Externalities, market power and vehicle taxation

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Electric Vehicles and Norway

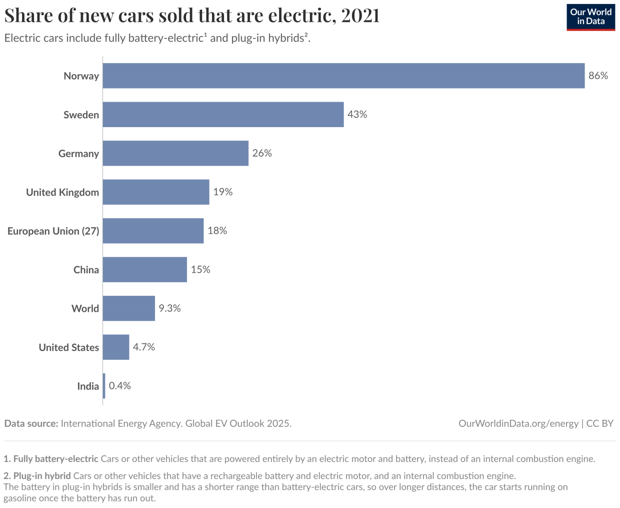


Figure 1: EV evolution (2010-2024)

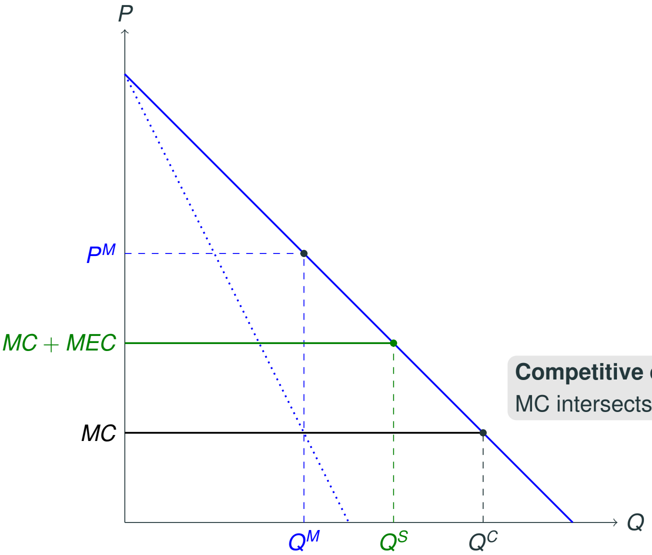
Table 1: Summary statistics for car options by fuel type (2021–2022)

	ICEV	EV
Electric range (km), PHEV/EV only	55.19	384.74
	(12.23)	(115.43)
Weight (1000 kg)	1.79	1.94
	(0.38)	(0.42)
Engine power (kW)	184.19	176.29
	(93.94)	(98.27)
SUV (0/1)	0.52	0.44
	(0.50)	(0.50)
Hybrid (0/1)	0.19	-
	(0.39)	(-)
Plug-in hybrid (0/1)	0.26	-
	(0.44)	(-)

Table 2: Cost Summary statistics for car options by fuel type (2021–2022)

	ICEV	EV
Purchase price excluding taxes (1000 EUR)	32.75	36.47
	(20.20)	(17.35)
Purchase taxes (1000 EUR)	23.41	0.00
	(17.13)	(0.00)
Cost per 100 km excluding taxes (EUR)	4.27	1.33
	(2.18)	(0.25)
Taxes per 100 km (EUR)	3.64	0.56
	(1.93)	(0.10)
CO2 emissions (g/km)	137.82	0.00
	(71.06)	(0.00)
PM emissions (mg/km)	26.96	27.66
	(3.13)	(3.32)

Buchanan (1969): Market Power vs Externalities



Competitive equilibrium
MC intersects demand at Q^C.

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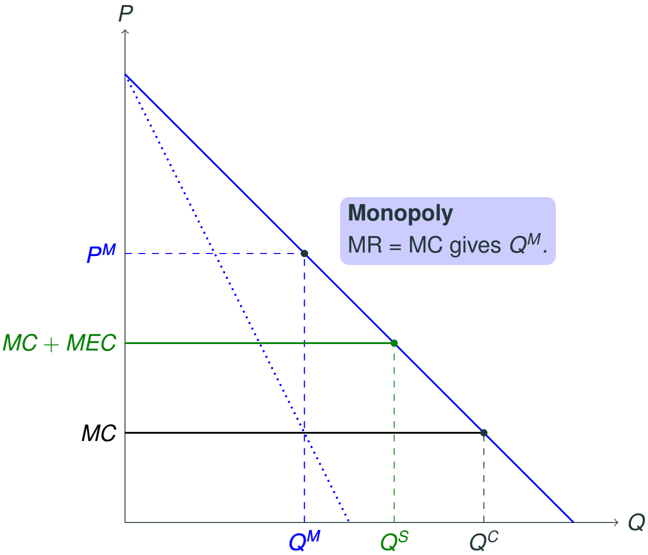

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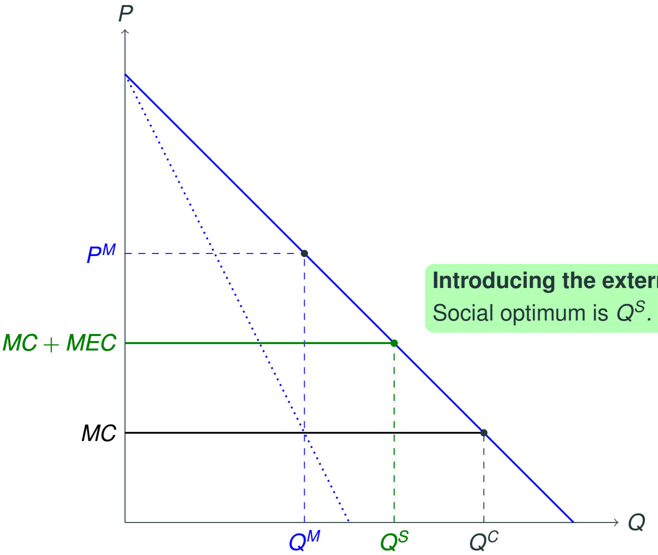
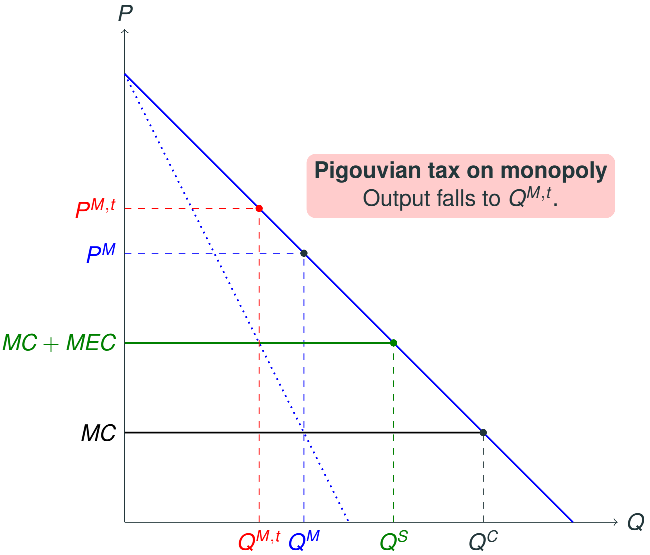


Introducing the externality

Social optimum is Q^S.

Buchanan (1969): Market Power vs Externalities



Pigouvian tax on monopoly
Output falls to $Q^{M,t}$.

This paper. *Contribution*

Tax design with market power and imperfectly targeted environmental externalities.

Model: Equilibrium model of vehicle choice and driving mileage.

1. Market power ($p > mc$) in a Betrand Nash perfect information game (*Buchanan 1969*)

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2. Externalities (CO_2, NO_x, PM, accidents) (*Pigou 1920*)
   - Internalised through vehicle-specific and per km taxes
3. Imperfect targeting (*Sandmo 1976*)
   - Hard to measure externalities: PM and accidents (but correlated to weight!).
   - Usage heterogeneity from variation in driving patterns.

This paper. ***Choices, data and results***

- Consumers choose cars and km driven, based on their expected driving costs.
  - Extensive margin: car choice (depends on driving cost, car price and other car attributes)
  - Intensive margin: driving intensity (affected by driving costs)
- Setting: new cars in Norway. Why?
  - variation in taxes across car models: High taxes for ICEVs, and tax exemptions for EVs
  - high EV adoption rates (charging station availability is no longer a constraint in most places)

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  - high EV adoption rates (charging station availability is no longer a constraint in most places)
- Transaction data on all privately owned vehicles in Norway (owner, location, car) and usage (odometer, km driven)
- Interim results:
  - Inelastic driving to costs (< 0.4), elastic car choice to car price ($\approx$ 5 for ICEV, 9 for EV)
  - Pass-through $\approx$ 75%
  - Pigouvian taxes are not optimal due to market power.
  - Fuel taxes “hit quite well”: CO_2, weight correlation.

Related Literature

Market power and policy design.

- Preonas (2024): market power in coal shipping $\Rightarrow$ implications for climate policy (RES).
- Grieco, Murry & Yurukoglu (2024): evolution of market power in the U.S. auto industry (QJE).
- Asker, Collard-Wexler, De Cannière, De Loecker & Knittel (2024): oil market power vs emissions (NBER WP).
- Fowlie, Reguant & Ryan (2016): market-based, emissions regulation with industry dynamics (JPE).

Auto demand, fuel costs, and tax policy.

- Grigolon, Reynaert & Verboven (2018): consumer valuation of fuel costs and taxes (AEJ:Pol).
- Durrmeyer & Samano (2018): feebates vs. fuel economy standards (EJ).
- Barwik, Kwon and Li (2024), attribute based subsidies and with endogenous product attributes, environmental externalities, and market power. (NBER WP)
- Reynaert (2020): compliance / abatement strategies under emissions standards (RES).

EV adoption, substitution, and externalities.

- Xing, Leard & Li (2021): what do EVs replace? (JEEM).
- Gallagher & Muehlegger (2011): incentives and hybrid adoption (JEEM).
- Muehlegger & Rapson (2023): correcting EV abatement estimates (JAERE).

Scope and Limitations

- Focus on new car purchases (2021–2022 cohort).

  Tax revenues from old cars not considered. Consumers choice: new car vs. status quo.
- Manufacturers keep fixed the product attributes and the set of car models (unlike in Remmy, 2025, AEJ:Pol; Barwik, Kwon and Li, 2024, NBER WP).
- Static choice model based on current price and future usage costs.
- Mature EV technology.
- External costs: carbon emissions, usage pollution and accidents (not production, congestion, noise).

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  Charging infrastructure is not a binding constraint, and network effects are not relevant.
- External costs: carbon emissions, usage pollution and accidents (not production, congestion, noise).

Externalities from Car Use

Imperfect targeting: Fuel taxes internalize ICEV externalities, but EVs lack an equivalent km-based tax that internalizes the EC of accidents and PM.

EC per 1000 km

1. Climate: CO_2 (gasoline/diesel only with 2.3/2.7 kg/liter fuel, and EUR 189 CO_2 price)
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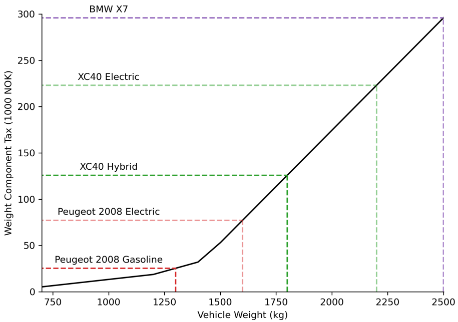
EC estimates for CO_2, PM, NO_x (Van Essen 2019, EU-Commission).
EC for accidents from Anderson & Auffhammer QJE (2013)
Non exhaust: brake, tyre, road wear (negligible for passenger cars), $\propto$ vehicle weight (OECD 2020) Congestion: time- and location-specific, better addressed with cordon/time-varying pricing, (Durrmeyer & Martinez 2024)

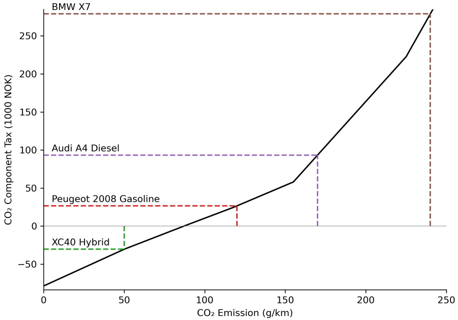
Ownership and usage taxes

- High **registration taxes**: tax based on weight, CO_2, NOx, (typically 113.7–341.1 USD),
- High **fuel taxes** (in 2021, gasoline tax: 6.38 NOK/l, 0.7 USD/l)
- **VAT** is 25% of the car price,
- Other taxes: tolls, insurance tax, parking fees, ferry fees.

Weight



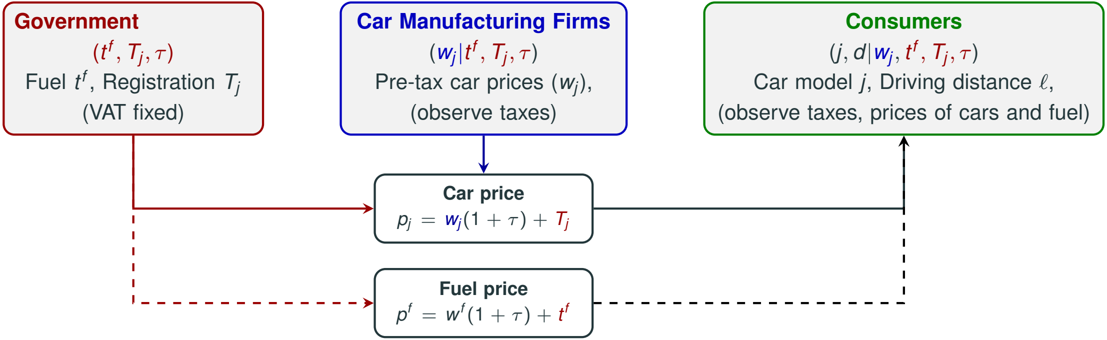
CO_2



(2023: small, flat weight tax introduced + partial VAT for EVs)

Model

Model. *Agents and Choice variables*



VAT in Norway is 25%

Demand. *Model*

Consumer i chooses vehicle j (outside option $j = 0$: not buying a new car ($u_{i0} = \epsilon_{i0}$).
Then drives for ℓ_{ijt} distance in $t = 0, \dots, T$.

The indirect discounted utility at purchase with rational expectations is

$$u_{ij} = \underbrace{\sum_{t=0}^{T} \delta^t \, \mathrm{E}_0 \left[v_i(\ell_{ijt}) - \alpha_i k_{jt} \, \ell_{ijt} \right]}_{\text{discounted driving utility}} - \alpha_i p_j + x_j' \beta_i + \xi_j + \epsilon_{ij},$$

- Decreasing marginal driving utility, $\frac{\partial^2 v_i(\ell_{ijt})}{\partial \ell^2} < 0$

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- k_{jt} is the cost of driving (per km), p_j is the price of a car, α_i the price sensitivity.
- $\epsilon_{ij} \sim$ EV1 and ξ_j an unobserved demand shock,

Demand. *Optimal Driving*

The optimal driving ($\ell^*_{ijt} = \frac{\gamma_i - \alpha_i k_{jt}}{\eta_i} + \nu_{ijt}$) depends on k_{jt}, α_i, driving utility curvature ($\eta_i > 0$), and driving preference shocks, $\nu_{ijt} \sim \mathcal{N}(0, \sigma^2_\nu)$.

$$v_i(\ell) \;=\; \gamma_i(\ell - \nu) \;-\; \frac{1}{2}\,\eta_i(\ell - \nu)^2.$$

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$$v_i(\ell) \; = \; \gamma_i(\ell - \nu) \; - \; \frac{1}{2}\,\eta_i(\ell - \nu)^2.$$

Per-period optimum driving (FOC):

$$\ell^*_{ijt} \; = \; \frac{\gamma_i - \alpha_i k_{jt}}{\eta_i} \; + \; \nu_{ijt} \; \equiv \; \widehat{\ell}_i(k_{jt}) \; + \; \nu_{ijt}.$$

Expected per-period net surplus (at the optimum)

$$\mathrm{E}_0\left[\, v_i(\ell^*_{ijt}) - \alpha_i k_{jt} \ell^*_{ijt} \,\right] \; = \; \frac{(\gamma_i - \alpha_i k_{jt})^2}{2\,\eta_i}.$$

Stable fuel costs expected

$$E_0[k_{jt}] \; = \; k_{j0}$$

No driving trend

$$\mathrm{E}_0[\nu_{ijt}] \; = \; 0$$

Data and Estimation Strategy

Data Sources

- **Vehicle register (NPRA)**: all new car registrations (private users), 2021–2022
  - Technical characteristics: engine power, fuel efficiency, weight, fuel type
  - Owner characteristics: municipality (centrality), age
- **OFV**: list prices, battery capacity, electric range
- **Odometer readings**: annual driving distance from periodic inspections
- **SSB**: monthly fuel and electricity prices

Estimation Strategy

- Two-stage demand estimation:
  1. Driving model: estimate from odometer readings
     - Captures systematic heterogeneity in driving elasticities
     - Provides inputs for driving surplus term in choice utility
  2. Choice model: estimate car preferences from purchase decisions
     - Distribution of price sensitivity and non-price preferences
     - Demographic interactions, e.g., higher EV demand in central areas, young buyers prefer smaller cars
- Supply side: recover marginal costs c_j from firms' first-order conditions
- Identification: Use tax parameters as instruments to deal with price endogeneity (ξ)

Driving Model Estimation

- Specification: optimal driving per spell

$$\ell_{in} = \frac{\gamma_{g(i)}}{\eta_{g(i)}} - \frac{\alpha}{\eta_{g(i)}} k_{in} + \nu_{in}$$

- Projection of driving ℓ_{in} on costs k_{in} interacted with group dummies
- Identifies relative γ_g, η_g across demographic groups
- Captures systematic heterogeneity in driving elasticities
- Provides the driving surplus term for the choice utility

Driving Model

Driving Cost Region Income

Cost $\times$ Income Cost $\times$ Centrality

Estimation Strategy. *Choice Model*

Indirect utility (compact form) estimated via random coefficients logit model

$$u_{ij} = \underbrace{\Delta_T \cdot \frac{(\gamma_i - \alpha_i k_j)^2}{2\,\eta_i}}_{\text{discounted driving surplus}} - \alpha_i p_j + x_j' \beta_i + \xi_j + \epsilon_{ij}.$$

- Simulated maximum likelihood.
- Gaussian quadrature nodes for (α_i, β_i) distribution.
- y_i follows log-normal income distribution by demographic group, and $\alpha_i = -\exp(\alpha\pi(y_i^\lambda - 1)/\lambda)$.
- Control function approach for net-of-tax price residual (correcting endogeneity of p_j).

Car Characteristics

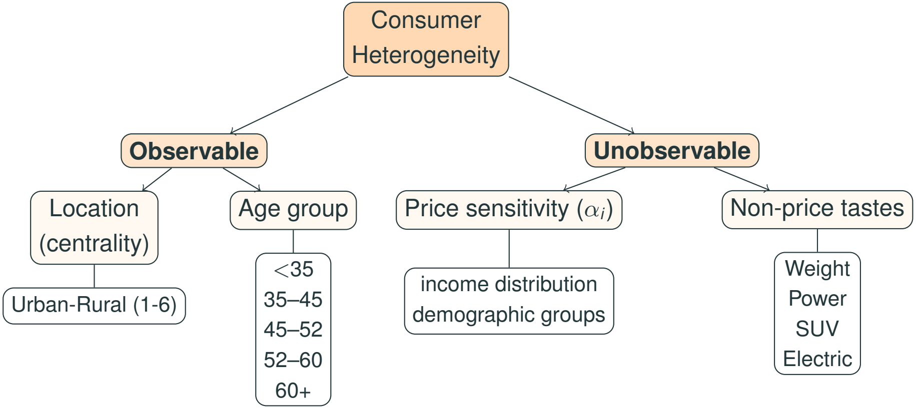
Price | ***Fuel Type*** | Weight | Engine Power | ***Body Style*** | Range

Body Style: Sport | Large | Small | Luxury | Compact | SUV

Fuel Type: Electric Battery | Hybrid / Plug-in Hybrid | Gasoline | Diesel

where $\Delta_T \equiv \sum_{t=0}^{T} \delta^t = \frac{1-\delta^{T+1}}{1-\delta}$

Estimation Strategy. *Choice Model Heterogeneity*



e.g. higher EV demand in central areas, younger buyers prefer smaller cars

Endogeneity & Identification

$$u_{ij} \;=\; \Delta_T \cdot \frac{(\gamma_i - \alpha_i k_j)^2}{2\,\eta_i} \;-\; \alpha_i p_j \;+\; x_j'\beta_i \;+\; \xi_j \;\;+\; \epsilon_{ij}$$

Instruments for p_j (uses the Norwegian tax system)

- Registration taxes and VAT exemptions $\Rightarrow$ variation in net-of-tax prices
- Fuel taxes interacted with fuel efficiency $\Rightarrow$ variation in the effective per km cost

Control function approach (corrects for correlation between p_j and ξ_j)

- First stage: regress price on tax shifters and characteristics
- Include residuals ($\hat{r}_j$) in choice utility: $u_{ij} = \cdots + \rho\hat{r}_j + \epsilon_{ij}$

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Identification

- Heterogeneity in α_i is pinned down by within-group substitution patterns
- price effects are separated from ξ_j by using the *exogenous tax variation*

Estimation Results and Welfare

Results

- Inelastic driving to the cost per km (0.44-0.5)
- Elastic car choices to price ($\approx$ 5 for ICEV and 9 for EV)
- Markups 28% average, (similar to Grieco et al, 2024)
- Substantial heterogeneity in tastes, “unobserved” and geographic/socio-economic
- Large and important heterogeneity in preferences/WTP for EVs
- 75% pass-through of cost/taxes to car prices

Welfare

- Welfare:

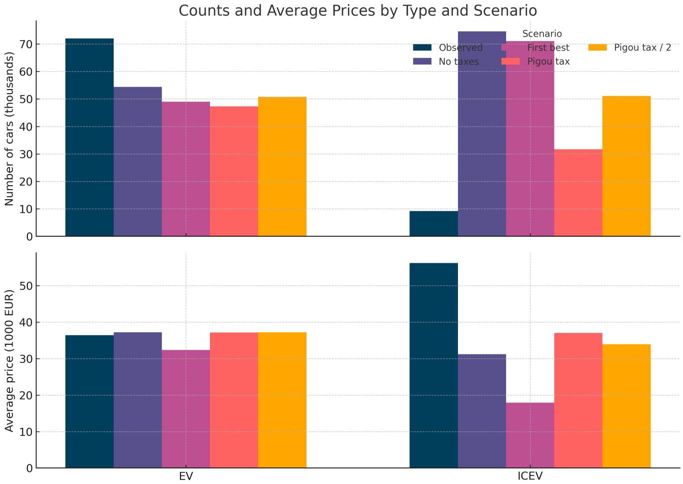
$$W = CS + \Pi + TR \cdot (1 + MCPF) - EC.$$

- Components (at equilibrium $\mathbf{w}^*$):
  - **CS:** logit expected max utility aggregated over heterogeneity; *driving surplus enters directly*.
  - **Profits:** $\Pi = \sum_m \pi_m(\mathbf{w}^*, \mathcal{T})$.
  - **Tax revenue:** Registration taxes, fuel taxes and VAT, adjusted by MCPF.

$$TR = \underbrace{\sum_j \tau_j \, w_j \, q_j}_{\text{VAT on pre-tax price}} + \underbrace{\sum_j T_j \, q_j}_{\text{registration}} + \underbrace{\sum_j \Delta_T \, \tau_j^f \; \mathrm{E}[\widehat{\ell}_i(k_j) \mid j] \; q_j}_{\text{driving/fuel}} .$$

  - **External costs:** Total pollution and accident EC for chosen vehicles and driving

1 No tax
2 First best ($p = mc$), with usage tax
3 Market power ($p > mc$) and usage tax
4 Market power and 1/2 usage tax



Tax wedge between ICEVs and EVs is much larger than justified by external costs ⇒ choice distortion.

Welfare

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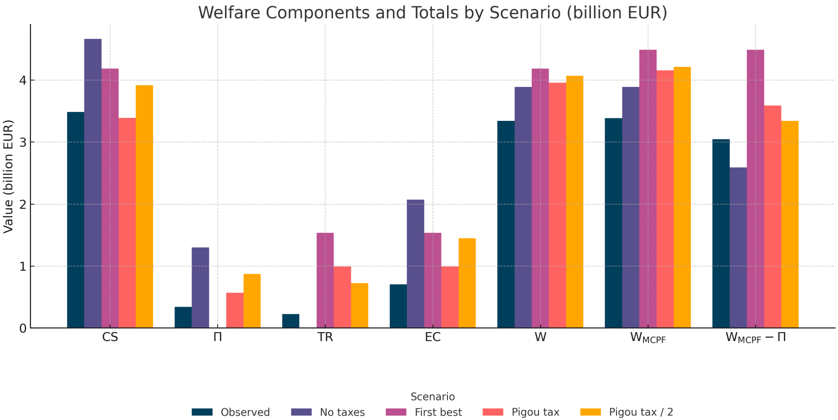


- For welfare: Usage tax (with or without market power) $\succ$ No taxes $\succ$ Observed
- No taxes: large shift toward ICEVs, $\uparrow$ external costs, but $\uparrow\uparrow$ private surplus.
- First-best with usage tax: balances ICEV/EV composition, internalizes externalities, maximizes total welfare (when ignoring profits).
- 1/2 usage tax: close to optimal when profits matter, preserves industry rents while $\downarrow$ externalities.

Note: Optimal tax design will depend on whether producer profits are valued in social welfare.

Conclusion and Next Steps

- While current taxes might have had braoder goals such as increasing adoption, for the future (with $\approx$100% EV share for new cars) the tax rates could be improved.
- PM and accidents should be incorporated into the tax system to fully account for the EC.
- Inelastic driving to fuel cost but elastic car choice to fuel prices

Next Steps

- Welfare effects of inefficient driving vs. inefficient car purchases.
- Explore optimal taxation level under imperfect competition.
- Role of vehicle replacement and fleet turnover in long-run outcomes.
- Potential extensions: interactions with charging infrastructure, EV learning and adoption dynamics.

Appendix

Additional Figures and Results

Supply Side and Profit Maximization

- Manufacturer m chooses pre-tax prices $\{w_j : j \in \mathcal{J}_m\}$ to maximize

$$\pi_m = \sum_{j \in \mathcal{J}_m} (w_j - c_j)\, q_j(\mathbf{w}, \mathcal{T}),$$

  where demand q_j is evaluated at consumer prices $p_j = w_j(1 + \tau_j) + T_j$.

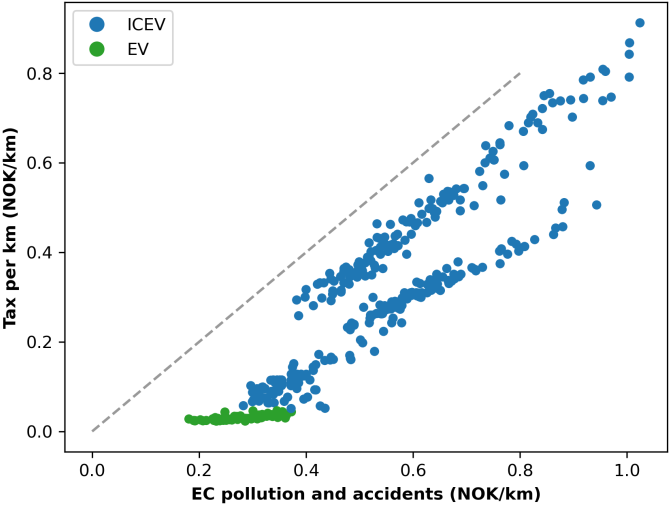
- Nash–Bertrand FOCs in w:

$$\frac{\partial \pi_m}{\partial w_j} = q_j(\mathbf{w}^*, \mathcal{T}) + \sum_{k \in \mathcal{J}_m} (w_k - c_k) \frac{\partial q_k}{\partial w_j}(\mathbf{w}^*, \mathcal{T}) = 0.$$

- Producer margin (per unit, in resource terms): $(w_j - c_j) = \frac{p_j - T_j}{1+\tau_j} - c_j$.

Taxes versus social cost per kilometer

At observed 2021 tax levels: usage taxes (per km) < external cost (pollution + accidents)



Lifetime taxes versus social cost

At observed 2021 taxes levels, the taxes paid for a car in the lifetime (registration + usage)

- are below the external cost of pollution for EVs,
- are above the external cost of pollution for ICEVs,