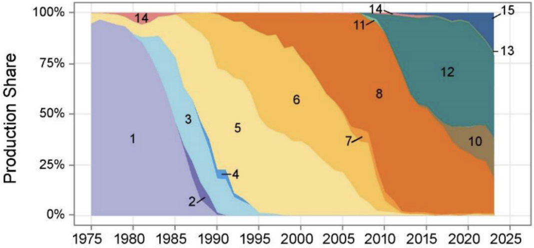
Whitefoot, Fowlie and Skerlos (2017)

- Trade-offs reduce costs by 1/3

What are we missing?

And can innovation substitute for GHG regulation?

Figure 4.3. Production Share by Engine Technology



Fuel Delivery	Valve Timing	Number of Valves	Key
Carbureted	Fixed	Two-Valve	1
		Multi-Valve	2
Throttle Body Injection	Fixed	Two-Valve	3
		Multi-Valve	4
Port Fuel Injection	Fixed	Two-Valve	5
		Multi-Valve	6
	Variable	Two-Valve	7
		Multi-Valve	8
Gasoline Direct Injection (GDPI)	Fixed	Multi-Valve	9
	Variable	Multi-Valve	10
Gasoline Direct Injection (GDI)	Fixed	Multi-Valve	11
	Variable	Multi-Valve	12
		Two-Valve	13
Diesel	—	—	14
EV/PHEV/FCV	—	—	15

Source: EPA Trends Report 2023

- Aghion et al. (2016*b*) $\uparrow$ gas price $\Longrightarrow$ $\uparrow$ green patents
- How does innovation interact with preferences, gas prices, and policy?

This paper

What we do

- Decompose the drivers of fleet attributes into preferences, policy, gas prices, technical change
- Technical change of different types
  - attribute-neutral
  - biased
  - discrete

How we do it

- Highly tractable model of long-run equilibrium attribute choices
- Estimate structural parameters with US purchase data 1995-2017
  - Producer attribute costs and trade-offs
  - Heterogeneous consumer preferences and demand elasticity's
- Simulate attribute mix turning off different channels

This paper

What we find

- Technical change biased against size and acceleration

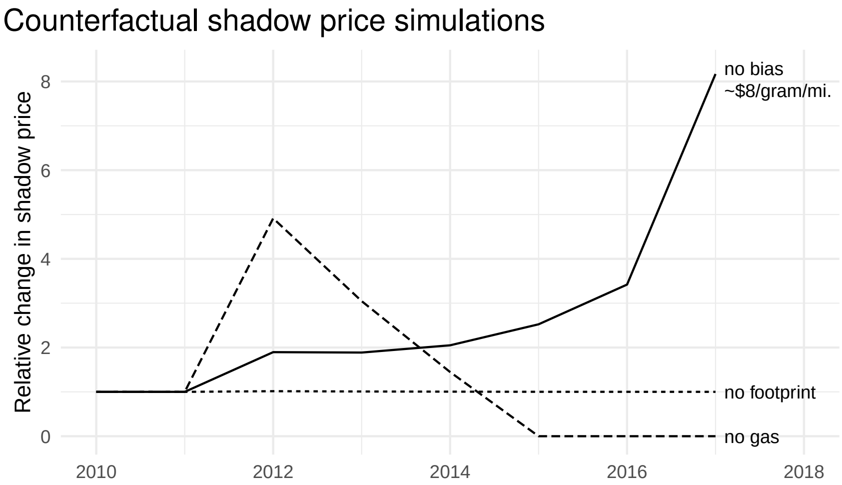
  No tech bias: mpg -9%; size $+4\%$; speed $+21\%$
- Increasing preferences for size

  No pref shift: mpg $+52\%$; size -25%; speed -30%
- Effect of CAFE/GHG standards was small

Implications

- Technical change re-allocated to other attributes
- Policy and (biased) technical change are complements

Bias technical change accounts for difference from TSD



Our contributions

Using market data to infer **attribute trade-offs** and technical change for energy-using products (Newell, Jaffe and Stavins 1999; **Knittel (2011)**)

- Microfoundations with technology, preferences, and policy
- Control for gas prices to recover costs

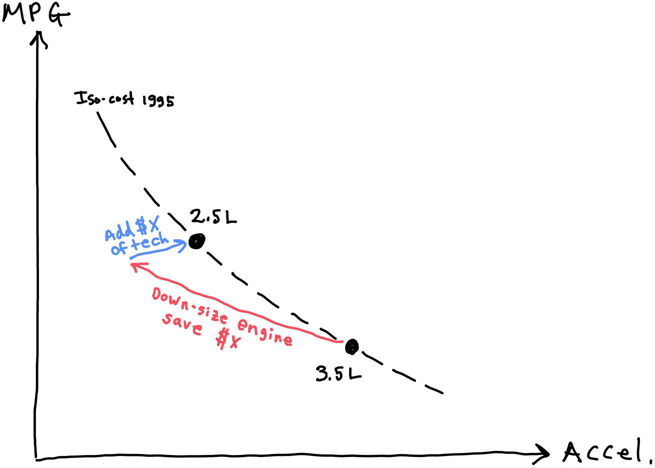
Carbon taxes and **directed technical change** (Hicks 1932; Acemoglu et al. 2012) for hybrids, EVs, and hydrogen engines (Aghion et al. 2016*a*)

- Implications of d.t.c. for car attributes in equilibrium

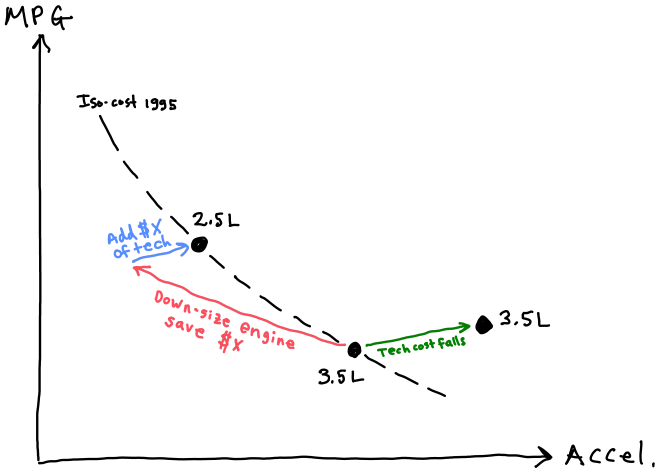
Estimating how car market responds to gas prices and **efficiency standards** (many; see Anderson and Sallee 2016 for a review)

- Tractable structural model that disentangles costs and preferences
- Long-run attribute trade-offs and technical change

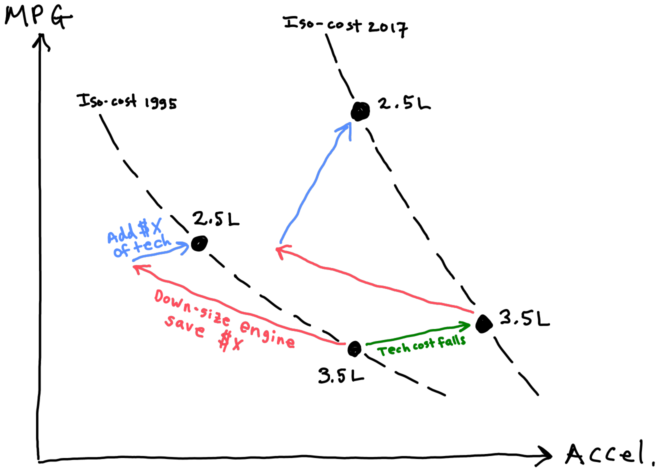
Technologies and design choices trace out the iso-cost



As tech costs decline, more care for same $



Attribute-biased technical change



Theory of attribute production

Model

$$\max_{s,a,g} u(s,a,g) = \underbrace{y}_{\text{income}} + \underbrace{v(s,a)}_{\text{u from } a,s} - \underbrace{pgm}_{\text{fuel cost}} - \underbrace{c(s,a,g)}_{\text{car cost}} - \underbrace{\tau[g-\sigma(s)]}_{\text{efficiency std.}}$$

s: size (volume = $l \times w \times h$)

a: acceleration (HP/weight)

g: gallons-per-mile (a bad)

p: gasoline price

m: lifetime miles

σ: efficiency standard

τ: shadow cost (credit price)

Demand: multiple consumer types, unit demand for a car, quasilinear preferences

Supply: competitive, constant marginal cost per car, zero fixed cost for new models

Equilibrium: costs pass-through to consumer, each consumer type gets a car custom-tailored to their unique preferences

Model with functional-form assumptions

$$\max_{s,a,g} u(s,a,g) = \underbrace{y}_{\text{constant}} - \underbrace{[\beta_s s^{-\mu_s} + \beta_a a^{-\mu_a} + \beta_g g]}_{\text{disutility from bads}}$$

$$-\underbrace{k e^{-\theta} s^{\alpha_s} a^{\alpha_a} g^{-\alpha_g} \times \text{markup}}_{\text{car cost}} + \underbrace{\tau\sigma(s)}_{\text{footprint std.}}$$

β's: heterogeneous preferences
$\beta_g = pm + \tau$

μ's: declining marginal utility
demand elasticity $= -1/(1+\mu)$
common to all

k: cost shifter
θ: attribute-neutral technology
α's: attribute-specific cost parameters

Necessary conditions

$$\text{MB} = \text{MC}$$

$$\text{s: } \beta_s = \frac{\alpha_s c(s,a,g)}{s^{-1}}$$

$$\text{a: } \beta_a = \frac{\alpha_a c(s,a,g)}{a^{-1}}$$

$$\text{g: } \beta_g = \frac{\alpha_g c(s,a,g)}{g}$$

$$\text{MRS} = \text{MRTSA}$$

$$\frac{\beta_s}{\beta_g} = \frac{\alpha_s}{\alpha_g}\frac{s}{g^{-1}}$$

$$\frac{\beta_a}{\beta_g} = \frac{\alpha_a}{\alpha_g}\frac{a}{g^{-1}}$$

$$\frac{\beta_s}{\beta_a} = \frac{\alpha_s}{\alpha_a}\frac{s}{a}$$

MRS = marginal rate of substitution (utility)

MRTSA = marginal rate of technical substitution in attributes (cost)

Constant MRTSA elasticity = α_j/α_k

Necessary condition for mpg identifies cost parameters

MPG conditional on size and acceleration

$$\ln g^{-1} \approx \tfrac{\theta}{1+\alpha_g} + \tfrac{1}{1+\alpha_g} \ln(pm + \tau) - \tfrac{\alpha_s}{1+\alpha_g} \ln s - \tfrac{\alpha_a}{1+\alpha_g} \ln a - \tfrac{1}{1+\alpha_g} \ln k$$

Estimate θ and α's via OLS regression

unconditional equilibrium attribute equations

The other two conditions identify demand parameters

Size

$$\ln s = \tfrac{1}{\alpha_s+\mu_s} \underbrace{\left(\theta - \alpha_a \ln a + \alpha_g \ln g - \tau \frac{\sigma_s}{c_s}\right)}_{\text{cost shifter for } s} + \tfrac{1}{\alpha_s+\mu_s} \left(\ln \mu_s \beta_s - \ln \alpha_s k\right)$$

Acceleration

$$\ln a = \tfrac{1}{\alpha_a+\mu_a} \underbrace{\left(\theta - \alpha_s \ln s + \alpha_g \ln g\right)}_{\text{cost shifter for } a} + \tfrac{1}{\alpha_a+\mu_a} \left(\ln \mu_a \beta_a - \ln \alpha_a k\right)$$

Estimate μ's via OLS regression given $\hat{\theta}$ and $\hat{\alpha}$'s

unconditional equilibrium attribute equations

Heroic assumptions and caveats

1. Free entry

   We can ignore constant markups over attributes

   Median markups are approx. 20% for all years (Grieco, Murry and Yurukoglu 2021)

   Alternatively, interpret α's inclusive of markups

   Implies a car for every person $\rightarrow$ long-run interpretation

2. Future gas price expectations

   Anderson, Kellogg and Sallee (2013)

3. CAFE and GHG standards is small

   Linear approximation for small τ

   Effect is < 10% gas price

4. Common α and μ for all cars and consumers

Effects on car attributes

	fuel econ	size	accel	c^*
Attribute-neutral technical change (θ)	$+$	$+$	$+$	+/-
Discrete tech. adoption, e.g. hybrids ($\leftrightarrow$)	$+$	$+$	$+$	$+$
Biased technical change (fuel econ)	$+$	$-$	$-$	$+/-$
Gas price	$+$	$--$	$--$	$+/--$
Gas price $\times$ biased technical change	$++$	$-$	$-$	$++/-$

Note: $++ > + > 0 > - > --; ++/- > +/--$

equilibrium | neutral | discrete | bias | gas

Data

Data on car choices and attributes

NHTS
National Household Travel Survey
Our Nation's Travel

- Three waves: 2001, 2009, 2017
- 360,000 cars dating to 1980
- Year, state, miles, demographics

EPA

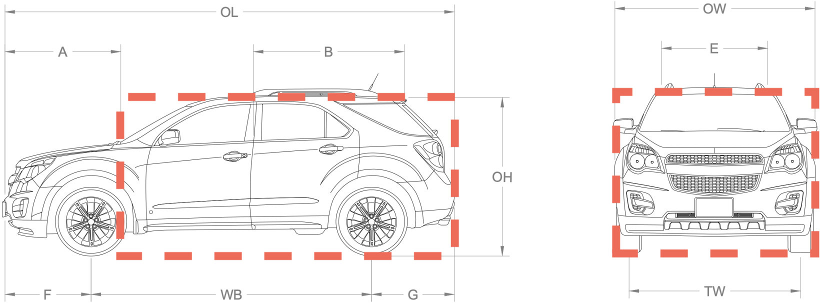
- Fuel economy and horsepower
- Total sales

Transport Canada
Canada

- Curb weight and volume ($l \times w \times h$)
- Data for 1995-present

Final matched sample: 250,000 cars purchased 1995–2017

How we measure volume



Source: Transport Canada

How we measure acceleration

HP/wight $\leftrightarrow$ acceleration time is relatively flat

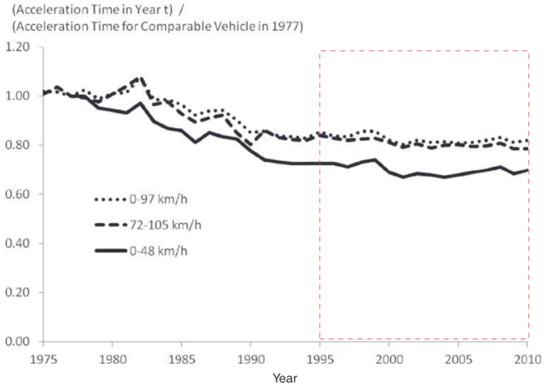
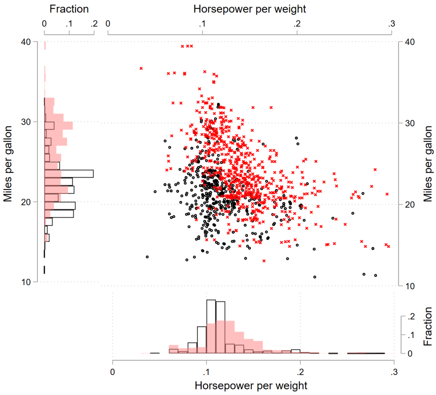
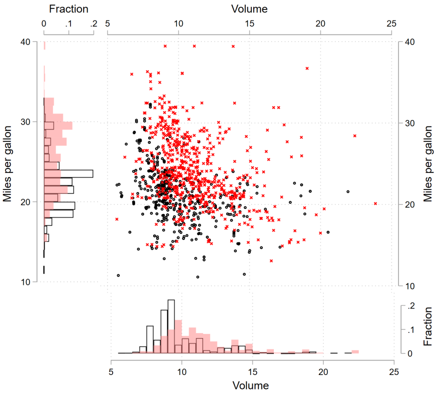


FIGURE 3 Ratio of expected acceleration time for vehicle in each year to that of comparable vehicle (i.e., same power, weight, transmission type, etc.) in 1977.

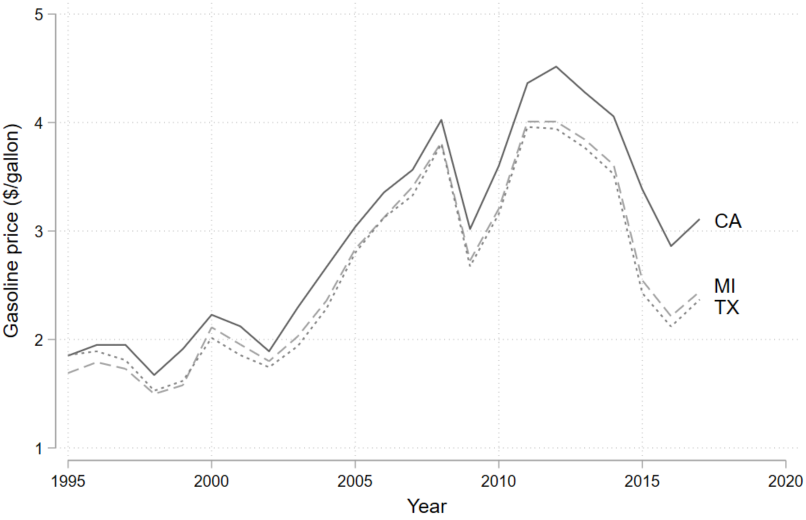
Source: MacKenzie and Heywood (2012)

MPG demand vs. fuel economy vs. size and acceleration

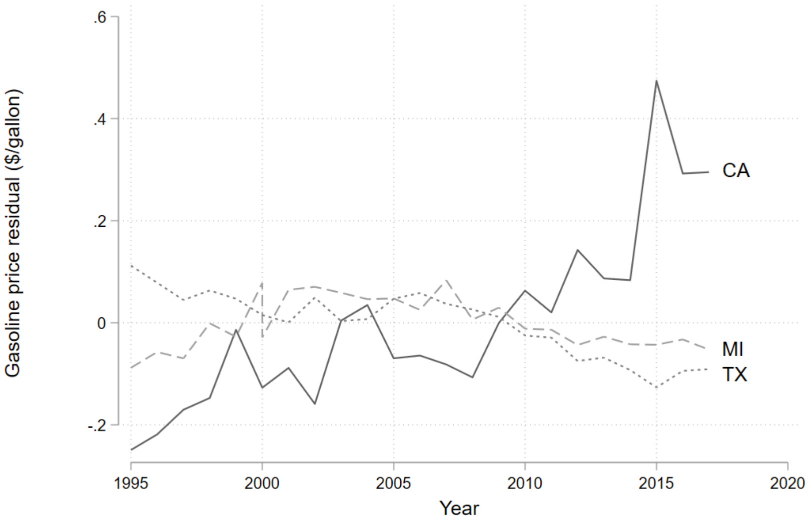




Identifying variation: State-level gasoline prices



Identifying variation: State-level gasoline prices



Estimation

Estimation via OLS

Regression model:

$$\ln \mathit{mpg}_{ijt} = \mathit{constant} + \theta(t) + \gamma_g \ln \mathit{gasprice}_{jt}$$

$$+\gamma_a \ln \mathit{hp}/\mathit{weight}_{ijt} + \gamma_s \ln \mathit{volume}_{ijt} + \mathit{controls}_{jt} + \epsilon_{ijt}$$

Details

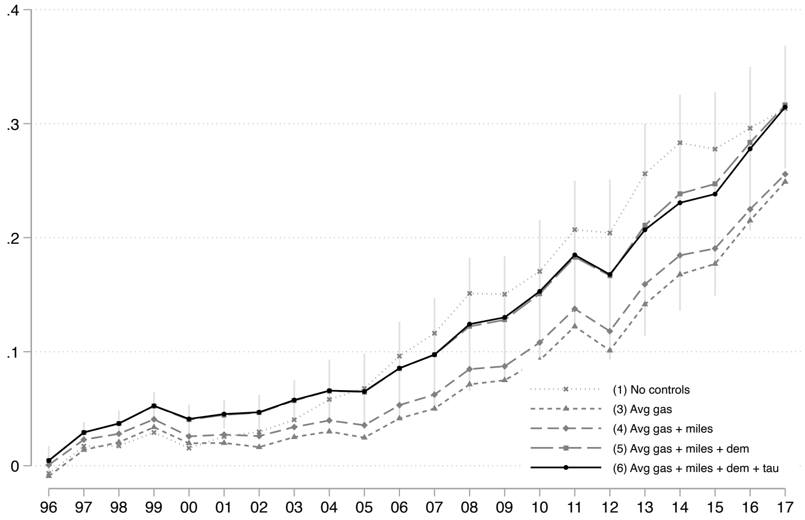
- Gas price: three year average
- $\theta(t)$: year dummies or linear trend
- State & pickup dummies in all models
- Optional controls: car age & log miles (squares, interaction), income, # people, # adults, # vehicles, homeown, urban, density
- Standard errors: clustered by state

Regression results: cost parameters

Dependent variable: *logmpg*

	(1)	(2)	(3)	(4)	(5)
Log 3-yr avg. gas price		0.111*	0.095*	0.093*	0.098*
		(0.042)	(0.042)	(0.043)	(0.045)
Log HP/weight (γ_a)	-0.509***	-0.509***	-0.509***	-0.508***	-0.507***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Log volume (γ_s)	-0.469***	-0.469***	-0.469***	-0.467***	-0.467***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Pickup	-0.068***	-0.068***	-0.067***	-0.065***	-0.065***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Year FEs	X	X	X	X	X
State FEs	X	X	X	X	X
VMT x Age			X	X	X
Demographics				X	X
Shadow cost					X
$\frac{\partial \ln \text{mpg}}{\partial \ln \text{HP/Wt}}\Big\vert_{\Delta c=0} \left(\frac{\alpha_a}{\alpha_g} = \frac{\gamma_a}{1-\gamma_g}\right)$		-0.573***	-0.563***	-0.560***	-0.562***
		(0.044)	(0.043)	(0.043)	(0.045)
$\frac{\partial \ln \text{mpg}}{\partial \ln \text{volume}}\Big\vert_{\Delta c=0} \left(\frac{\alpha_s}{\alpha_g} = \frac{\gamma_s}{1-\gamma_g}\right)$		-0.528***	-0.519***	-0.515***	-0.517***
		(0.031)	(0.030)	(0.030)	(0.032)

Attribute-neutral technical change aprox. 1.5% per year



MRATS increasing over time

	(1) 1995-01	(2) 2002-09	(3) 2010-17
Log 3-yr ave. gas price	0.040	0.093**	0.115*
	(0.030)	(0.032)	(0.044)
Log HP/weight (γ_a)	-0.212***	-0.525***	-0.589***
	(0.016)	(0.016)	(0.013)
Log volume (γ_s)	-0.346***	-0.456***	-0.508***
	(0.017)	(0.006)	(0.010)
Pickup	-0.012	-0.077***	-0.098***
	(0.012)	(0.008)	(0.005)
$\frac{\partial \ln \text{mpg}}{\partial \ln \text{HP/Wt}}\big\rvert_{\Delta c=0} \left(\frac{\alpha_a}{\alpha_g} = \frac{\gamma_a}{1-\gamma_g}\right)$	-0.221***	-0.579***	-0.666***
	(0.011)	(0.035)	(0.046)
$\frac{\partial \ln \text{mpg}}{\partial \ln \text{volume}}\big\rvert_{\Delta c=0} \left(\frac{\alpha_s}{\alpha_g} = \frac{\gamma_s}{1-\gamma_g}\right)$	-0.361***	-0.503***	-0.574***
	(0.010)	(0.024)	(0.039)
State, year, demo. FEs	X	X	X

Estimated cost parameters are robust to alternative specifications and estimators

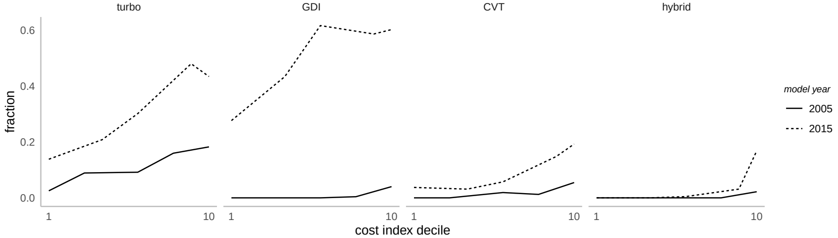
1. Gas price lags
2. Flexible cost function
3. Shadow price assumptions
4. Instruments for acceleration and size (implementing now)

Regression results: preference parameters

	(1) Vol	(2) Vol	(3) HP/Wt	(4) HP/Wt
$\theta - \alpha_a \ln a + \alpha_g \ln g \ (\lambda_s)$	0.093***	0.092***		
	(0.002)	(0.002)		
$\theta - \alpha_s \ln s + \alpha_g \ln g \ (\lambda_a)$			0.102***	0.101***
			(0.001)	(0.001)
$\mu_s = 1/\lambda_s - \alpha_s$	5.739***	5.885***		
	(0.232)	(0.199)		
$\mu_a = 1/\lambda_a - \alpha_s$			4.394***	4.457***
			(0.084)	(0.055)
$\frac{\partial \ln s}{\partial mc_s} = -\frac{1}{1+\mu_s}$	-0.148***	-0.145***		
	(0.005)	(0.004)		
$\frac{\partial \ln a}{\partial mc_a} = -\frac{1}{1+\mu_s}$			-0.185***	-0.183***
			(0.003)	(0.002)
State, year, demo. FEs		X		X

equal coef. checks

Tech is adopted in cars with higher attributes



	turbo	GDI	CVT	hybrid
est. cost index	0.007***	0.010***	0.035***	0.019***
	(0.001)	(0.001)	(0.001)	(0.000)
Num.Obs.	26096	26096	26096	26096
year FE	X	X	X	X

Simulations

Structural decomposition of trends in car attributes

Baseline scenario

Four counterfactual scenarios

1. No change in gas prices
2. No change in car technology
3. No bias in technological change
4. No change in preferences for size and acceleration
5. No standards

Caution!

- We implicitly hold shadow cost of CAFE and GHG standards fixed—interpret as effect absent policy
- No standards shows effect of shadow price only, **not dynamic innovation effects**

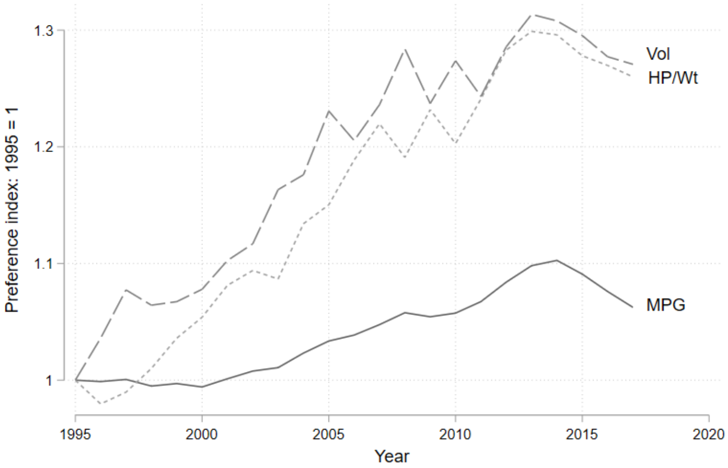
How we implement simulations

- Use unconditional equilibrium attribute equations
- Constant mpg cost (α_g)
- Linear trends in size and acceleration costs (α_s, α_a)
- Year dummies for attribute-neutral technology (θ)
- Shadow cost (τ_t) from literature; estimate linear σ_t given attribute basted standards

- Prefs for fuel economy given by: $\ln \beta_g = p_g + \ln m + \tau/pm$
  - $\ln p_g$: three-year average
  - $\ln m$: predict via regression
- Prefs for size and acceleration via necessary conditions
- Calibrate cost shifter by matching mpg choices (k)
- Turning off biased tech. change $\alpha_{kt} = \alpha_{k0} \frac{\sum_j \alpha_{jt}}{\sum_j \alpha_{j0}}$

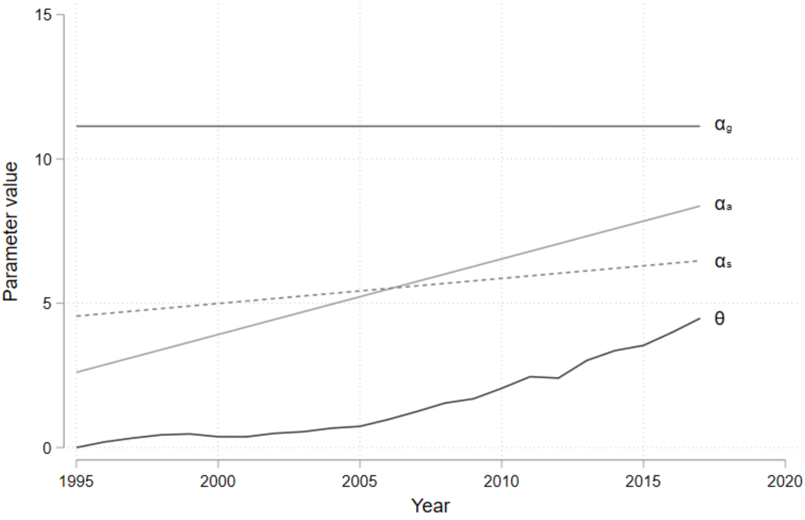
Baseline attributes

Prefs for all attributes grew; size the most

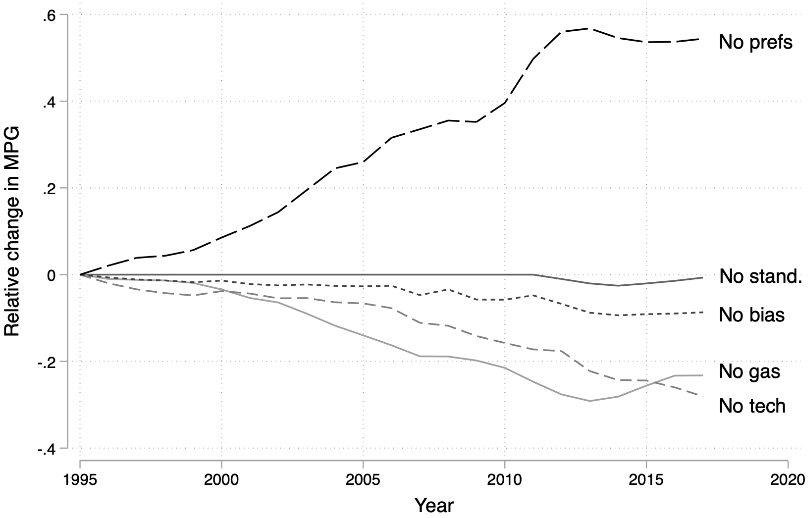


joint distribution of preferences
demographic correlates of preferences

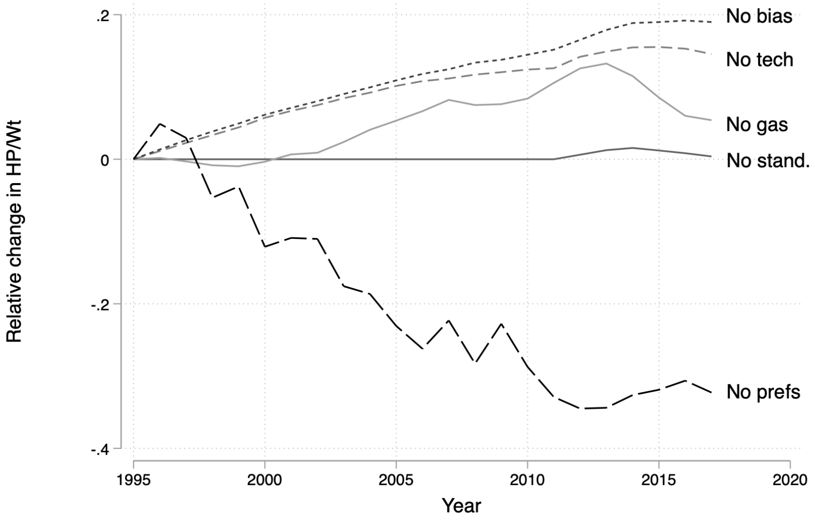
Technology parameters (θ and α's)



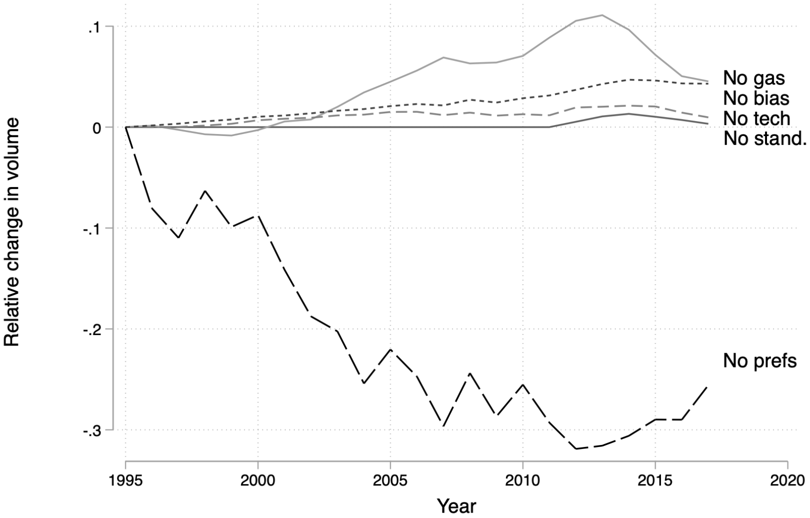
MPG: Changing prefs stole tech gains



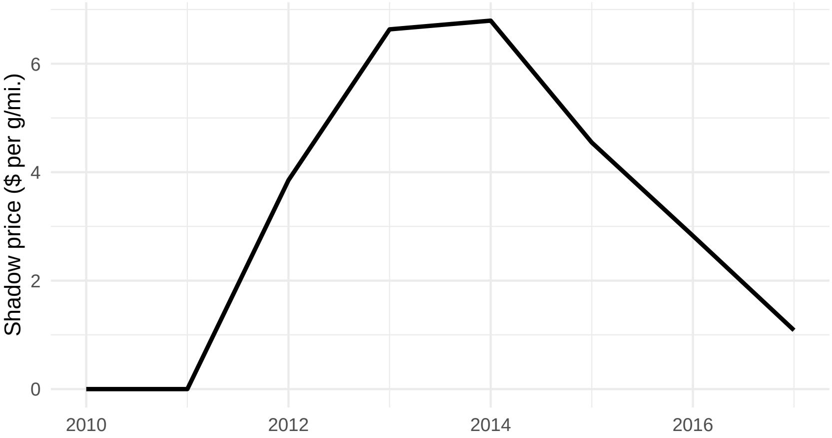
Acceleration: biased tech change dominates neutral tech change



Volume: Preferences matter most



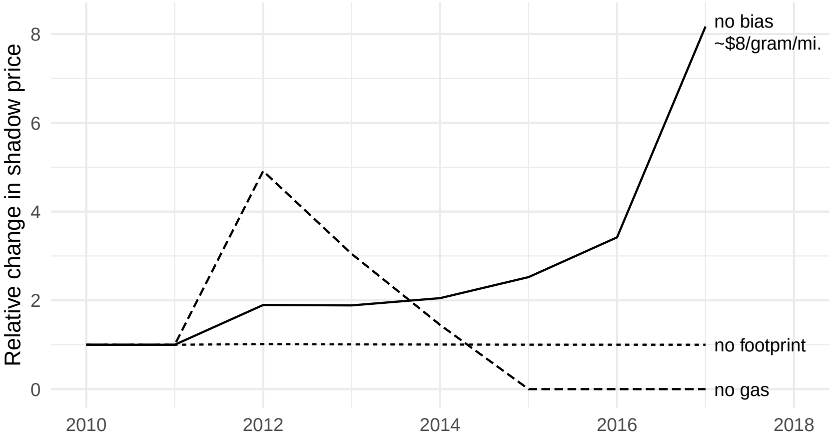
Shadow price of 2012 standards



Yeh et al. (2021)

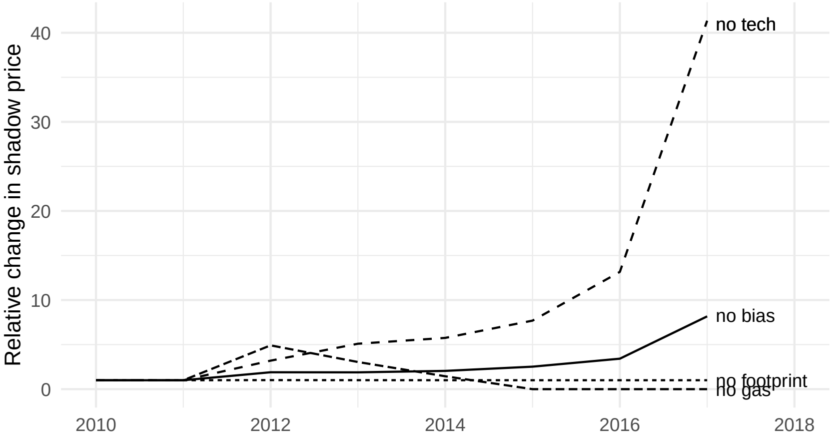
Bias is as important as gas price variation

Counterfactual shadow price simulations



Without technical change standard are expensive

Counterfactual shadow price simulations



Conclusions

Conclusions

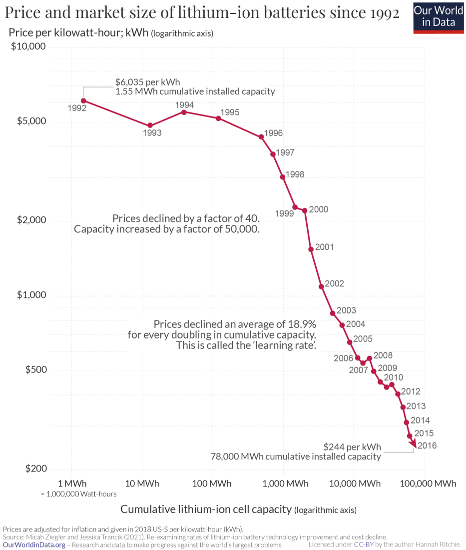
What was missing before?

- Flexibility
- The direction of technical change
- Interaction of costs and evolving heterogeneous consumer preferences

What is the effect of technical change?

- Energy-saving technology re-allocated to size and power
- Biased technical change makes size and acceleration less sensitive to policy and reduces the cost of regulation
- Fuel economy 3x more sensitive to gas prices, taxes, and standards
- Bias is opposite that suggested by ALPHA

Implications for EVs



- Our model suggests EVs will be adopted by drivers with high preferences for fuel economy and acceleration first
- Need to add range attribute
- How does EV technology change trade-offs?
- Increasing or decreasing marginal benefits of adoption?
- What about induced electricity supply?

Thank you

asa.watten@yale.edu

Appendix

References

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. 2012. "The Environment and Directed Technical Change." *American Economic Review*, 102(1): 131–166.

Aghion, Philippe, Antoine Dechezleprêtre, David Hemous, Ralf Martin, and John Van Reenen. 2016*a*. "Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry." *Journal of Political Economy*, 124(1): 1–51.

Aghion, Philippe, Ufuk Akcigit, Angus Deaton, and Alexandra Roulet. 2016*b*. "Creative destruction and subjective well-being." *American Economic Review*, 106(12): 3869–3897.

Anderson, Soren T, and James M Sallee. 2011. "Using Loopholes to Reveal the Marginal Cost of Regulation: The Case of Fuel-Economy Standards." 101(4): 1375–1409.

Anderson, Soren T, and James M Sallee. 2016. "Designing Policies to Make Cars Greener." *Annual Review of Resource Economics*, 8: 157–180.

Anderson, Soren T., Ryan Kellogg, and James M. Sallee. 2013. "What Do Consumers Believe About Future Gasoline Prices?" *Journal of Environmental Economics and Management*, 66(3): 383–403.

Grieco, Paul LE, Charles Murry, and Ali Yurukoglu. 2021. "The evolution of market power in the US auto industry." National Bureau of Economic Research.

Knittel, Christopher R. 2011. "Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector." *American Economic Review*, 101(7): 3368–3399.

MacKenzie, Don, and John Heywood. 2012. "Acceleration Performance Trends and Evolving Relationship between Power, Weight, and Acceleration in U.S. Light-Duty Vehicles: Linear Regression Analysis." 2287(1): 122–131.

Newell, Richard G, Adam B Jaffe, and Robert N Stavins. 1999. "The Induced Innovation Hypothesis and Energy-saving Technological Change." *The Quarterly Journal of Economics*, 114(3): 941–975.

Whitefoot, Kate S., Meredith L. Fowlie, and Steven J. Skerlos. 2017. "Compliance by Design: Influence of Acceleration Trade-offs on CO_2 Emissions and Costs of Fuel Economy and Greenhouse Gas Regulations." 51(18): 10307–10315.

Yeh, Sonia, Dallas Burtraw, Thomas Sterner, and David Greene. 2021. "Tradable Performance Standards in the Transportation Sector." *Energy Economics*, 102: 105490.

Necessary conditions

$$\text{MB} = \text{MC}$$

$$\text{s: } \beta_s = \frac{\alpha_s c(s, a, g)}{s^{-1}}$$

$$\text{a: } \beta_a = \frac{\alpha_a c(s, a, g)}{a^{-1}}$$

$$\text{g: } \beta_g = \frac{\alpha_g c(s, a, g)}{g}$$

$$\text{MRS} = \text{MRTSA}$$

$$\frac{\beta_s}{\beta_g} = \frac{\alpha_s}{\alpha_g}\frac{s}{g^{-1}}$$

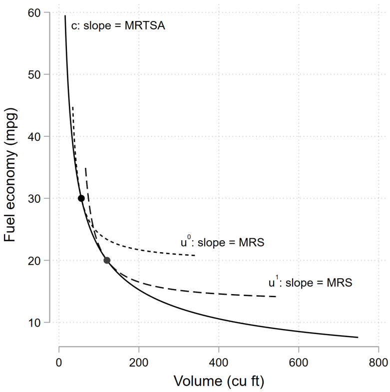
$$\frac{\beta_a}{\beta_g} = \frac{\alpha_a}{\alpha_g}\frac{a}{g^{-1}}$$

$$\frac{\beta_s}{\beta_a} = \frac{\alpha_s}{\alpha_a}\frac{s}{a}$$

MRTSA = marginal rate of technical substitution in attributes (cost)

MRS = marginal rate of substitution (utility)

Necessary conditions: MRS = MRTSA



Unconditional attribute choices

$$\ln s = \frac{1}{\psi}\Big[(\alpha_a + \mu_a + \alpha_g\mu_a)\ln\beta_s - \alpha_a\ln\beta_a - \alpha_g\mu_a\ln\beta_g + \mu_a\theta$$
$$+ (\alpha_a + \alpha_g\mu_a + \mu_a)(\ln\mu_s - \ln\alpha_s) + \alpha_a(\ln\alpha_a - \ln\mu_a) + \alpha_g\mu_a\ln\alpha_g - \mu_a\ln k\Big]$$

$$\ln a = \frac{1}{\psi}\Big[(\alpha_s + \mu_s + \alpha_g\mu_s)\ln\beta_a - \alpha_s\ln\beta_s - \alpha_g\mu_s\ln\beta_g + \mu_s\theta$$
$$+ (\alpha_s + \alpha_g\mu_s + \mu_s)(\ln\mu_a - \ln\alpha_a) + \alpha_s(\ln\alpha_s - \ln\mu_s) + \alpha_g\mu_s\ln\alpha_g - \mu_s\ln k\Big]$$

$$\ln g^{-1} = \frac{1}{\psi}\Big[(\alpha_s\mu_a + \alpha_a\mu_s + \mu_s\mu_a)\ln\beta_g - \alpha_s\mu_a\ln\beta_s - \alpha_a\mu_s\ln\beta_a + \mu_a\mu_s\theta$$
$$- (\alpha_s\mu_a + \alpha_a\mu_s + \mu_a\mu_s)\ln\alpha_g + \alpha_s\mu_a(\ln\alpha_s - \ln\mu_s) + \alpha_a\mu_s(\ln\alpha_a - \ln\mu_a) - \mu_a\mu_s\ln k\Big]$$

$$\psi \equiv \alpha_s\mu_a + \alpha_a\mu_s + \mu_s\mu_a + \alpha_g\mu_s\mu_a$$

▸▸ back to theory ▸▸ back to sims

What is the effect of higher gas prices?

$$\frac{\partial \ln s}{\partial \ln \beta_g} = -\frac{\alpha_g \mu_a}{\psi} < 0$$

$$\frac{\partial \ln a}{\partial \ln \beta_g} = -\frac{\alpha_g \mu_s}{\psi} < 0$$

$$\frac{\partial \ln g^{-1}}{\partial \ln \beta_g} = \frac{\alpha_s \mu_a + \alpha_a \mu_s + \mu_s \mu_a}{\psi} > 0$$

$$\psi \equiv \alpha_s \mu_a + \alpha_a \mu_s + \mu_s \mu_a + \alpha_g \mu_s \mu_a$$

$$-\frac{\partial \ln g^{-1}}{\partial \ln s}\bigg|_{\Delta \ln \beta_g} = \frac{\alpha_s}{\alpha_g} + \frac{\mu_s(\alpha_a + \mu_a)}{\alpha_g \mu_a}$$

$$-\frac{\partial \ln g^{-1}}{\partial \ln a}\bigg|_{\Delta \ln \beta_g} = \frac{\alpha_a}{\alpha_g} + \frac{\mu_a(\alpha_s + \mu_s)}{\alpha_g \mu_s}$$

back

What is the effect of technical change?

$$\frac{\partial \ln s}{\partial \theta} = \frac{\mu_a}{\psi} > 0$$

$$\frac{\partial \ln a}{\partial \theta} = \frac{\mu_s}{\psi} > 0$$

$$\frac{\partial \ln g^{-1}}{\partial \theta} = \frac{\mu_s \mu_a}{\psi} > 0$$

$$\psi \equiv \alpha_s \mu_a + \alpha_a \mu_s + \mu_s \mu_a + \alpha_g \mu_s \mu_a$$

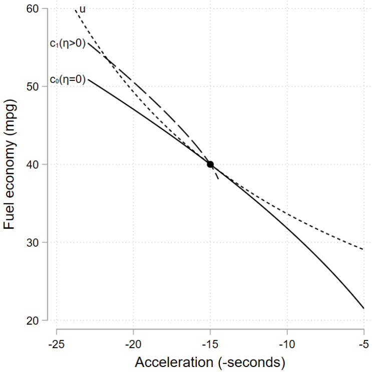
$$\left.\frac{\partial \ln g^{-1}}{\partial \ln s}\right|_{\Delta\theta} = \mu_s,$$

$$\left.\frac{\partial \ln g^{-1}}{\partial \ln a}\right|_{\Delta\theta} = \mu_a,$$

$$\left.\frac{\partial \ln a}{\partial \ln s}\right|_{\Delta\theta} = \frac{\mu_s}{\mu_a}$$

⏩ back

What is the effect of biased technical change?



Linear add-on to cost:

$$\tilde{c}(s,a,g) = c(s,a,g) + \eta(g - g_0)$$

Marginal cost of g:

$$\frac{\partial \tilde{c}}{\partial g} = -\frac{\alpha_g c}{g} + \eta > -\frac{\alpha_g c}{g}$$

$\implies$ Fuel economy now cheaper

back

What is the incentive to adopt discrete technology?

Adoption costs and benefits

- Fixed cost κ
- Improves acceleration by factor $\omega > 0$

Utility conditional on adoption

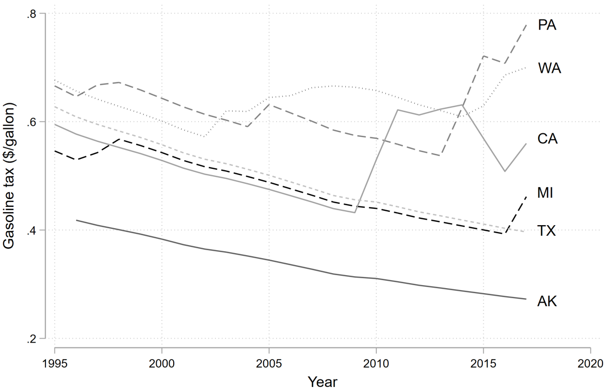
$$u(s, a, g; \omega) = y + \tau\sigma - \beta_s s^{-\mu_s} - \beta_a(\underbrace{(1+\omega)a}_{\text{acceleration}})^{-\mu_a} - \beta_g g - c(s, a, g),$$

Net utility gain from adoption

$$\begin{aligned} \approx \frac{\partial u(\omega = 0)}{\partial \omega} \cdot \omega - \kappa &\approx \omega \mu_a \beta_a a^{-\mu_a} - \kappa \\ &= \omega \alpha_a c^* - \kappa \end{aligned}$$

back

Gasoline taxes



A closer look at lifetime fuel expenditures

Expected lifetime fuel costs:

$$pmg = p \underbrace{\left[\int_{t=0}^{\infty} e^{-rt} m(t) dt \right]}_{\text{present-value miles}} g$$

Assume annual flow of miles:

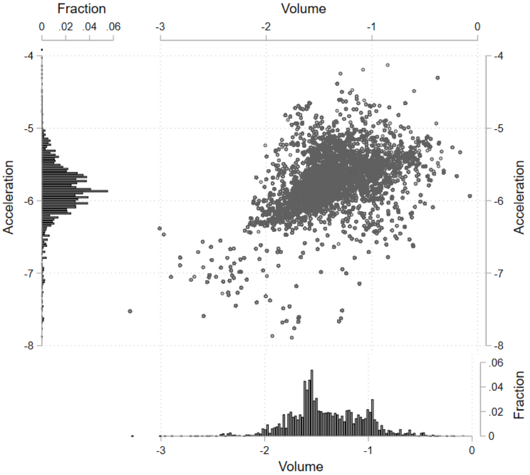
$$m(t) = e^{-(\rho+\delta)t}$$

where ρ is scrappage and δ is miles decay

Then lifetime miles:

$$m = \frac{m(0)}{r + \rho + \delta}$$

Distribution of preferences: $\ln(\beta_a/\beta_g)$ vs. $\ln(\beta_s/\beta_g)$



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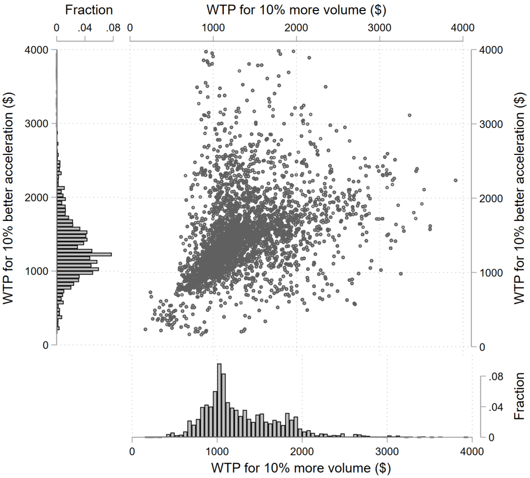
Preferences @ median car, 150k miles, and $3 gas



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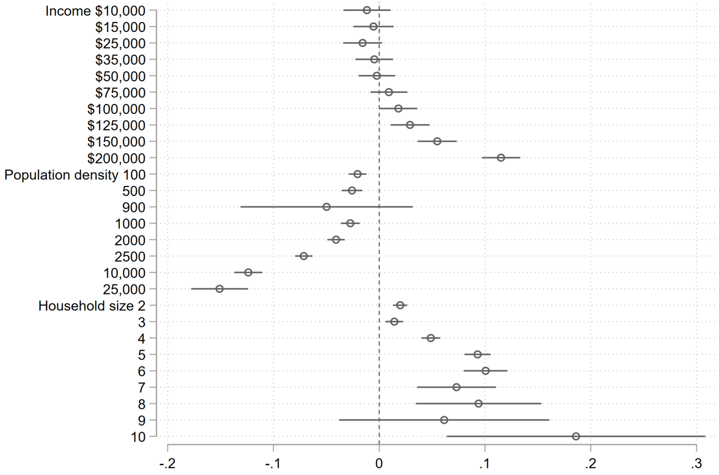
Correlates of preferences for acceleration: $\ln(\beta_a/\beta_g)$



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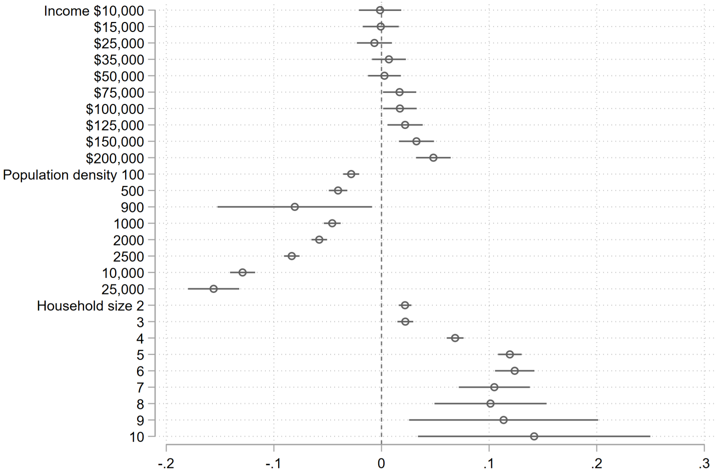
Correlates of preferences for size: $\ln(\beta_s/\beta_g)$



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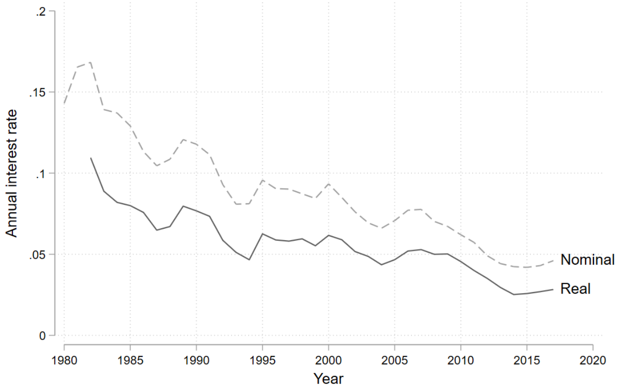
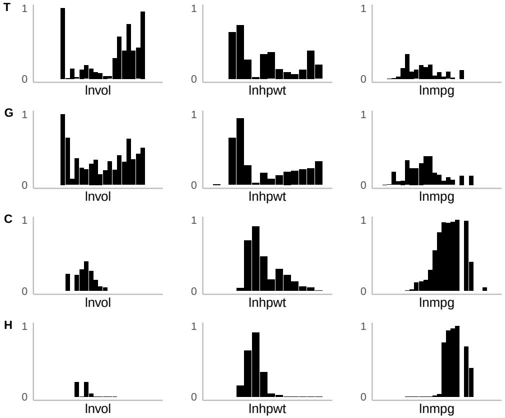
Interest rate on 48-month new car loan

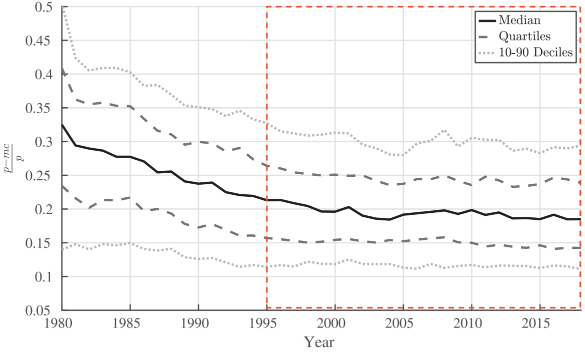


Tech adoption by attribute



Can we ignore markups?

Median markups were relatively stable after 1995



Source: Grieco, Murry and Yurukoglu (2021)

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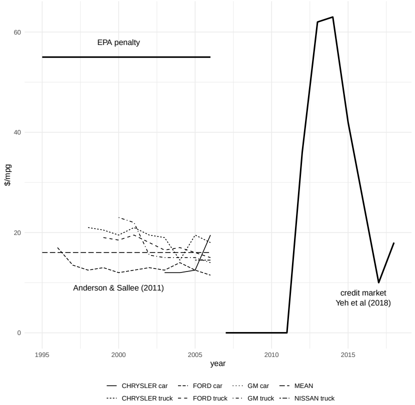
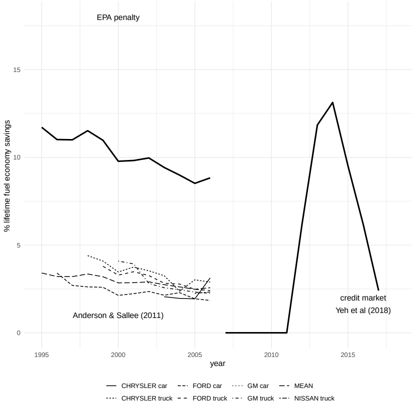
Estimates of shadow cost of standards from the literature





Sources: Anderson and Sallee (2011); Yeh et al. (2021)

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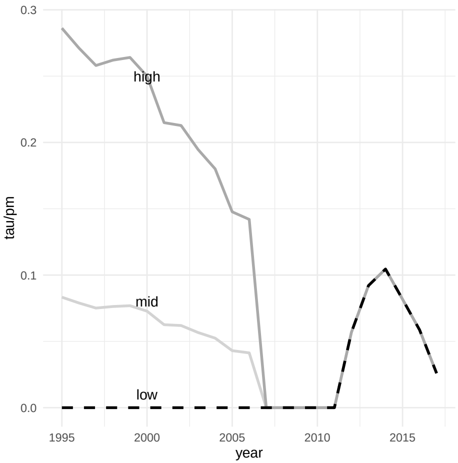
Effect of standards on gas price variable assumptions



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Regression results: shadow cost

	(1) Low	(2) Mid	(3) High
log gas price + $\frac{\tau}{pm}$	0.091*	0.101*	0.115*
	(0.042)	(0.044)	(0.046)
ln hp/wt	−0.508***	−0.508***	−0.507***
	(0.017)	(0.017)	(0.017)
ln vol	−0.467***	−0.467***	−0.467***
	(0.007)	(0.007)	(0.007)
N	245 497	245 497	245 497
R^2	0.61	0.61	0.61

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

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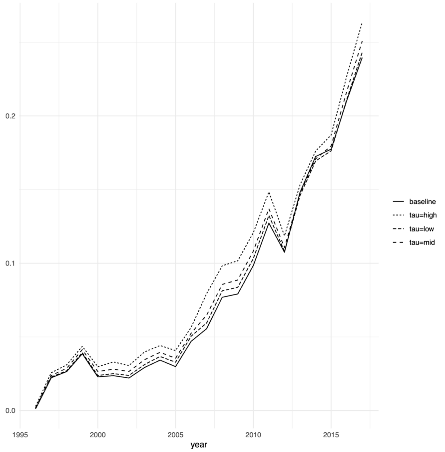
Time trend: shadow cost



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Regression results: gas price lags

	(1)	(2)	(3)	(4)	(5)
log gas price$_t$	0.065*	0.034+	0.032+	0.032+	0.033+
	(0.025)	(0.019)	(0.018)	(0.017)	(0.018)
log gas price$_{t-1}$		0.050**	0.039**	0.041**	0.041**
		(0.018)	(0.013)	(0.014)	(0.014)
log gas price$_{t-2}$			0.022	0.035+	0.034+
			(0.026)	(0.019)	(0.017)
log gas price$_{t-3}$				−0.033+	−0.037*
				(0.019)	(0.014)
log gas price$_{t-4}$					0.008
					(0.027)
ln hp/wt	−0.507***	−0.507***	−0.507***	−0.507***	−0.507***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
ln vol	−0.467***	−0.467***	−0.467***	−0.467***	−0.467***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
sum log gas price		0.084**	0.093**	0.075**	0.078**
		(0.032)	(0.043)	(0.047)	(0.055)
N	245 497	245 497	245 497	245 497	245 497
R^2	0.61	0.61	0.61	0.61	0.61

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

back

Regression results: Flexible MRTSA elasticity

	(1) all years	(2) 1995-01	(3) 2002-09	(4) 2010-17
ln gas price	0.096*	−0.001	−0.088	0.105***
	(0.040)	(0.084)	(0.061)	(0.017)
log vol × tercile 1	−0.336***	−0.238***	−0.345***	−0.357***
	(0.009)	(0.019)	(0.019)	(0.010)
log vol × tercile 2	−0.356***	−0.271***	−0.366***	−0.372***
	(0.008)	(0.019)	(0.018)	(0.009)
log vol × tercile 3	−0.369***	−0.258***	−0.375***	−0.394***
	(0.008)	(0.017)	(0.015)	(0.010)
log hp/wt × tercile 1	−0.552***	−0.164***	−0.615***	−0.592***
	(0.015)	(0.011)	(0.014)	(0.011)
log hp/wt × tercile 2	−0.568***	−0.167***	−0.642***	−0.591***
	(0.014)	(0.012)	(0.014)	(0.010)
log hp/wt × tercile 3	−0.578***	−0.153***	−0.664***	−0.597***
	(0.015)	(0.013)	(0.015)	(0.012)
pickup	−0.065***	−0.003	−0.077***	−0.095***
	(0.007)	(0.012)	(0.007)	(0.002)
N	245 497	51 986	117 544	75 967
R^2	0.62	0.31	0.63	0.68

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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Detailed regression results: preference parameters

	(1) Vol	(2) Vol	(3) Vol	(4) HP/Wt	(5) HP/Wt	(6) HP/Wt
$\theta - \alpha_a \ln a + \alpha_g \ln g \; (\lambda_s)$		0.093***	0.092***			
		(0.002)	(0.002)			
$\theta - \alpha_s \ln s + \alpha_g \ln g \; (\lambda_a)$					0.102***	0.101***
					(0.001)	(0.001)
θ	0.122***			0.128***		
	(0.001)			(0.002)		
$-\alpha_a \ln a$	0.112***					
	(0.001)					
$-\alpha_s \ln s$				0.125***		
				(0.001)		
$\alpha_g \ln g$	0.086***			0.095***		
	(0.001)			(0.001)		
$\mu_s = 1/\lambda_s - \alpha_s$		5.739	5.885			
		0.232	0.199			
$\mu_a = 1/\lambda_a - \alpha_s$					4.394	4.457
					0.084	0.055
$\frac{\partial \ln s}{\partial mc_s} = -\frac{1}{1+\mu_s}$		-0.148	-0.145			
		0.005	0.004			
$\frac{\partial \ln a}{\partial mc_a} = -\frac{1}{1+\mu_s}$					-0.185	-0.183
					0.003	0.002
State, year, demo. FEs			X			X

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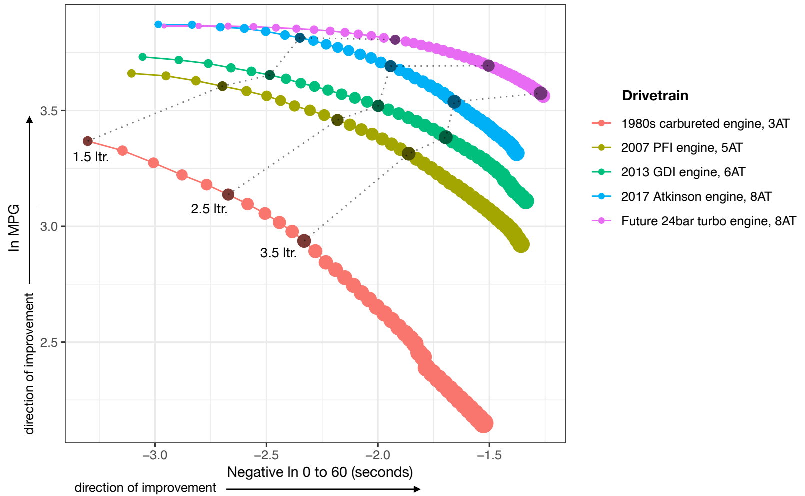
ALPHA simulations



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Changing marginal damages on the grid

Figure 2: *Marginal CO2 estimates*

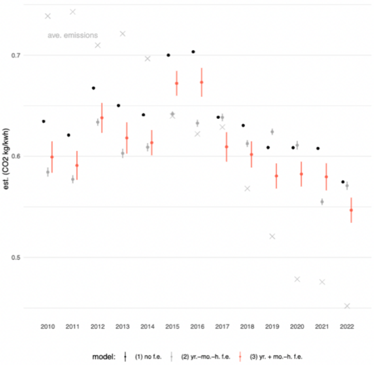

Table 1: *Long-run energy shock elasticity estimates*

	(1)	(2)	(3)	(4)	(5)
ln load$_{t-1}$	−0.443***	−0.464***	−0.439***		−0.641*
	(0.093)	(0.092)	(0.090)		(0.211)
ln peak$_{t-1}$				−0.211**	0.142
				(0.065)	(0.122)
ln load$_t$	0.856***	0.848***	1.344***	1.390***	1.316***
	(0.157)	(0.155)	(0.228)	(0.242)	(0.228)
t × ln load$_t$			−0.055*	−0.059**	−0.052*
			(0.018)	(0.018)	(0.018)
t	−0.036***	−0.035***	0.145*	0.154*	0.139*
	(0.004)	(0.004)	(0.058)	(0.060)	(0.056)
t × month	X	X	X	X	X
month f.e.	X	X	X	X	X
drop Feb. 2021		X	X	X	X
Num.Obs.	144	143	143	143	143
R2	0.941	0.942	0.947	0.944	0.947
R2 Within	0.784	0.788	0.806	0.798	0.807

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Note: The dependent variable is the natural log of monthly CO2 emissions. Lags are the same month of the previous calendar year. Models (2)-(5) drop the February 2021 Texas power crisis.

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