Externalities, market power and vehicle taxation

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Electric Vehicles and Norway

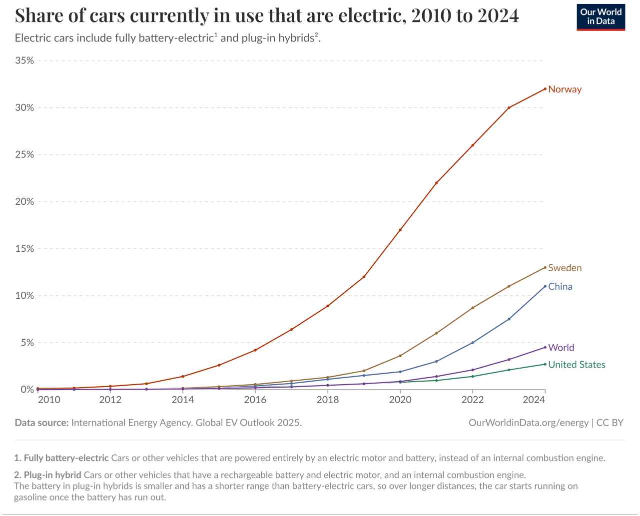


Figure 1: EV evolution (2010-2024)

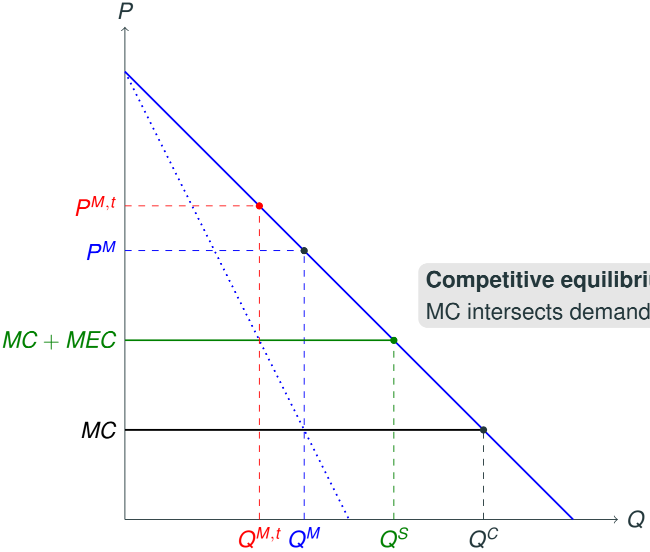
Table 1: Summary statistics for car options by fuel type (2021-2022)

	ICEV	Diesel	Electric
Electric range (km)			384.74
	(27.18)	(15.81)	(115.43)
Weight (1000 kg)	1.76	1.88	1.94
	(0.40)	(0.34)	(0.42)
Engine power (kW)	199.71	150.87	176.29
	(104.90)	(50.66)	(98.27)
SUV (0/1)	0.49	0.60	0.44
	(0.50)	(0.49)	(0.50)
Hybrid (0/1)	0.18	0.20	-
	(0.39)	(0.40)	-
Plug-in hybrid (0/1)	0.36	0.06	-
	(0.48)	(0.24)	-

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

	Gasoline	Diesel	Electric
List price (1000 EUR)	57.10	54.10	36.50
	(40.50)	(23.70)	(17.40)
Registration tax (1000 EUR)	14.20	17.30	0
	(14.00)	(10.40)	(4.30)
Cost per 100 km (EUR)	7.83	8.09	1.91
	(4.70)	(2.17)	(0.35)
Tax per 100 km (EUR)	2.70	2.35	-
	(1.65)	(0.61)	-
CO_2 emissions (g/km)	127.77	158.02	0.00
	(79.57)	(43.46)	(0.00)
PM emissions (mg/km)	26.60	27.73	27.66
	(3.22)	(2.77)	(3.32)

Buchanan (1969): Market Power vs Externalities



Competitive equilibrium
MC intersects demand at Q^C.

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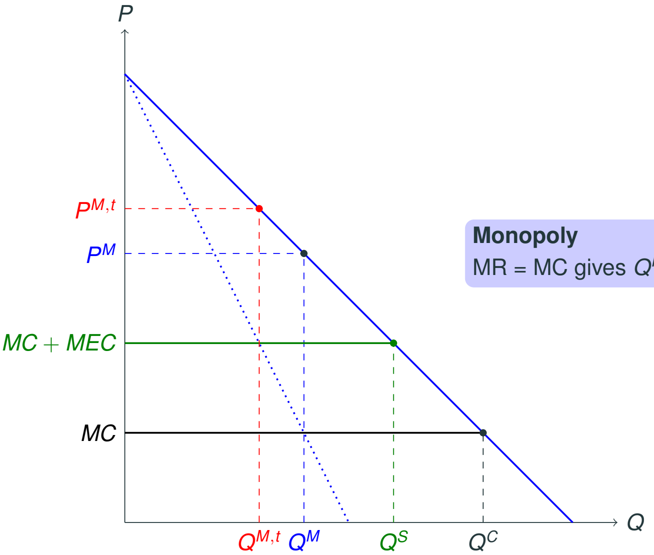

Monopoly
MR = MC gives Q^M.

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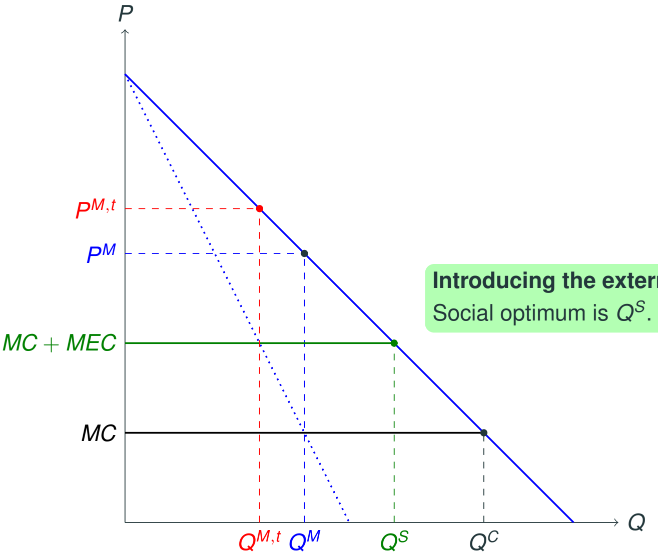
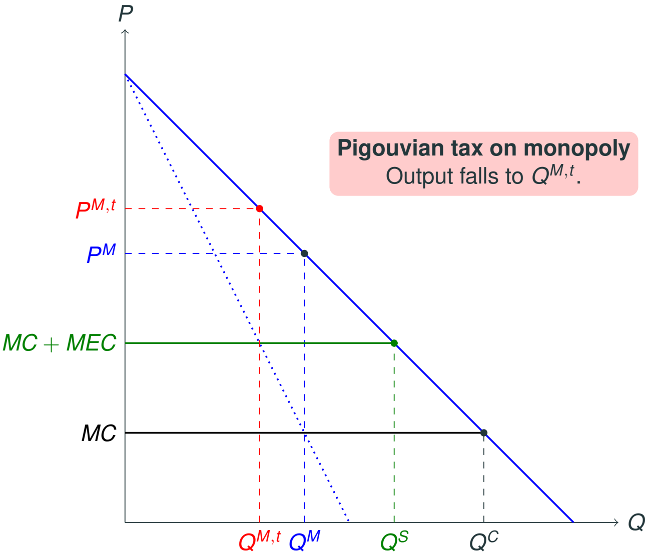


Introducing the externality
Social optimum is Q^S.

Buchanan (1969): Market Power vs Externalities



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

This paper

$$\underbrace{\text{EC } CO_2}_{189 \text{ EUR/t}CO_2} \times \underbrace{CO_2 \text{ Consumption}}_{\text{t}CO_2\text{/km, for each car model}}$$

1. Externalities (CO_2, NO_x, PM, accidents),
   - Pigouvian vehicle-specific and per km taxes
   - Fuel taxes "hit quite well": CO_2, weight correlation. (*Pigou 1920*)
2. Market power: $p > mc$ already provides "correction" (*Buchanan 1969*)
3. Imperfect targeting:
4. EC is not easily observed and it depends on use, (*Sandmo 1976*)
   - Hard to measure externalities: PM and accidents (but correlated to weight!)
   - Usage heterogeneity: driving patterns are heterogenous
     - Driving cost matters for car choice (extensive margin)
     - Driving cost matter for driving intensity (intensive margin)

Trade-off: Gains from EC reduction with DWL of overshooting

Optimal Vehicle Taxation with Externalities and Market Power

Goal: Tax design with distortions from market power and imperfectly targeted externalities.

- Structural model of vehicle choice and driving:
    1. Externalities reducing welfare: CO_2, NO_x, PM (tailpipe + non-exhaust), accidents
    2. Imperfect price competition (Betrand Nash).
    3. Consumers choose cars and km driven, based on their expected driving costs.

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  3. Consumers choose cars and km driven, based on their expected driving costs.
- Transaction data on all privately owned vehicles in Norway (owner, location, car) and usage (odometer, km driven)
- Interim results:
  - Inelastic driving (< 0.4), elastic car choice (≈ 5 for ICEV, 9 for EV)
  - Pass-through $\approx 75\%$
  - Pigouvian taxes are not optimal due to market power.

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).
- Durrmeyer (2021): distributional effects of feebates (EJ).
- 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 (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 come from 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 come from usage pollution and accidents (not production, congestion, noise).

Externalities from Car Use

Policy challenge: Fuel taxes internalize ICEV externalities well; EVs lack an equivalent km-based tax that internalises EC of accidents and PM.

- **Climate:** CO_2 (gasoline/diesel only, 2.3/2.7 kg/liter fuel and EUR 189 carbon price)
  - EC of 28 EUR/1000 km if 150 g/km (6.5 l/100 km),
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  - 18 EUR / 1000 km for 1800 kg vehicle

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EC estimates (Van Essen 2019, EU-Commission).
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)

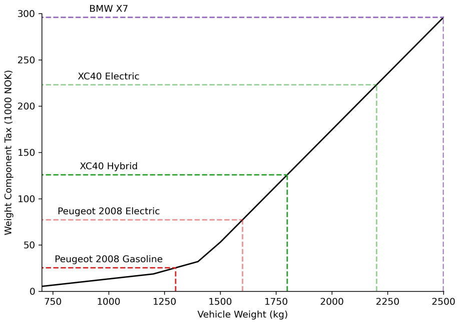
Ownership and usage taxes

- High **registration taxes**: tax based on weight, CO_2, NOx, (typically 1000–3000 NOK, 113.7–341.1 USD/l), EVs are exempt!

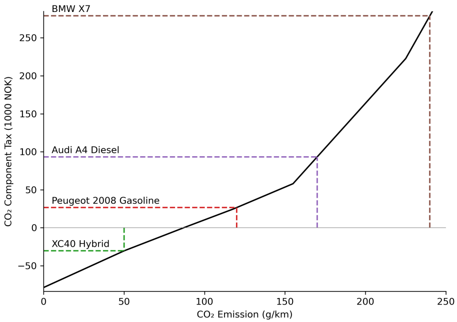
  Note: Weight drives non-exhaust particulate matter emissions (also for EVs)

- High **fuel taxes** (in 2021, gasoline tax: 6.38 NOK/l, 0.7 USD)
- VAT is 25% of the car price, EVs are exempt!
- Other taxes: tolls, insurance tax, parking fees, ferry, etc. EVs are exempt! or face lower rates.

Weight

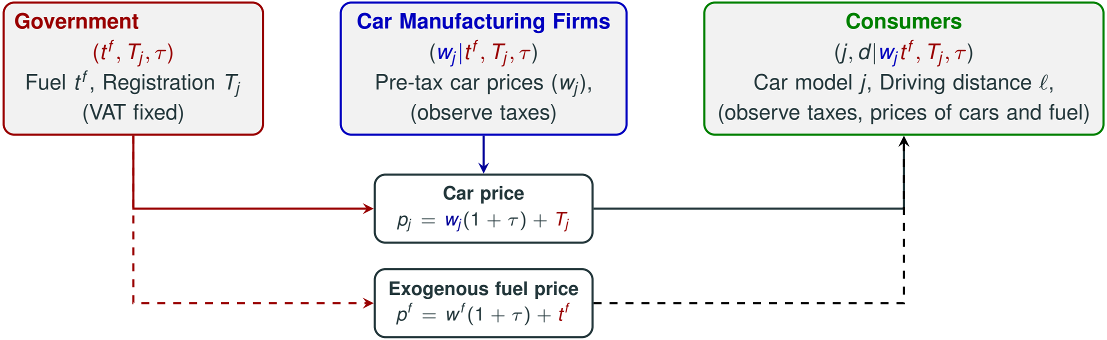


CO_2



Model

Model. *Agents and Choice variables*



VAT in Norway is 25%

Fuel taxes are chosen instead of registration in the counterfactuals

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 $t = 0, \ldots, T$.

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 driving utility, $\frac{\partial v_i(\ell_{ijt})}{\partial \ell} < 0$

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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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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 private new car registrations, 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**: periodic inspections $\Rightarrow$ annual driving distance
- **SSB**: monthly fuel and electricity prices

Observed heterogeneity: owner location (centrality, region), age group

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, younger 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)

Estimation Strategy. *Choice and Driving Model Attributes*

Car Characteristics

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

Sport | Large | Small | Luxury | Compact | SUV

Electric Battery | Hybrid / Plug-in Hybrid | Gasoline | Diesel

Driving Variables

Income | Location (urban/rural) | Operating Cost

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

Driving Model Estimation

- Specification: optimal driving per spell

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

- Estimation:
  - OLS / NLLS projection of driving ℓ_{in} on costs k_{in} interacted with group dummies
  - Identifies relative γ_g, η_g across demographic groups
- Interpretation:
  - Captures systematic heterogeneity in driving elasticities
  - Provides inputs for driving surplus term in choice utility

Estimation Strategy. *Choice Model*

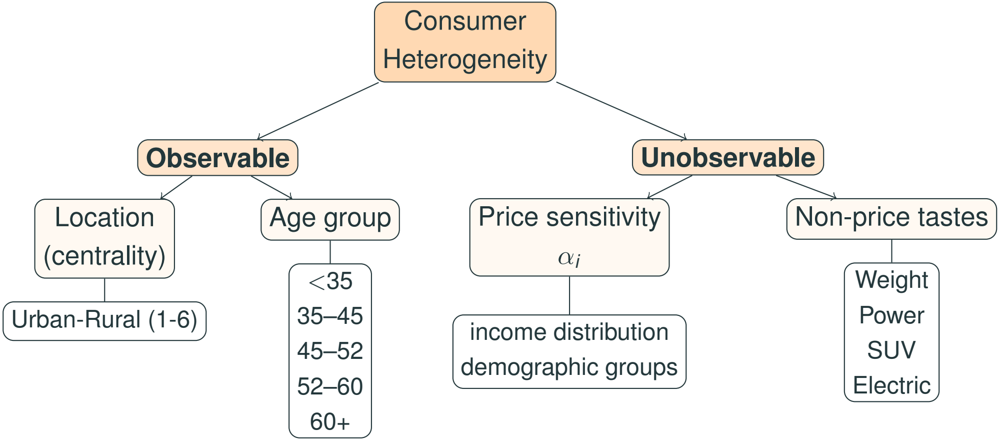
Indirect utility (compact form) estimated via random coefficients logit model

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

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

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

Estimation Strategy. *Choice Model Heterogeneity*



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

Endogeneity & Identification

"Firms optimally raise prices when demand is high", cov(p_j, ξ_j) > 0

Instruments for α_i and β_i

- Use structure of Norwegian tax system
- Registration taxes and VAT exemptions generate variation in net-of-tax prices
- Fuel taxes interact with efficiency φ_j to shift effective per km cost

Control function approach

- First stage: regress pre-tax price residuals on tax shifters
- Construct control function term $\hat{r}_j$
- Include $\hat{r}_j$ in choice utility: $u_{ij} = \cdots + \rho\hat{r}_j + \epsilon_{ij}$
- Corrects for correlation between p_j and ξ_j

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Identification

- *Within-group substitution patterns* pin down heterogeneity in α_i
- *Exogenous tax variation* separates price effects from ξ_j

Estimation Results and Welfare

Results

- Sensible estimates of driving and choice model
  - Driving (wrt cost per km): 0.44-0.5
  - Price $\approx$ 5 for ICEV and 9 for EV
  - Markups 28% average, similar to other studies (Grieco et al, 2024)
- Substantial heterogeneity in tastes, “unobserved” and geographic/socio-economoc
- Large and important heterogeneity in preferences/WTP for EVs

Counterfactuals

- Counterfactual policies
  1. No tax
  2. First best ($p = mc$, Pigouvian usage tax per km, corresponding to ec)
  3. Imperfect competition ($p = mc + markup$) and Pigouvian tax (ec per km)
  4. Imperfect competition $p = mc + markup$ and half Pigouvian tax (ec / 2 per km)
- Outcomes:
  - Number of cars, prices
  - Consumer surplus, profits, tax revenue, external costs

Welfare

- Welfare:

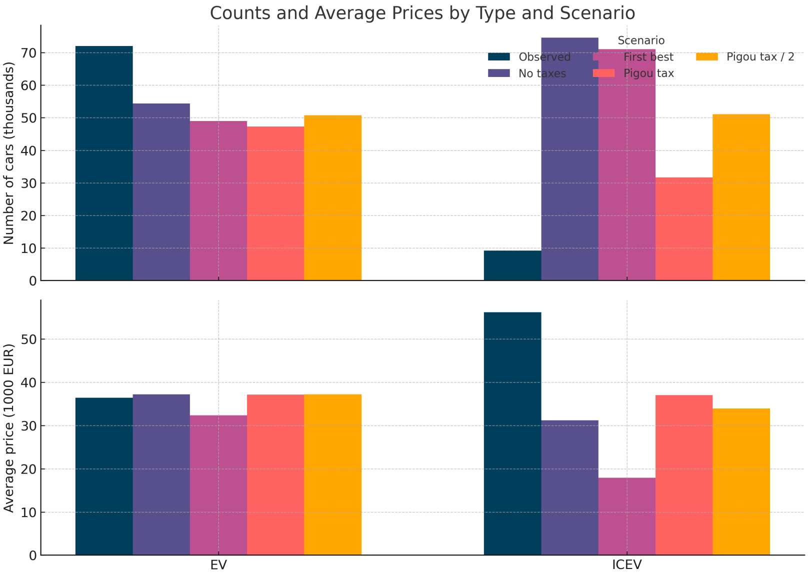
$$W \;=\; CS \;+\; \Pi \;+\; TR\cdot(1+MCPF) \;-\; EC.$$

- 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.

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

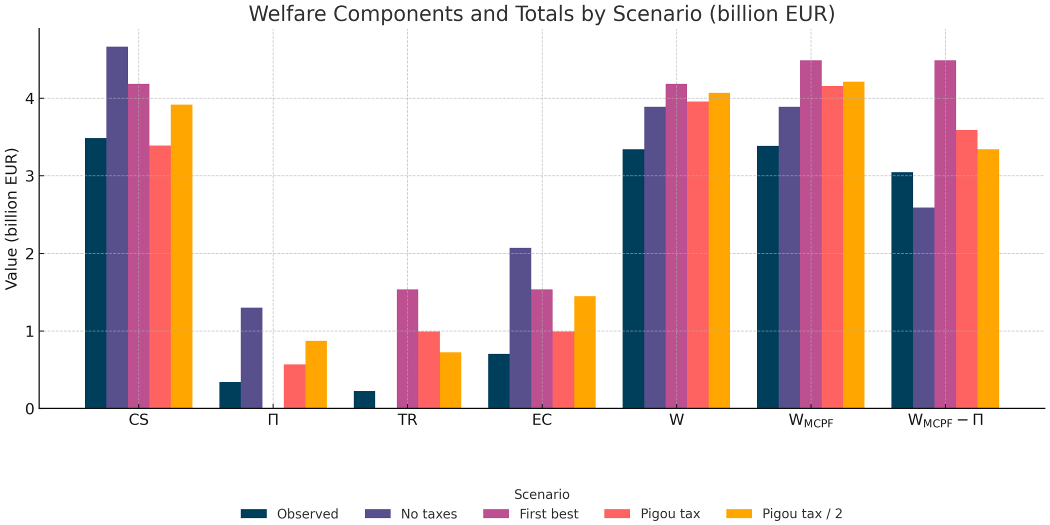
  - **External costs:** Total pollution and accident EC for chosen vehicles and driving

Vehicles



Counts and Average Prices by Type and Scenario
Scenario
Observed
No taxes
First best
Pigou tax
Pigou tax / 2
Number of cars (thousands)
0
10
20
30
40
50
60
70
Average price (1000 EUR)
0
10
20
30
40
50
EV
ICEV

Welfare


Welfare Components and Totals by Scenario (billion EUR)
Value (billion EUR)
0
1
2
3
4
CS
Π
TR
EC
W
W_{MCPF}
$W_{MCPF} - \Pi$
Scenario
Observed
No taxes
First best
Pigou tax
Pigou tax / 2

Summary of Results

- Current (2022) tax wedge between ICEVs and EVs is much larger than justified by external costs $\Rightarrow$ strong choice distortion.
- Removing all taxes: large shift toward ICEVs, higher external costs, but (much) higher private surplus.
- First-best (Pigouvian) tax: balances ICEV/EV composition, internalizes externalities, maximizes total welfare (when ignoring profits).
- Pigouvian tax at half the rate: close to optimal when profits matter, preserves industry rents while reducing externalities.
- Optimal tax design will depend on whether producer profits are valued in social welfare.

Next Steps

- Distortions from market power, external costs and “incomplete” taxation (EVs exempt from km-based accident/PM taxes)
- Welfare effects of inefficient driving vs. inefficient car purchases.
- Explore optimal taxation regimes 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 $p_j = w_j(1 + \tau_j) + T_j$.

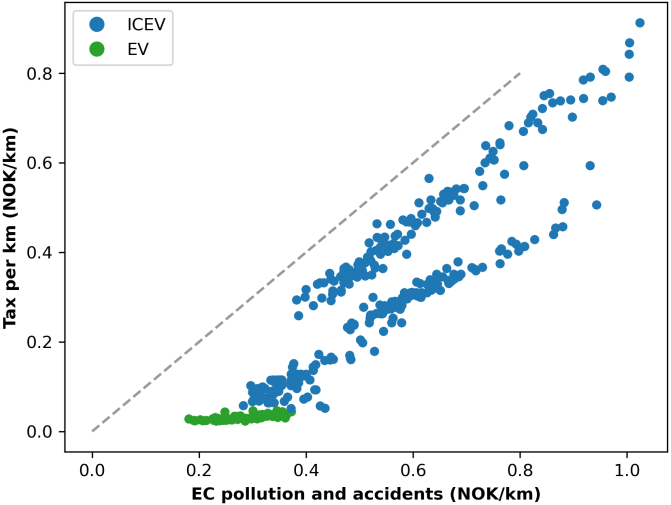
- Nash–Bertrand FOCs in w:

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

- 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,