Regulating Untaxable Externalities:
Are Vehicle Air Pollution Standards Effective and Efficient?

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October 2021

Overview

Overview

- **Vehicle air pollution important**
  - Annual US environmental/health costs: $72 billion, 37,000 deaths
  - Annual global deaths: 250,000
- **Textbook solution infeasible**
  - Pigouvian tax requires observing pollution
  - Real-time monitoring infeasible, announced testing problematic
- **Alternative: exhaust standards**
  - Maximum standard for every vehicle; fleet-wide average
  - Separate from fuel economy (CAFE) standards
  - Important in U.S., EU, Japan, China, India, Brazil, ...
- **Research questions:**
  - Trends in vehicle pollution?
  - Causal effect of exhaust standards?
  - Cost-effective?
  - Gains from counterfactual policies?

Approach and Main Results

1. **Trends: 1957-2020**
   - 65 million vehicle emission tests
   - 99% decrease in "local" pollutants since 1960s
   - CO_2: $<$ 50% decrease

2. **Causes: regressions**
   - Variation across model years, vehicle classes, regions, pollutants
   - Exhaust standards caused 50-100% of the long-term decline

3. **Stylized facts**
   - $>$ 75% of emissions from old ('unregulated') vehicles
   - Existing property taxes/registration fees higher on cleaner vehicles

4. **Analytical and quantitative models**
   - Result: if production emissions are "small," should tax used vehicles
   - Reforming registration fees increases welfare $\approx$\$300 billion
   - Distributional consequences important

What is New Here

1. **Comprehensive analysis of exhaust standards**
   - Policy papers describe them (Kahn 1996, Fullerton and West 2010)
   - Much Clean Air Act research studies industry (Greenstone 2002; Walker 2013)

2. **Analyze vehicle property taxes**
   - Existing studies analyze real estate property taxes (Poterba and Sinai 2008; Cabral and Hoxby 2015)

3. **Equilibrium model of vehicles with endogenous pollution control**
   - Existing work focuses on fuel economy (Goldberg 1998; Goulder et al. 2012)
   - Resemblance to spatial models? (Ahlfeldt et al. 2015; Balboni 2019)

4. **Unique setting: one regulation mostly explains pollution time series**
   - Industry: less clear if pollution trends due to trade, regulation, productivity (Levinson 2009; Shapiro & Walker 2018)

Outline

- **Background**
- Data
- Trends
- Causes
- Stylized facts
- Models
- Conclusions

Policy Background: Timeline

- **US timeline**
  - Tier 0 (1968-1993)
  - Tier 1 (1994-1998)
  - NLEV (1999-2003)
  - Tier 2 (2004-2016)
  - Tier 3 (2017-2025)
  - We provide separate estimates for each "Tier"
- **Requirements vary by standard**
  - Maximum rate per vehicle: Tier 0, Tier 1
  - Fleet averages: NLEV, Tier 2, Tier 3

Policy Background

- **Technology**
  - Centerpiece: catalytic converters
  - Mechanism: rhodium, platinum, palladium
  - Complementary technologies: fuel injection, oxygen controls, etc.

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Data

- **New vehicle emissions tests** (N $\approx$ 20,000)
  - Determine compliance with Clean Air Act
- **Inspection and maintenance / smog check** (N $\approx$ 12 million)
  - Shorter version of new vehicle test
- **Remote sensing** (N $\approx$ 50 million)
  - Impervious to manufacturer "defeat devices"
- **In-use vehicle tests** (N $\approx$ 10,000)
  - Determine recalls
- **Synopsis**
  - Longest-lasting high-quality data on pollution for any country/sector

Data

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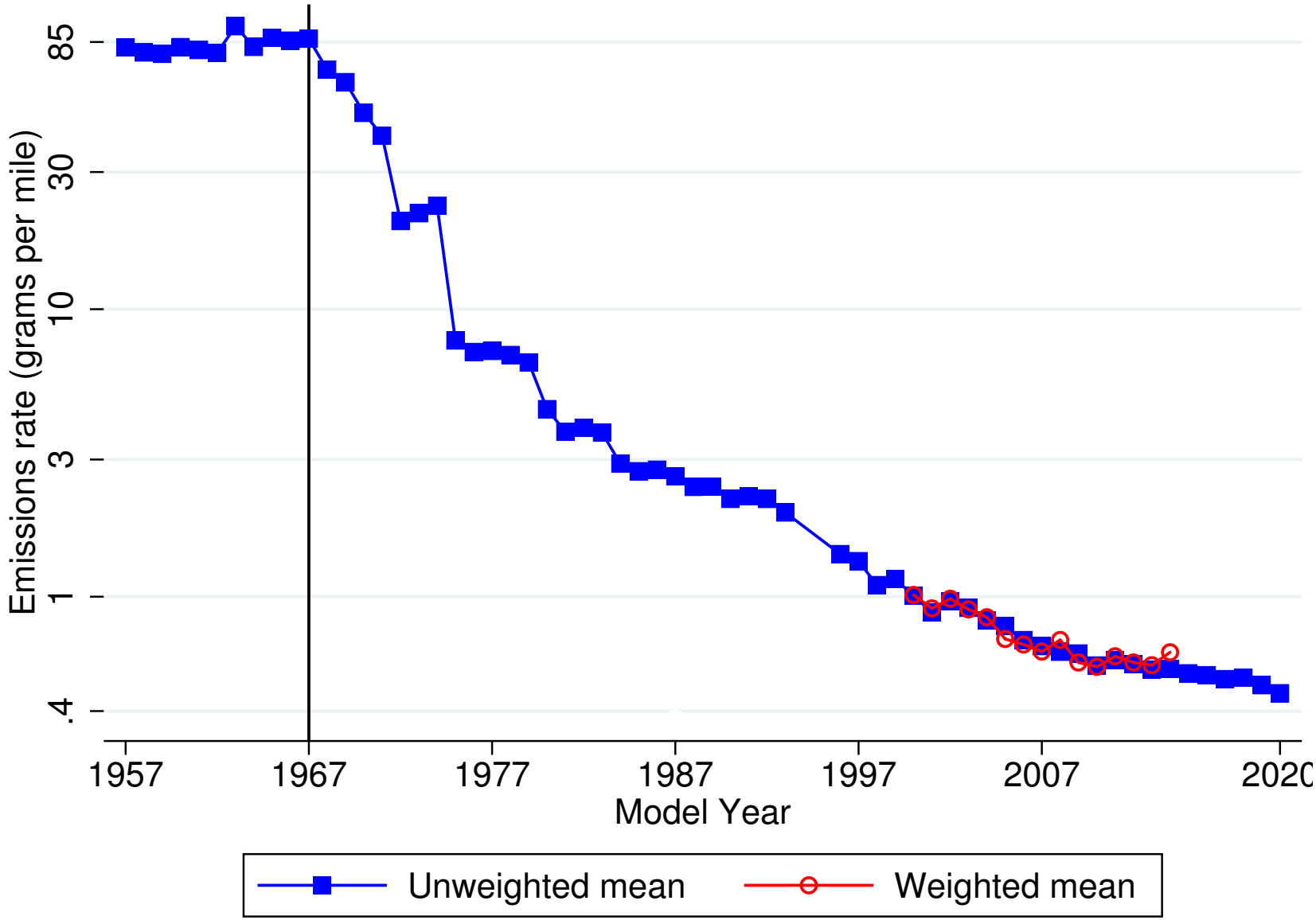
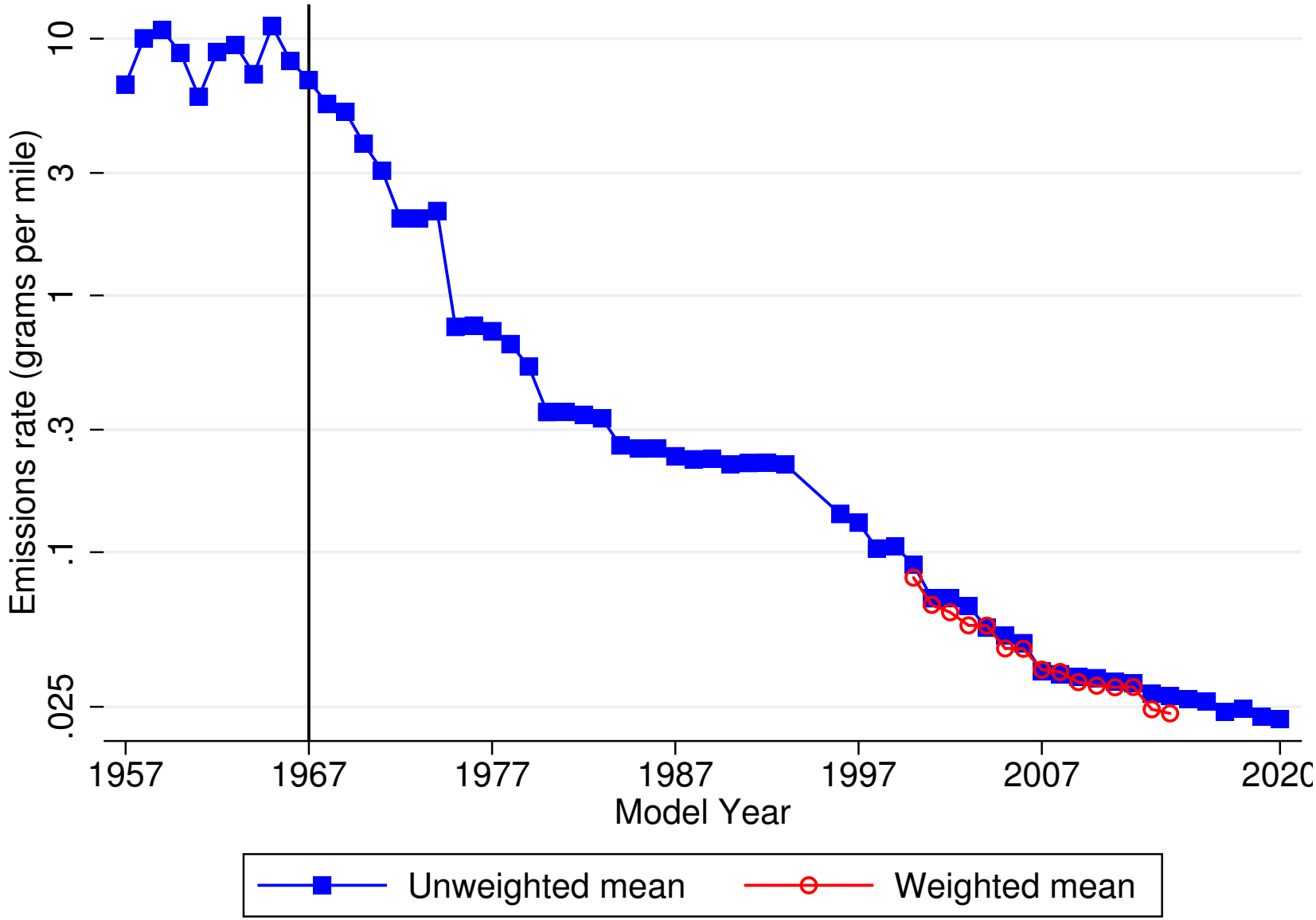
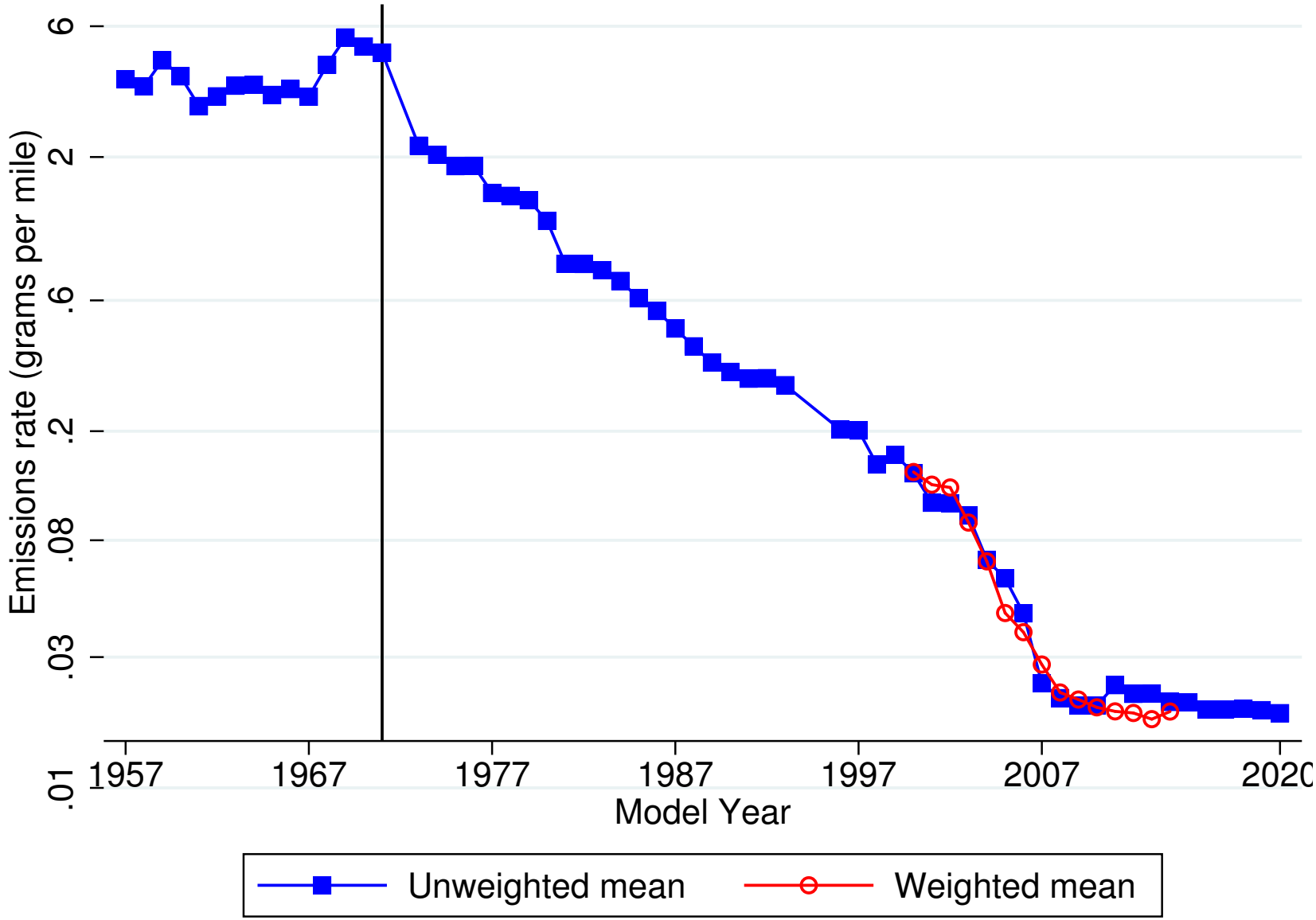
Trends: Carbon Monoxide



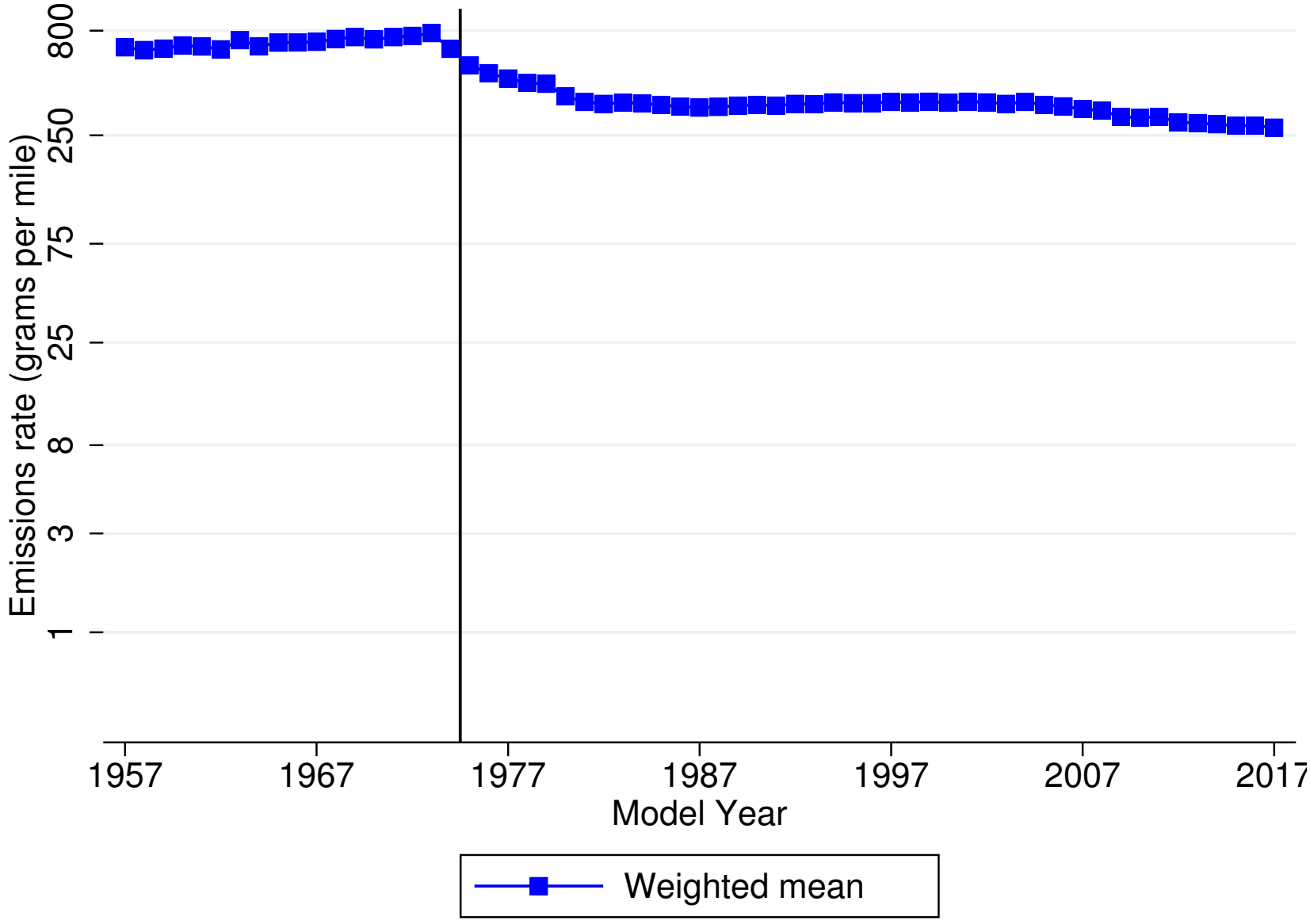
Trends: Hydrocarbons



Trends: Nitrogen Oxides



Trends: Carbon Dioxide



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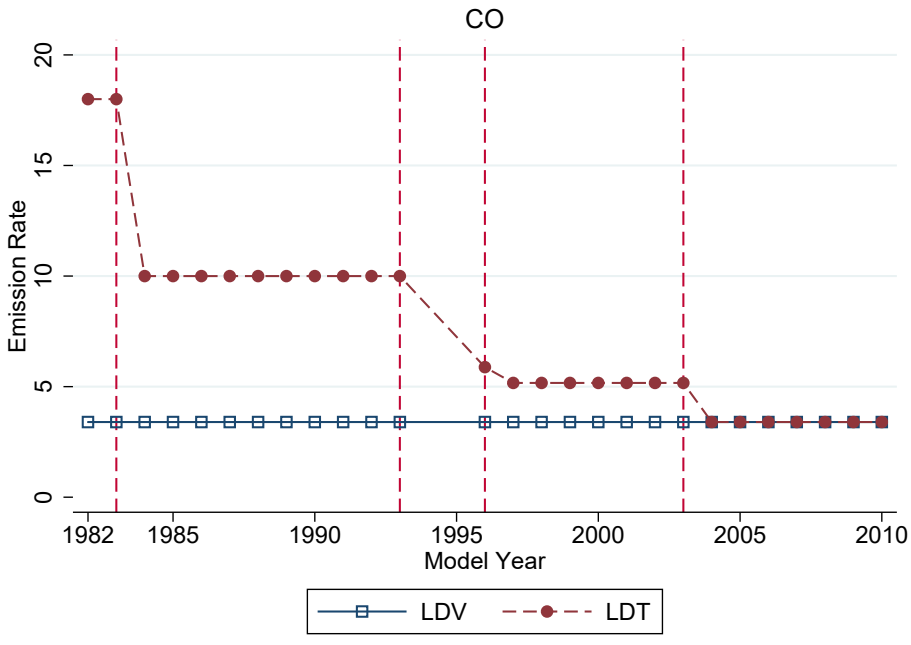
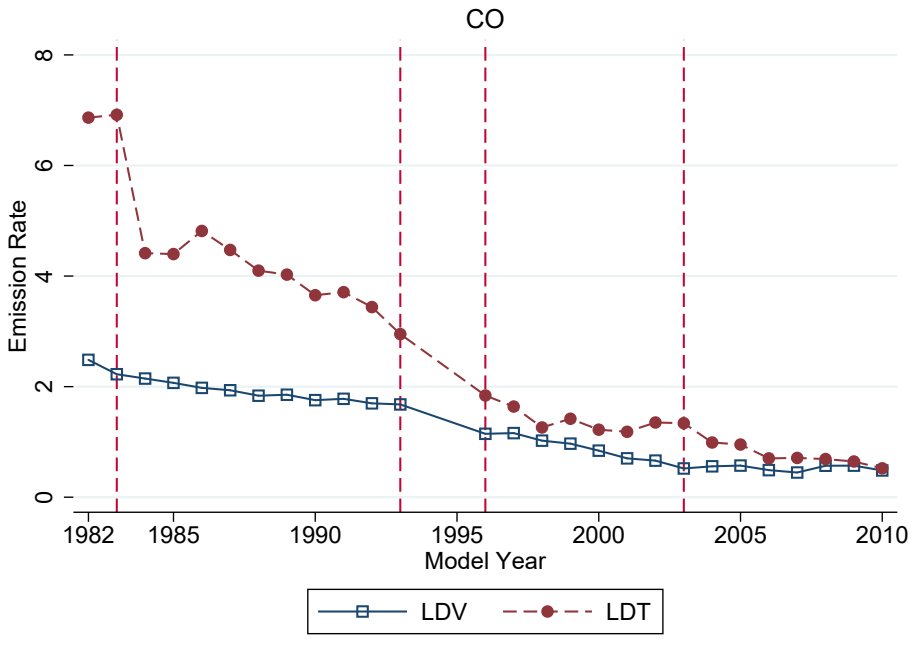
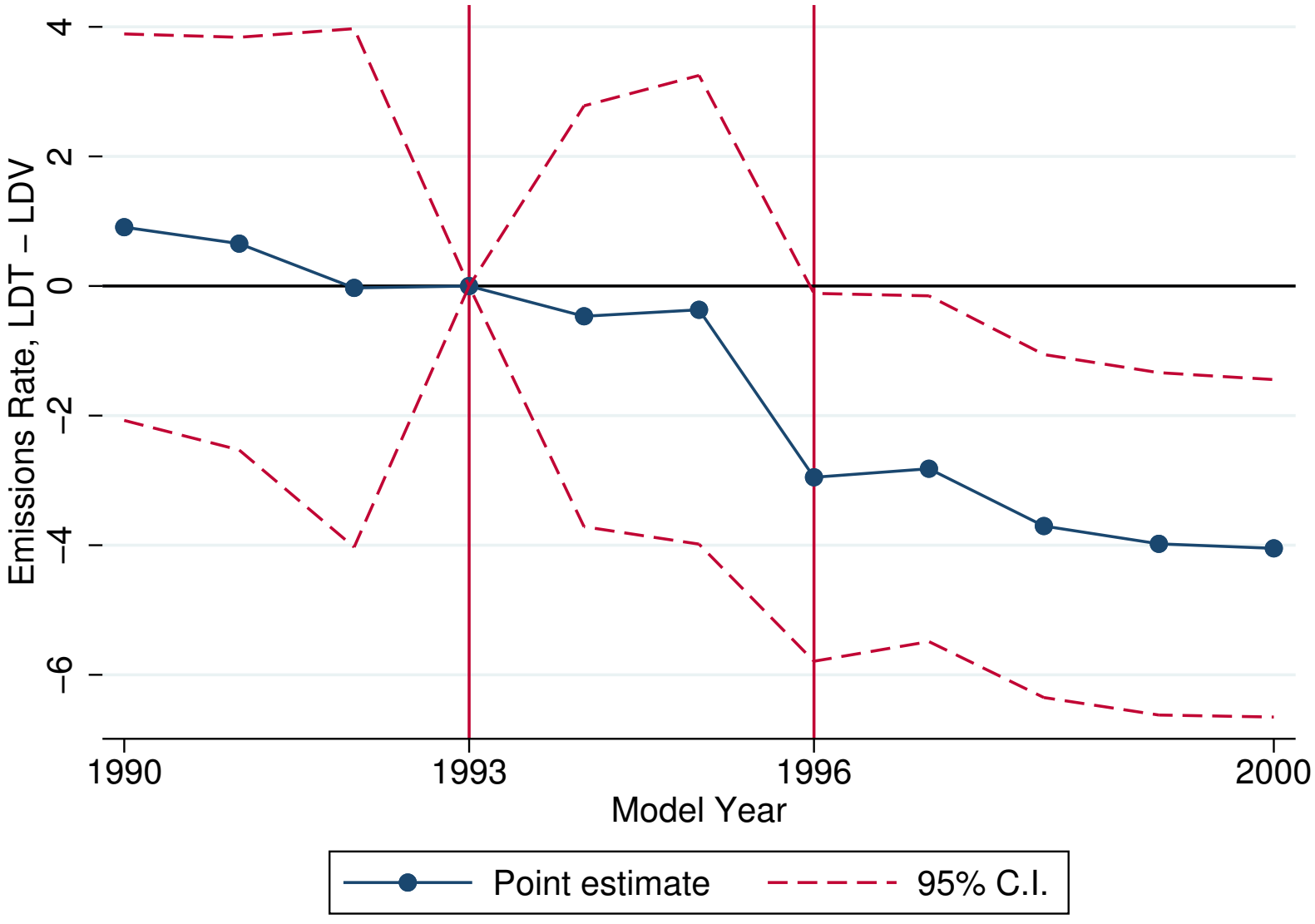
Effects of Standards on Emissions: 1982-2010 Graphs





Tier 1 Event Study Graphs: Carbon Monoxide

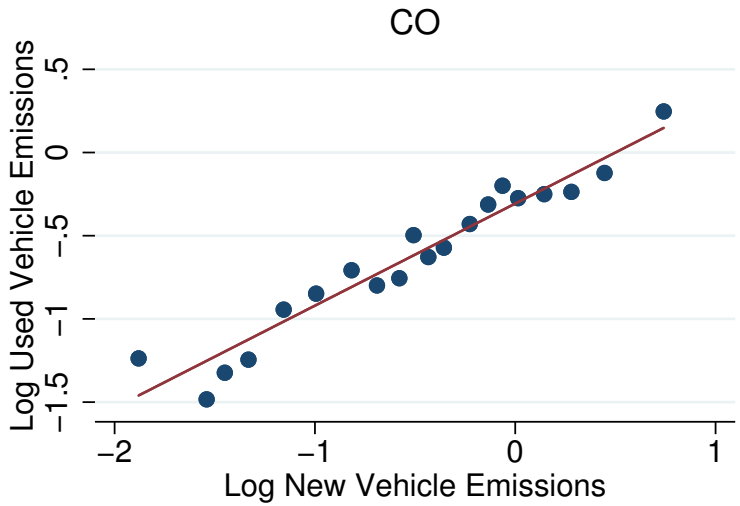


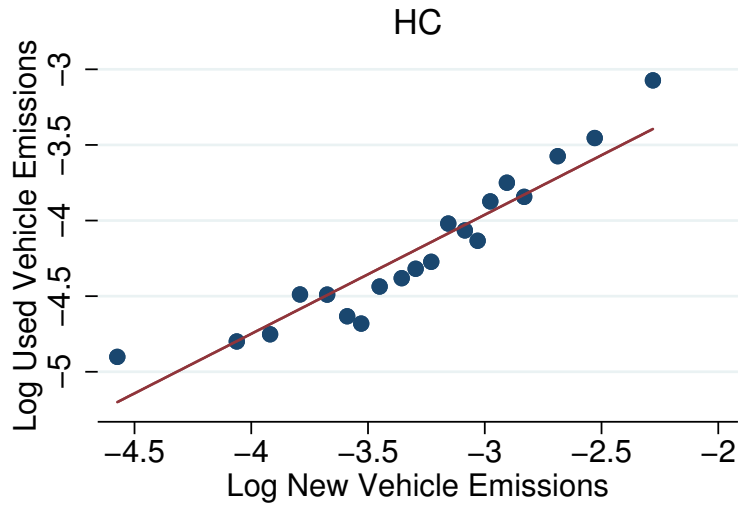
Effects of Standards on Emissions: 1990s (Tier 1) Table

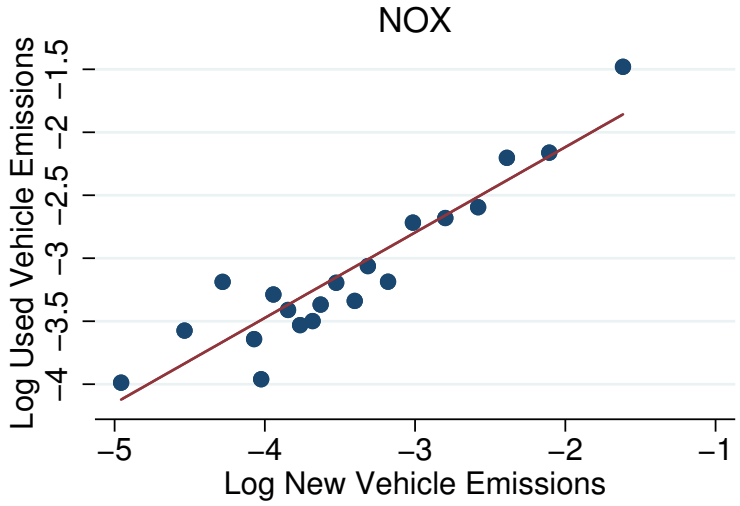
Table 3—Effects of Tier 1 Exhaust Standards on Used Vehicle Emissions

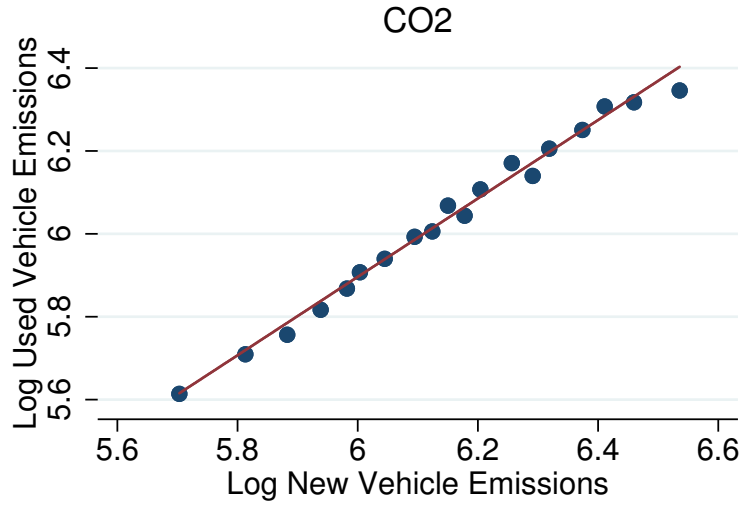
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Panel A. All Pollutants				
Exhaust standard	0.93***	0.52***	0.47***	0.49***	0.35***	0.55***	1.14***
	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)	(0.09)	(0.09)
N	28,560,842	28,560,842	28,560,842	28,560,842	6,827,280	36,996,512	28,621,296
			Panel B. Carbon monoxide (CO)				
Exhaust standard	1.60***	0.71***	0.70***	0.51**	0.94***	0.76***	0.77***
	(0.14)	(0.09)	(0.12)	(0.24)	(0.11)	(0.07)	(0.11)
N	7,112,400	7,112,400	7,112,400	7,112,400	1,695,559	9,220,310	7,155,324
			Panel C. Hydrocarbons (HC)				
Exhaust standard	1.61***	1.57***	1.63***	1.55**	1.93***	1.08***	1.41***
	(0.13)	(0.24)	(0.28)	(0.66)	(0.25)	(0.17)	(0.23)
N	7,141,284	7,141,284	7,141,284	7,141,284	1,707,181	9,249,168	7,155,324
Pollutant fixed effects	X	X	X	X	X	X	X
Model yr. fixed effects	—	X	X	X	X	X	X
Age fixed effects	X	X	X	X	X	X	X
Light duty truck FE	X	X	X	X	X	X	X
Odometer	X	X	X	X	X	X	X
CAFE standards	—	—	X	—	—	—	—
Smog check stds.	—	—	X	—	—	—	—
Gasoline cost per mile	—	—	X	—	—	—	—
Ethanol share	—	—	X	—	—	—	—
Sulfur content	—	—	X	—	—	—	—
Model yr.*truck trend	—	—	—	X	—	—	—
Ages 4-6	—	—	—	—	X	—	—
Model yrs. 1982-2000	—	—	—	—	—	X	—
Levels	—	—	—	—	—	—	X

Tier 2: New Vehicle Tests Predict Used Vehicle Emissions









2000s (Tier 2) Regression Table

Table 4—Assessment of Tier 2 Exhaust Standards: Do New Predict Used Vehicle Emissions?

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Carbon monoxide (CO)								
New vehicle emissions	0.61***	0.64***	0.67***	0.64***	0.63***	0.71***	0.19***	0.57***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.05)	(0.01)	(0.06)
N	143,168	143,168	143,168	143,168	19,363	143,168	3,392,901	3,392,901
Panel B. Hydrocarbons (HC)								
New vehicle emissions	0.79***	0.62***	0.50***	0.61***	0.40***	0.81***	0.36***	1.38***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)	(0.08)	(0.01)	(0.07)
N	143,168	143,168	143,168	143,168	19,363	143,168	3,392,901	3,392,901
Panel C. Nitrogen oxides (NO_x)								
New vehicle emissions	0.68***	0.37***	0.37***	0.36***	0.35***	1.04***	0.21***	1.42***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.08)	(0.01)	(0.10)
N	143,168	143,168	143,168	143,168	19,363	143,168	3,392,901	3,392,901
Panel D. Carbon dioxide (CO_2)								
New vehicle emissions	0.95***	0.87***	0.85***	0.87***	0.83***	0.76***	0.78***	0.72***
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
N	143,168	143,168	143,168	143,168	19,363	143,168	3,392,901	3,392,901
Age, model year FE	—	X	X	X	X	X	—	—
Light duty truck FE	—	X	X	X	X	X	—	—
Odometer	—	X	X	X	X	X	—	—
CAFE standards	—	—	X	—	—	—	—	—
Smog check standards	—	—	X	—	—	—	—	—
Gasoline cost per mile	—	—	X	—	—	—	—	—
Ethanol share	—	—	X	—	—	—	—	—
Sulfur content	—	—	X	—	—	—	—	—
Model year * truck type tr	—	—	—	X	—	—	—	—
Ages 4-6	—	—	—	—	X	—	—	—
Levels	—	—	—	—	—	X	—	X
Include abbreviated tests	—	—	—	—	—	—	X	X

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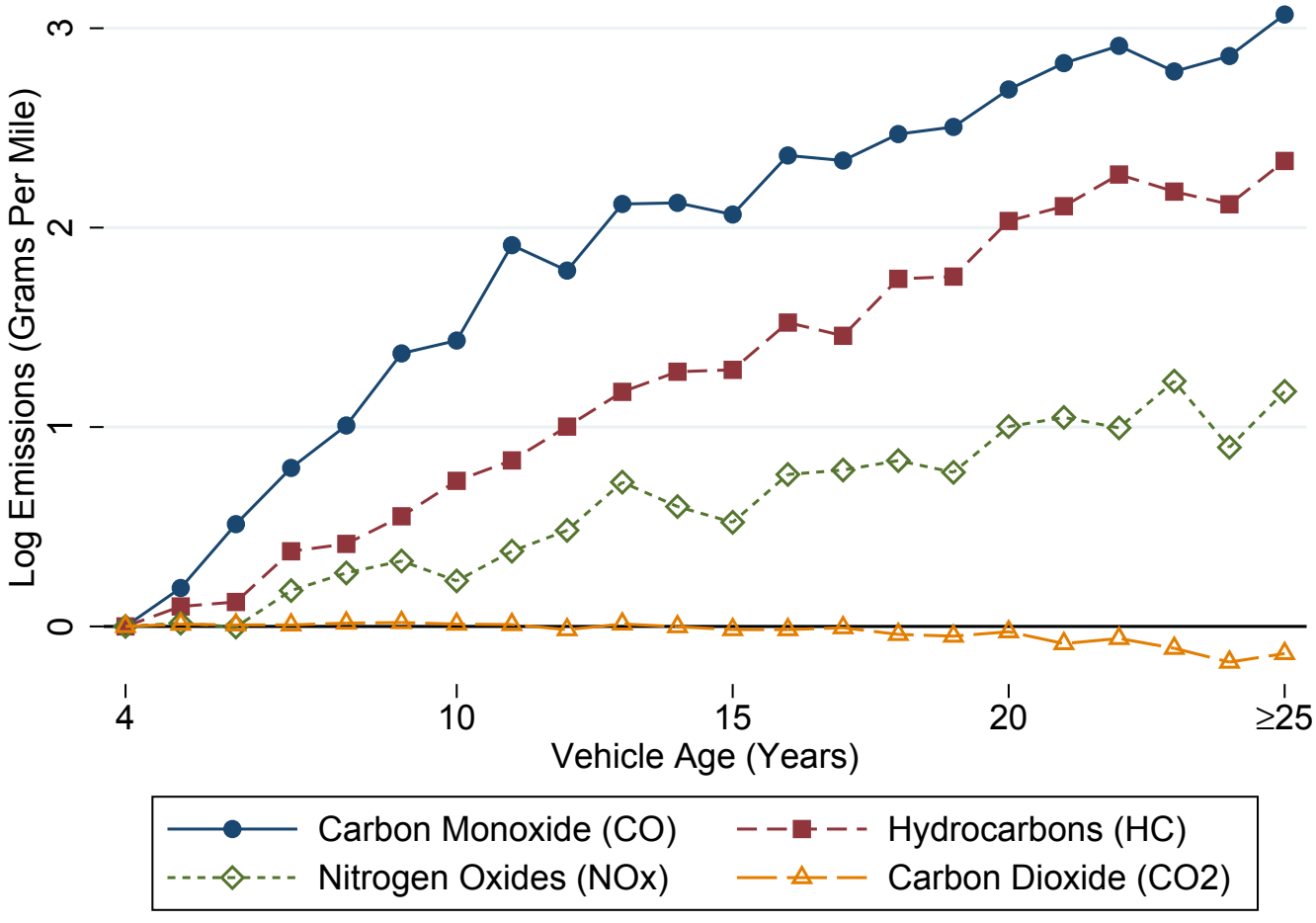
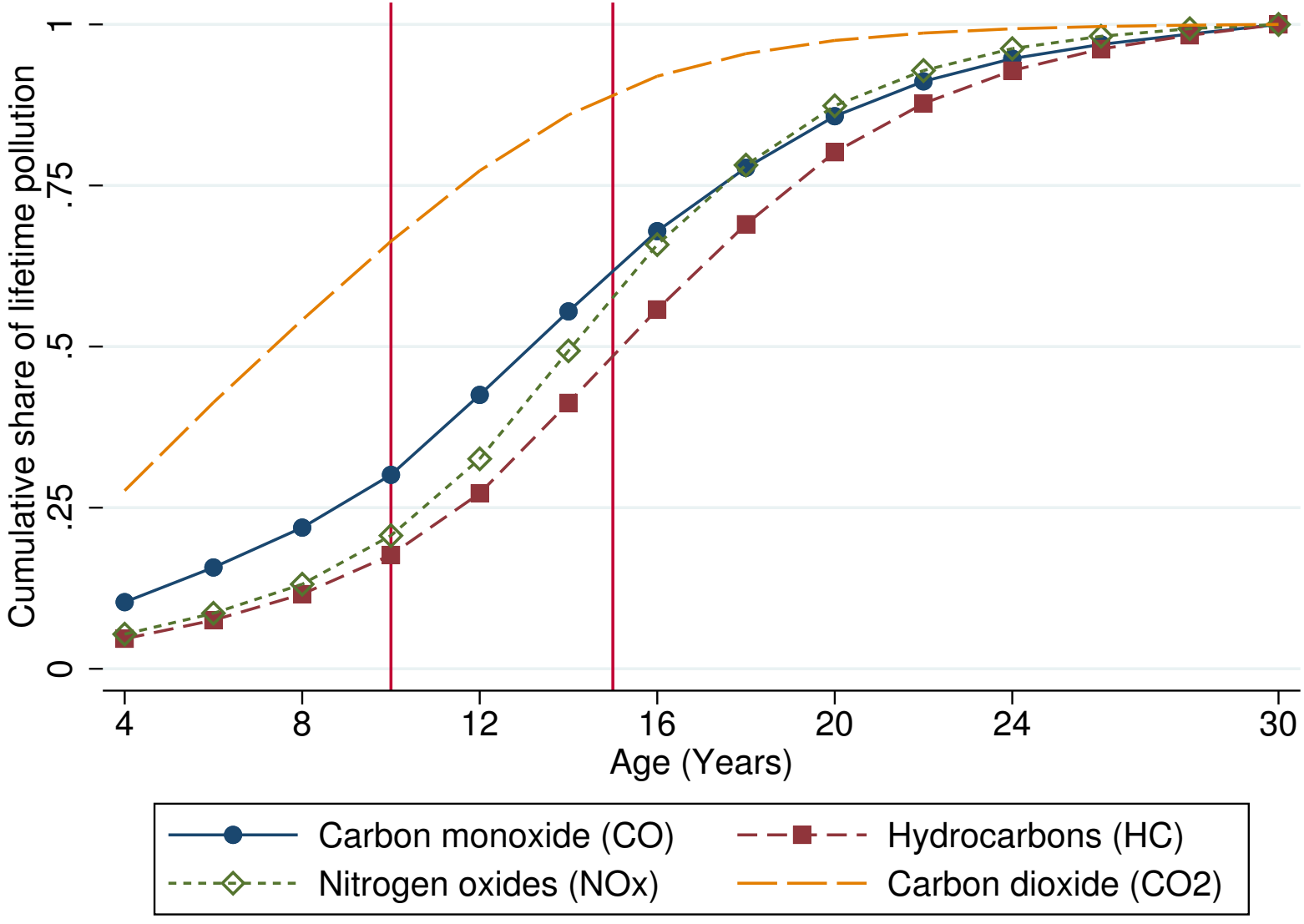
Emissions increase with vehicle age

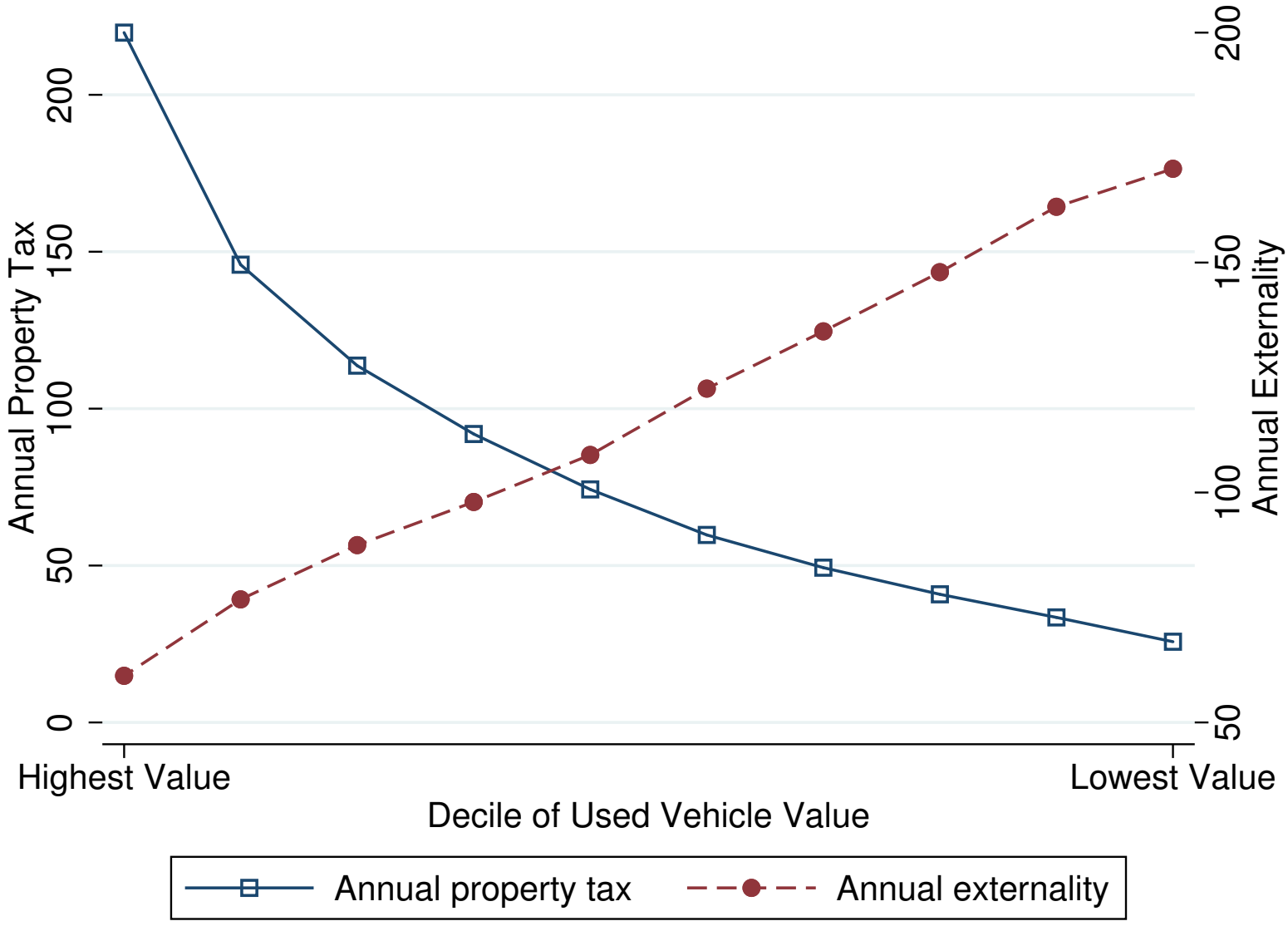


- Controls for odometer and VIN fixed effects

Older Vehicles Account for Most Pollution



Dirtier Vehicles Face Lower Registration Fees



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Analytical Model

- **Goals**
  - Algebraic results, few functional forms
  - Focus on registration fees
- **Consumers**
  - Buy new or used vehicles and outside good, repair or scrap used vehicles
  - Demand: differ in preference for new cars
  - Supply: repair new vehicle if new vehicle price exceeds repair cost
- **Firms**
  - Supply new vehicles at price p

Analytical Model

- **Equilibrium**
  - Firms choose new vehicle prices to maximize profits
  - Consumers choose new/used vehicle purchase, repair/scrap to max utility
  - Vehicle markets clear

- **Proposition**
  - If production emissions are sufficiently low, optimal ownership fees for used vehicles exceed fees for new vehicles.

Quantitative Model: Consumers

- **Representative agent**:

$$\max_{v,x} U(v,x) = (\alpha_v v^{\rho_u} + \alpha_x x^{\rho_u})^{\frac{1}{\rho_u}} \quad (1)$$

$$s.t.\ e_v v + e_x x \leq M \quad (2)$$

- **Operating cost**:

$$e_{csam} = r_{csam} + \tau_{csam} + \sigma_{csam}$$

- **Notation**
  - Vehicles v, outside good x, substitution elasticity ρ_u, prices e_v, e_x, income M
  - Vehicle rental price r, registration fees τ, operating costs σ
  - Vehicle class c, size s, age a, manufacturer m

Quantitative Model: Vehicle Manufacturers

- **Firms**:

$$\max_{p_{cs},\phi_{cs},f_{cs}} \sum_{c,s} [(p_{cs} - c_{cs}(\phi_{cs}, f_{cs})) * q_{cs}(\mathbf{p}, \mathbf{f})] \tag{3}$$

$$\text{s.t.} \quad \phi_{cs} \leq \overline{\phi}_{cs} \tag{4}$$

$$\frac{\sum_s q_{cs}}{\sum_s (q_{cs}/f_{cs})} \geq \overline{f}_c \tag{5}$$

- **Notes**
  - Compete Bertrand to maximize profits subject to exhaust, fuel economy standards
  - Price p, quantity q, marginal cost c, emission rate ϕ, fuel economy f
  - Fleet $c \in$ (passenger car, light duty truck) and vehicle size $s \in$ (small,large)

Quantitative Model: Competitive Vehicle Renters

- **Timing within period**
  - Inherit used vehicles; rental, driving, and pollution ; scrap, repair, and new vehicle purchases
- **Rental price dynamics**

$$\mathbb{E}[r_{csam,t+1}] = r_{csam,t}$$

- **Scrap**

$$y_{at} \equiv \frac{q_{a-1,t-1} - q_{at}}{q_{a-1,t-1}} = b_a (p_{at})^{\gamma} \tag{6}$$

- **Repair cost shock** H_a

$$\tilde{h}_a \equiv \mathbb{E}(H_a | h_a < p_a) = \frac{b_a^{-1/\gamma}\gamma - b_a \gamma p_a^{1+\gamma}}{(1+\gamma)(1 - b_a p_a^{\gamma})} \tag{7}$$

- **Vehicle asset values** (=prices)

$$\begin{aligned} p_A &= r_A \\ p_a &= r_a + (1 - y_{a+1}) \left(\frac{p_{a+1} - \tilde{h}_{a+1}}{1+\delta} \right) \end{aligned} \tag{8}$$

Quantitative Model: Equilibrium

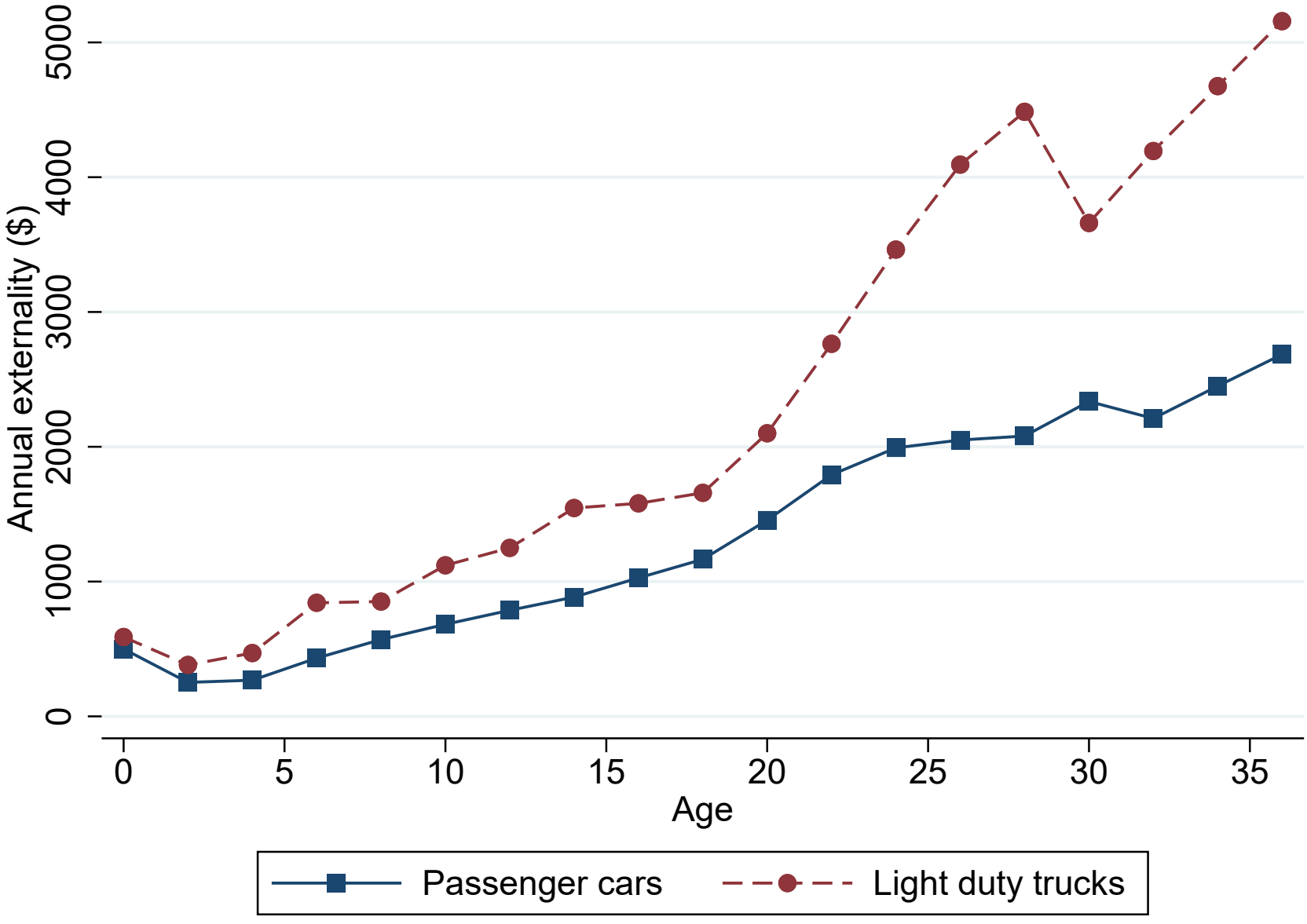
- **Competitive equilibrium**: Prices and pollution $(p_{csam}, \phi_{cs}, f_{cs})$ so
  - Representative agent maximizes utility (1) s.t. budget constraint (2)
  - Vehicle manufacturers maximize profits (3) s.t. pollution standards (4), (5)
  - Vehicle renters choose scrap (6), repair (7) to maximize profits
  - Vehicle rental values follow (8)
  - New and used vehicle markets clear

- **Social Welfare**: combines
  - Consumer surplus (equivalent variation)
  - Producer surplus (manufacturer profits)
  - Environmental externalities

Quantitative model: Calibration

- **Data/parameter sources**
  - Vehicle p, q: from industry publications (Wards, NADA)
  - Pollution emissions: microdata used for regressions
  - Fuel economy, scrap: industry publications (Polk)
  - Engineering cost of pollution abatement: industry/regulators (EPA, NRC)
  - Demand, scrap elasticities (Jacobsen & van Benthem 2015)

Quantitative Model: Annual Externality



Quantitative Model: Counterfactual Policies

1. **Environmental tax**
   - Tax each vehicle type at period-specific damages
   - Vehicle type $=$ age$\times$type$\times$size$\times$manufacturer
2. **New vehicle tax**
   - Tax new vehicles based on expected lifetime externality
3. **Flat tax**
   - All vehicle types face same (flat) annual ownership tax
4. **Standards**
   - Further tighten emission standards

Quantitative Model: Results

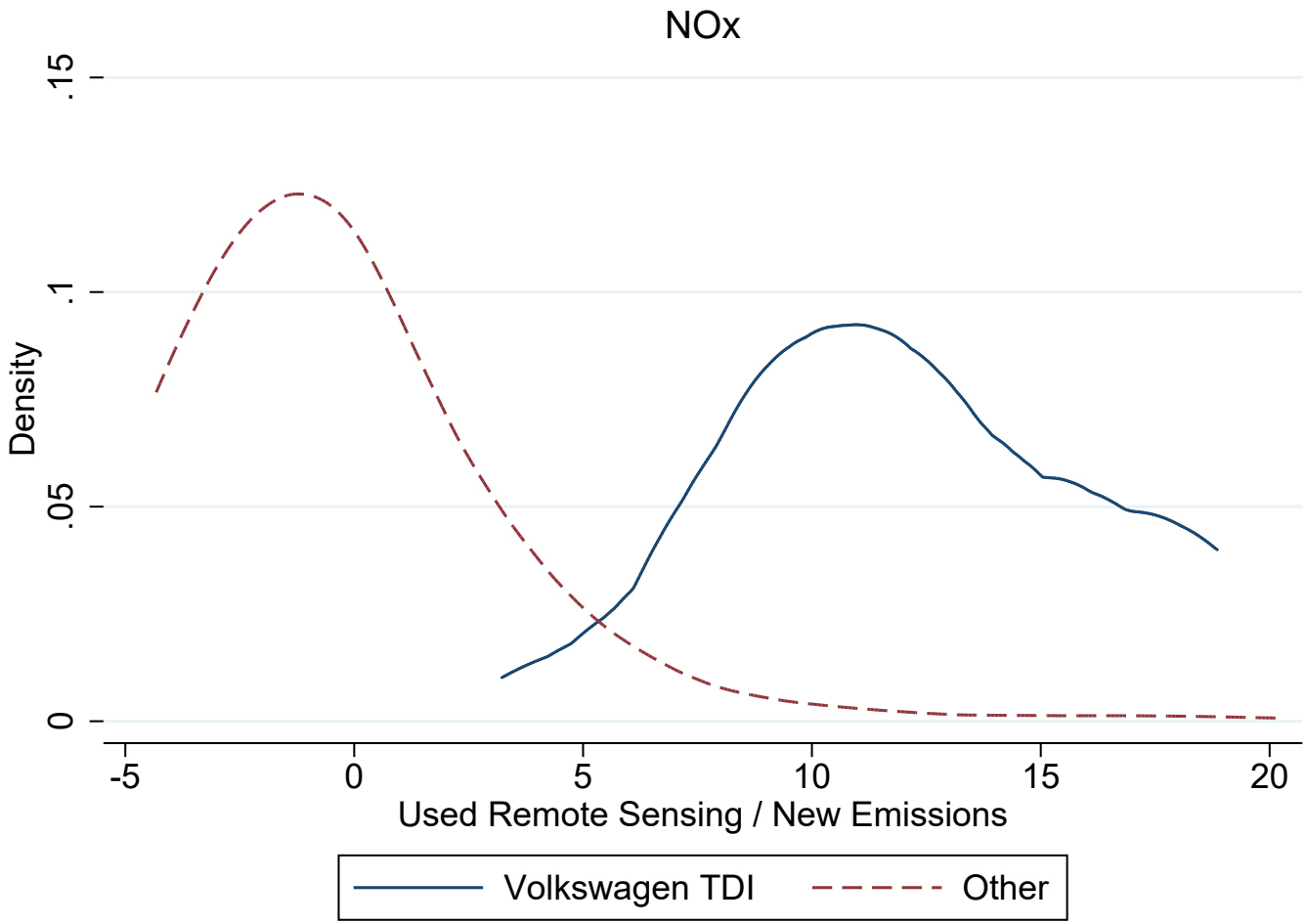
	Change in surplus (1)	Change in damages (2)	Change in welfare (3)	Change in tax revenues (4)
Simulated policy:				
Age-type used-vehicle tax	-182	-510	328	1163
New-vehicle tax	-34	5	-39	324
Flattened registration fees	-17	-115	98	0
10% tailpipe improvement	-11	-35	24	0

Conclusions

- **Summary**
  - Trend: 99% reduction
  - Cause: exhaust standards
  - Pattern: most pollution from old, unregulated vehicles
  - Analytical model: registration fees should be higher on used cars
  - Quantitative model: welfare gains, distributional consequences from reforming registration fees

- **Broader comments**
  - Gasoline $\rightarrow$ electric
  - Equity: dirtier cars in low-income communities, communities of color

Effects of Tier 2 standards



- Ratio of used-to-new emissions is disproportionately high for Volkswagen (remote sensing data)

▸ Return to Tier 2 results