Competing Forces in the German New Car Market: How do they Affect Diesel, PHEV, and BEV sales?

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Motivation

• Transportation ≈ 20-30% of total GHG emissions
  • In the US, 29% of total GHG emissions in 2019*
  • Light duty vehicles ≈ 58% of the emissions from the transportation sector in 2019*
• A difficult sector!
• Many policies aimed at reducing GHG emissions from cars
  • Regulations
    • on automakers, relying on technology (EU regulations)
    • On drivers (driving bans)
  • Taxes
    • on the product (the car) (Klier and Linn, 2015) on the energy inputs (fuels)
    • Carbon tax (Rivers and Schaufele, 2015)
  • Subsidies
    • To the purchase of clean cars
    • To the construction of EV charging stations (Springel, 2021; Cole et al., 2021)

* Source: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
Passenger cars in Germany

- Largest fleet (47+ mill.) and largest new car market (3+ mill. sold/year) in Europe
- Historically high-emitting fleet
  - In 2020, BEVs are 0.64% and PHEVs are 0.59% of the fleet (EAFO, 2021)
  - Cfr. France 0.84% and 0.40%, resp. (EAFO, 2021)
  - Cfr. Norway 11.83% and 4.98%, resp. (EAFO, 2021)
- Important automaking industry
- Government commitment to help finance the transition to a low- or zero-emissions fleet
- Several concurrent policies
Policies

• EU CO₂ emissions regulations
• Circulation tax linked to the CO₂ emissions rate of the car (since 2009) (Alberini and Horvath, 2021)
• Diesel bans (in specific cities, due to air quality concerns)
• Bonus to EV cars (BEV and plug-ins, federal)

• Climate Action Program:
  • Goal to have 7-10 million EVs and 1 million charging points by 2030
  → EV Charging infrastructure (federal, Bundesland, and local)
  • Carbon tax (€ 25/ton CO₂ since Jan. 2021; will rise to € 55/ton by 2025) (federal)
Research Questions

• Are these policies effective at shaping new car sales?
• What CO$_2$ emissions reductions do they attain?
• What is the cost effectiveness of these policies?
Spoiler Alert

• We take advantage of the variation across places and over time
• Expectations on the future of certain types of fuels seem to be important (diesel bans)
• Do not neglect transition technologies, like conventional hybrids
• Very little effect on \( \text{CO}_2 \) emissions...
• ...and at high cost per ton of \( \text{CO}_2 \) reduced
The Data - 1

<table>
<thead>
<tr>
<th>Sales of each type of passenger cars in each Bundesland each month from Jan. 2015 to Mar. 2020 (from IHS-Markit)</th>
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<tr>
<td>“Type of passenger car” = combination of make, model, variant and trim, fuel type, engine size, horsepower, body type, drivetrain (front, rear, or AWD), etc.</td>
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| For ICEs: fuel consumption rate, CO₂ emissions rate (g/km), euro standard (from IHS-Markit) |
| For PHEVs and BEVs: kwh/100 km, liters/100 km (PHEVs only), electric battery capacity and range, CO₂ emissions rate (g/km) if PHEV (from ADAC) |

| Fuel prices in each Bundesland and month of the study period (tankerkönig.de) |
| Monthly electricity prices (nationwide) (Eurostat and Statistisches Bundesamt) |

| Counts of publicly accessible normal (≤22 kW) and fast (>22 kW) charging points available in each Bundesland in each month of the study period (Bundesnetzagentur) |
| Media reports about discussions, proposals, adoptions and repeals of diesel bans in German cities during the study period |
Shares of sales by fuel type

**2015**
- Gasoline: 52%
- Diesel: 46%
- HEV: 1%
- PHEV + BEV: 1%

**2019**
- Gasoline: 60%
- Diesel: 33%
- HEV: 4%
- PHEV + BEV: 3%
Shares of car sales by fuel type (no LCVs)
Alternative Fuel Passenger Car Sales

HEV sales
BEV sales
PHEV sales
Sales-weighted average CO₂ emissions rate

![Graph showing sales-weighted average CO₂ emissions rate from Jan-15 to Oct-19. The graph compares legal CO₂ and NEDC CO₂ emissions over time. The emissions fluctuate with a general trend of increasing CO₂ levels.](image-url)
Diesel Bans

• Discussions, proposals, adoptions, repeals:
  • start in 2017
  • much action in spring 2018

• Diesel vehicles ≤ euro 5 not allowed to enter certain cities

• Technically, they should *not* affect the sales of new diesel cars over our study period (already at euro 6)...

• ...so if we find an association between the decline of diesel sales and diesel bans, it must because of *expectations*
Diesel Bans: Population Affected by Proposed or Actual Diesel Bans

![Graph showing population affected by diesel bans over time. The x-axis represents months from January 2015 to January 2020, and the y-axis represents population affected (ban discussed or proposed) and population affected (ban in place). The graph shows an increasing trend in population affected by diesel bans.](image-url)
Drop in diesel share 2015-2019

\[ y = 0.0451x + 0.1541 \]

Percentage point drop in the share of diesel cars vs. Share of the population affected by discussed or proposed bans.
Bonus for the purchase of an EV

• Starts July 2016 – € 4000 BEV, € 3000 euro PHEV
• Effective Nov 2019 – the above sums are increased by 50% if the price is up to € 40,000 and by 25% if the price is € 40,000 – 65,000 (and PHEV meets a minimum range or max emissions requirement)
• Nationwide
Charging Infrastructure

48% charge at home,
20% at work,
32% at public stations
(Schaufenster Elektromobilität, 2017)
Publicly Accessible Charging Points as of Nov. 2021

What about private charging points?
Private : Public
from 60:40 to 85:15 (Bundesregierung, 2019)
Figure 1. Electric vehicle share of new passenger cars in 2018 and cumulative electric vehicles per million inhabitants overlaid with charging station locations. Metropolitan and nonmetropolitan areas are based on Eurostat (n.d.).
Publicly Accessible Charging Infrastructure

- Total normal charging points
- Total fast charging points

The graph shows the increase in publicly accessible charging infrastructure from January 2015 to March 2020, with a significant rise in both normal and fast charging points during the latter part of the period.
Fast charging density in selected Bundesländer

![Graph showing the fast charging density in selected Bundesländer from Jan-15 to Jan-20.](image-url)
Change in BEV/PHEV share 2015-2019

\[ y = 1E^{-05}x + 0.0235 \]

- Percentage point change in the share of PHEVs and BEVs
- Avg. number of fast charging points added per year
Following Berry (1994), we start with a random utility model of the representative consumer, which posits that the indirect utility that he or she receives from new vehicle \( j \) is
\[
V_j = -\alpha \cdot P_j + x_j \beta + \varepsilon_j
\]
where \( P \) denotes the price of the vehicle, \( x \) is a vector of vehicle attributes, \( \alpha \) is the marginal utility of money and \( \beta \) the marginal utilities of the attributes of the vehicle. \( \varepsilon \) is an i.i.d. type I extreme value distribution.

On allowing for the “out of market good” (namely the possibility of no car purchase, or of purchasing a used car), the probability that the consumer purchases new vehicle \( k \) is
\[
\Pr(k) = \exp(w_k \gamma) /[1 + \sum_j \exp(w_j \gamma)],
\]
where \( w \) contains \( P \) and \( x \), and \( \gamma \) contains \(-\alpha\) and \( \beta \). Since the sales of vehicle \( k \) are equal to the total number of sales multiplied by vehicle \( k \)’s share (namely, equation (2)), it is easy to show that
\[
\ln \text{Sales}_k - \ln \text{Sales}_{\text{OMG}} = w_k \gamma.
\]
On appending an error term, equation (4) is thus a linear regression model.
The Model – 2

\[ \ln Sales_{imbt} = x_{imbt} \gamma + Z_{imbt} \delta + \alpha_{ib} + \tau_{mt} + \lambda_{bt} + e_{imbt} \]

where:

\( i = \) vehicle (exact specification)
\( m = \) make-model (e.g., Audi A3)
\( b = \) Bundesland
\( t = \) quarter and year

\( x = \) car attributes that change over time and/or across Bundesländer (e.g., fuel costs per km)
\( Z = \) policy variables interacted with car attributes

\( \alpha_{ib} = \) exact vehicle \( \times \) Bundesland fixed effect
\( \tau_{mt} = \) make-model \( \times \) quarter-year fixed effect
\( \lambda_{bt} = \) Bundesland \( \times \) quarter–year fixed effects

Difference-in-difference-in-difference model
Policy and policy variables

• Diesel bans:
  (share of the Bundesland popul. living in areas with proposed or actual diesel bans) × (diesel car)

• Charging infrastructure:
  (density of fast charging points in Bundesland) × (BEV or PHEV)
  where density = # fast charging points/population

• Carbon tax:
  (log) fuel cost per km

• EV bonus:
  (log) bonus (zero for non-electric vehicles)
Policy Simulations

• Sales of car $k = N \times \text{Share of sales at original value of policy variables} = N \times \Pr(k) = N \times \left( \frac{\exp(w_k \gamma)}{\sum_j \exp(w_j \gamma)} \right)

• Sales of car $k$ under different policy conditions =
  
  \[ = N \times \left( \frac{\exp(w'_k \gamma)}{\sum_j \exp(w'_j \gamma)} \right) \]

• $N$ = actual sales in that Bundesland and quarter-year

• ....so we are holding total sales constant and are examining how sales get redistributed across the various types of cars
<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff. (st. err)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log annual circulation tax</td>
<td>--</td>
</tr>
<tr>
<td>Log fuel price per km</td>
<td>-0.3508***</td>
</tr>
<tr>
<td></td>
<td>(0.0269)</td>
</tr>
<tr>
<td>Diesel × share of popul affected by proposed bans</td>
<td>-0.3606***</td>
</tr>
<tr>
<td></td>
<td>(0.0111)</td>
</tr>
<tr>
<td>Log bonus</td>
<td>0.0105**</td>
</tr>
<tr>
<td></td>
<td>(0.0039)</td>
</tr>
<tr>
<td>(BEV/PHEV) × density of fast charging points</td>
<td>0.0088***</td>
</tr>
<tr>
<td></td>
<td>(0.0006)</td>
</tr>
<tr>
<td>(BEV/PHEV) × Shannon index fast charging points</td>
<td>0.0659***</td>
</tr>
<tr>
<td></td>
<td>(0.0161)</td>
</tr>
<tr>
<td>Exact variant × Bundesland</td>
<td>Yes</td>
</tr>
<tr>
<td>Make-model × month year</td>
<td>Yes</td>
</tr>
<tr>
<td>Bundesland × month year</td>
<td>Yes</td>
</tr>
<tr>
<td>R square</td>
<td>0.7364</td>
</tr>
<tr>
<td>Nobs</td>
<td>1,592,999</td>
</tr>
</tbody>
</table>

Standard errors clustered at the Bundesland level.
** = significant at 5% level
*** = significant at the 1% level
Summary: Effects of...

• Diesel bans:
  • diesel car sales drop by up to 5%, but emissions decline by less than 1%
  • People might be responding to expectations of a bleak future for diesel cars

• Bonuses:
  • PHEV and BEV sales increase by 8%, but sales still not enough for a meaningful effect on emissions

• 20% increase in the number of (public) fast charging stations:
  • PHEV and BEV sales increase by 9%, but less than 0.25% reduction in emissions

• Adopting the € 55/ton CO2 carbon tax starting in Jan. 2015:
  • Reduce diesel sales by 1%
  • Increase gasoline car sales by 0.5%
  • Increase EVs by 0.25%
  • Negligible effect of emissions
Cost-Effectiveness of the EV Bonuses

The cost-effectiveness of the EV Bonuses is illustrated in the graph. The x-axis represents the years 2015.I to 2020.I, while the y-axis shows the cost per ton of CO2 avoided. The graph indicates a fluctuation in cost-effectiveness over the years, with peaks and troughs indicating periods of higher and lower effectiveness. The data points show a general trend of increasing cost per ton of CO2 avoided from 2015 to 2020.
Sales of BEVs and fast charging points

Predicted at +20% more fast charging points
Cost-effectiveness of a 20% increase in fast charging points with 4700 euro govt subsidy per newly added charging point

![Graph showing cost per ton of CO2 removed over time with a line at 625 euro/ton]
Effect of diesel bans + bonus on different types of cars

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<td>Diesel PHEV</td>
</tr>
<tr>
<td>Diesel</td>
</tr>
<tr>
<td>Gasoline and gas. HEV</td>
</tr>
<tr>
<td>BEV or gasoline PHEV</td>
</tr>
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Conclusions

• No wonder it’s difficult to decarbonize the passenger car sector!
• Each of the policies here considered accomplish less than a 1 reduction in CO₂ emissions...
• ...and at high cost per ton!
• Some suggestions consistent with others’ finding that bonuses to drivers are cost-ineffective compared to subsidies to charging stations (Cole et al., 2021; Springel, 2021)
• Don’t neglect “transition” technologies, like conventional hybrids
Future work

• More elaborate models (e.g., nested logit, BLP)
• Instrument for diesel bans, charging stations
  • Figure out effect of government funding to charging stations
  • Cleaner calculation of cost-effectiveness
• Build in explicit free riding assumptions
Thank you!
Questions? Comments?
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Additional slides
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Gasoline Prices in Germany, Jan. 2015-Mar. 2020

[Graph showing gasoline prices (2015 euro/liter) from January 2015 to March 2020]