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 CO_2 emissions regulations
- Circulation tax linked to the CO_2 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 CO_2 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

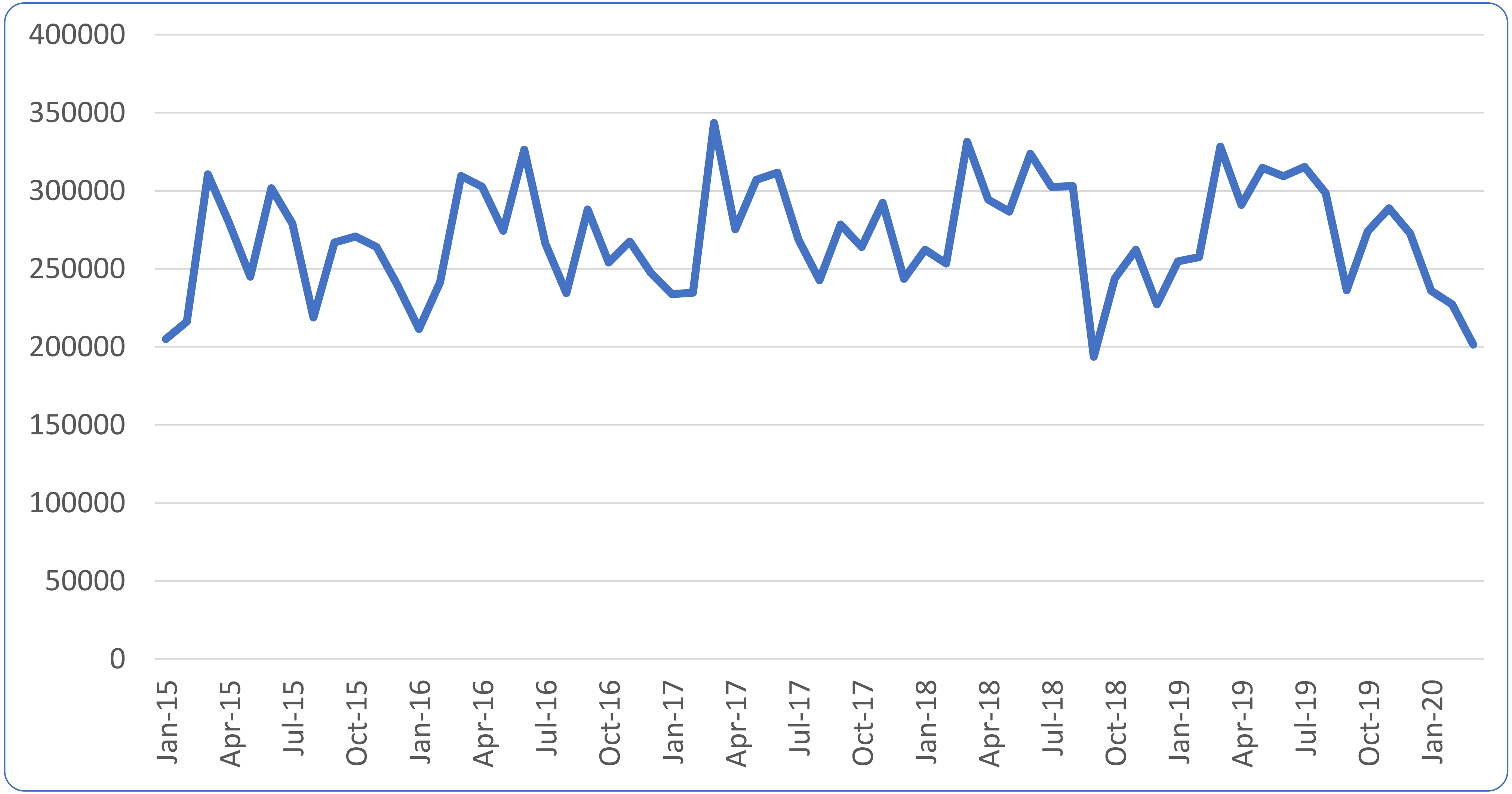
- We take advantage of the variation across places and over time
- Expectations on the future of certain types of fuels seem to be important (diesel bans)
- Do not neglect transition technologies, like conventional hybrids
- Very little effect on CO_2 emissions…
- …and at high cost per ton of CO_2 reduced

The Data - 1

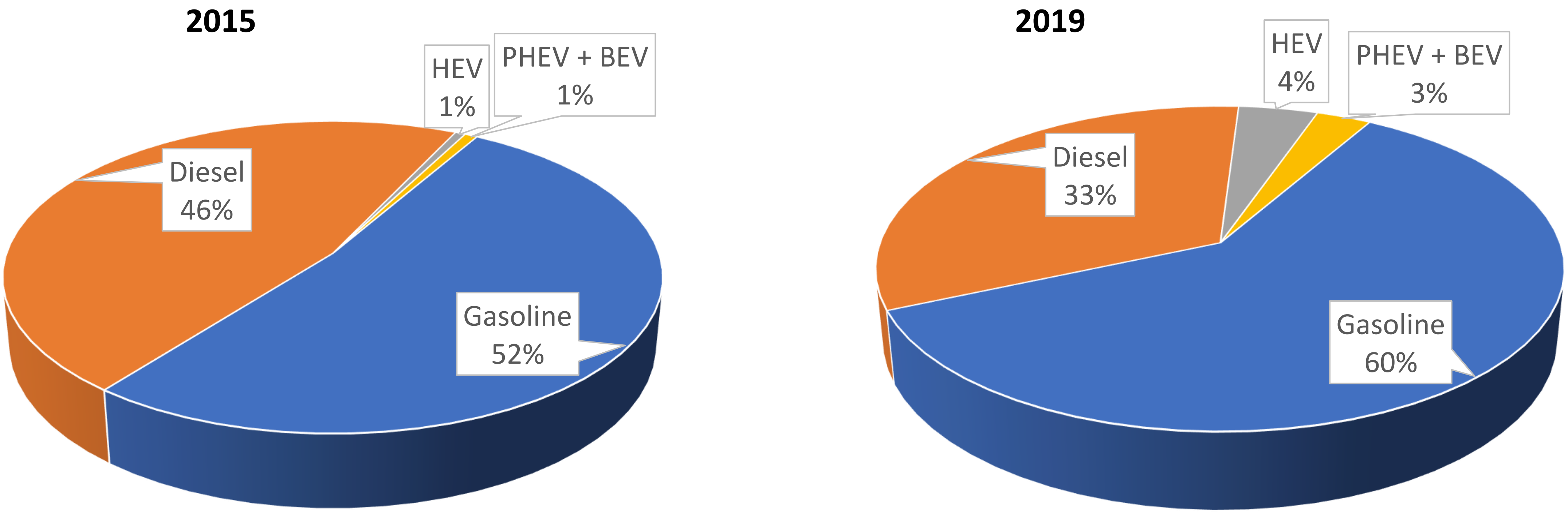
- **Sales** of each type of passenger cars in each Bundesland each month from Jan. 2015 to Mar. 2020 (from IHS-Markit)
  - “Type of passenger car” = combination of make, model, variant and trim, fuel type, engine size, horsepower, body type, drivetrain (front, rear, or AWD), etc.
- For ICEs: fuel consumption rate, CO_2 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, CO_2 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 ($\leq$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

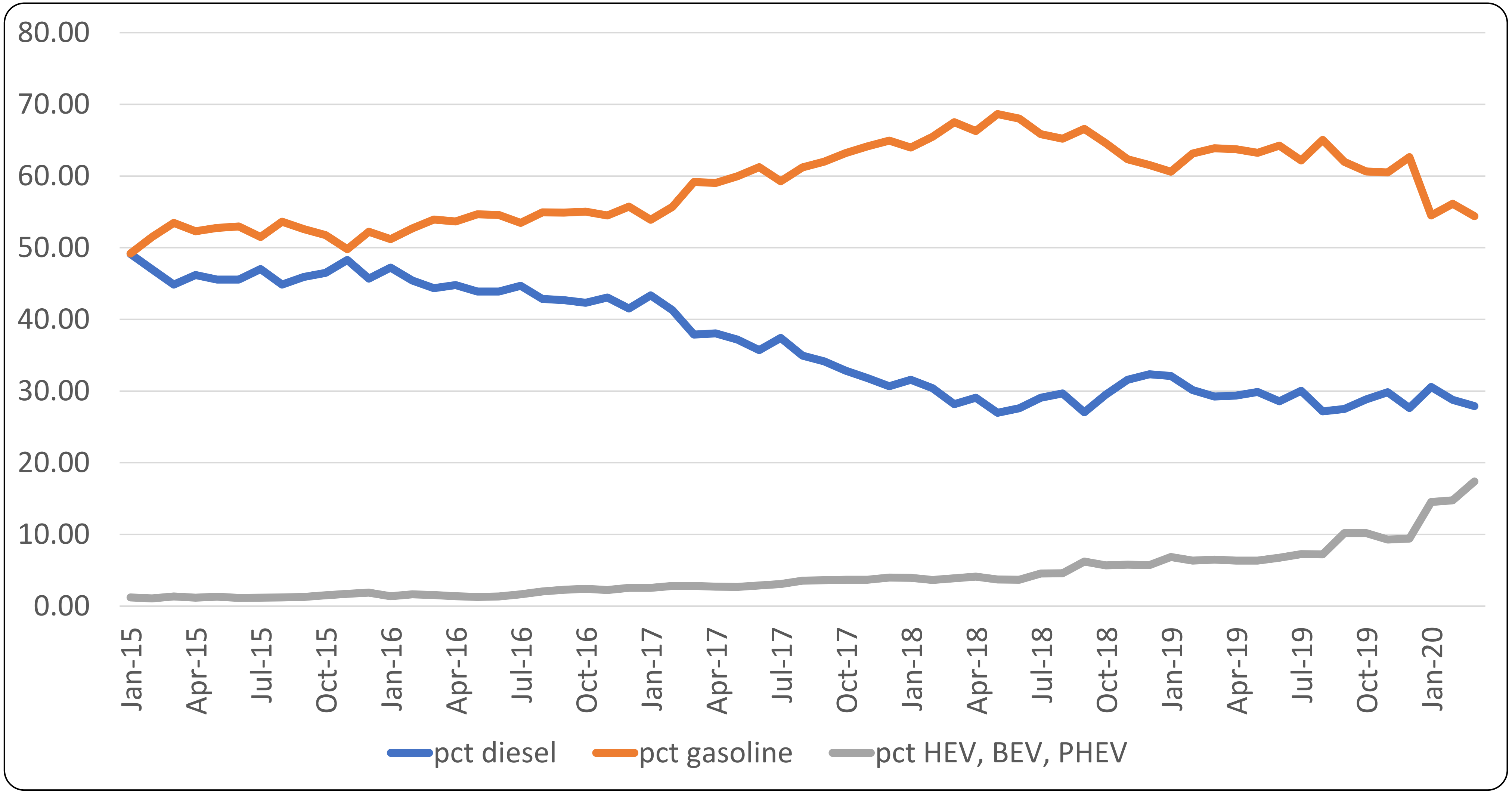
Monthly car sales in Germany Jan 2015-Mar 2020. No LCVs.



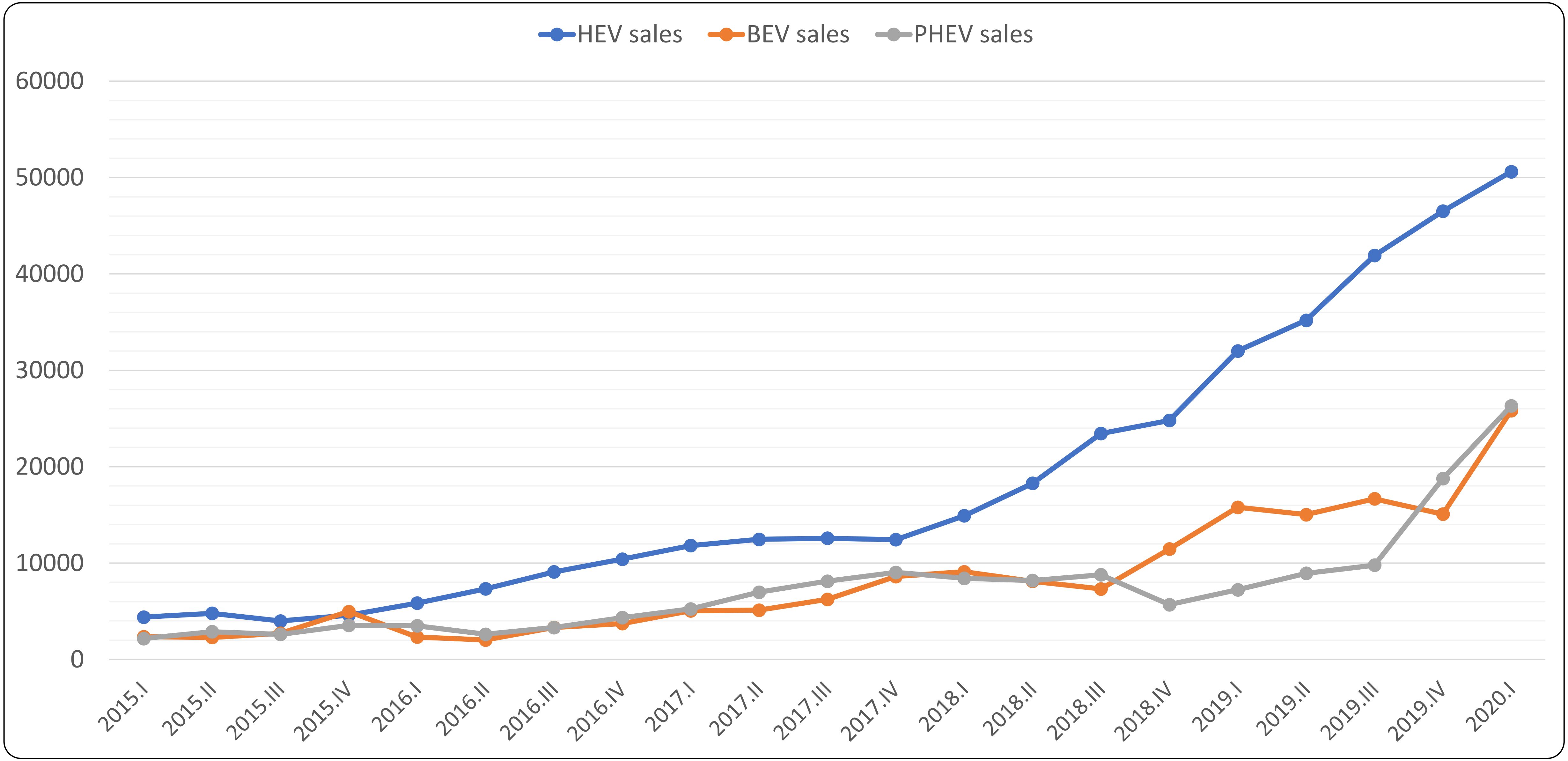
Shares of sales by fuel type



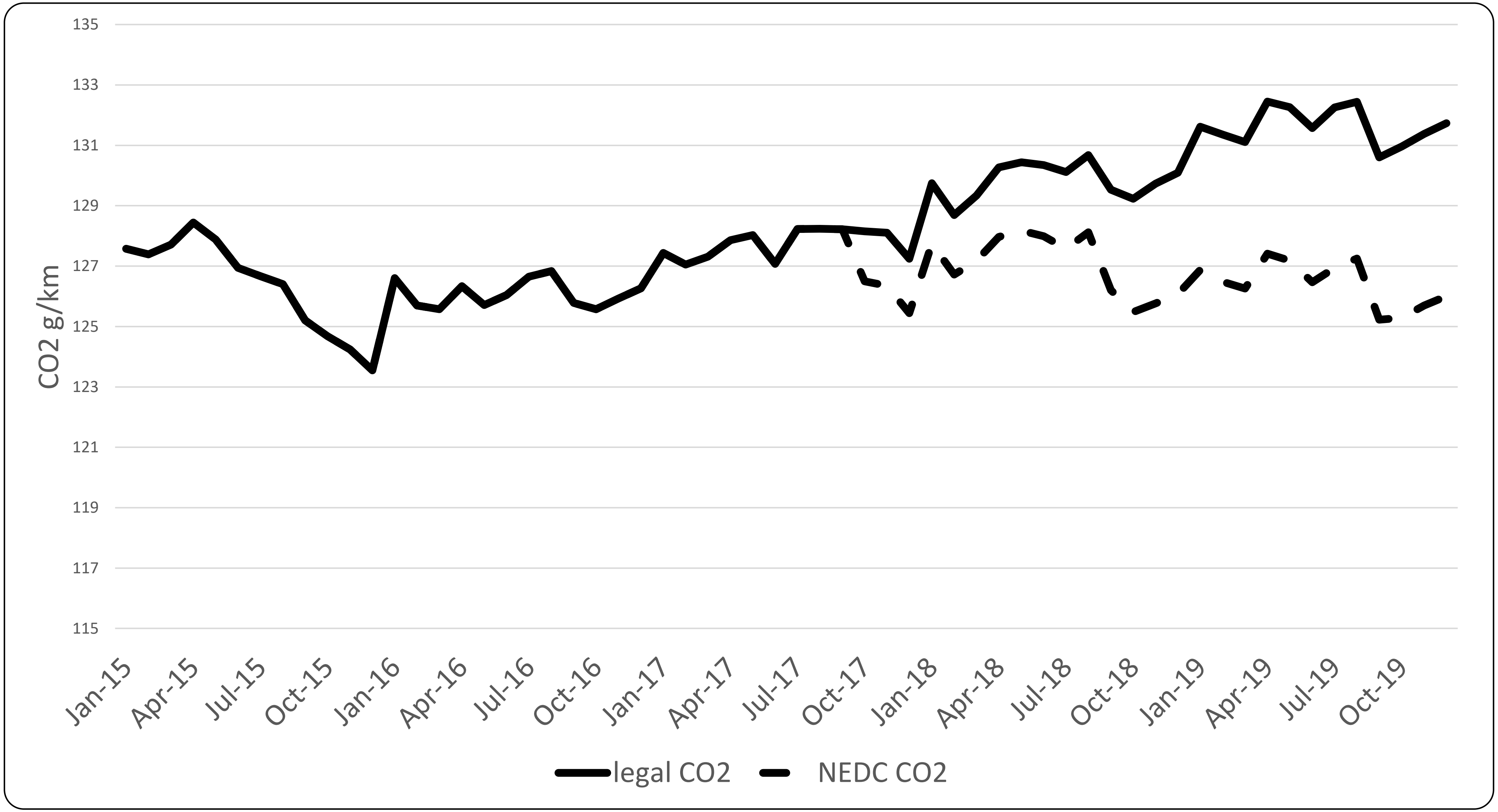
Shares of car sales by fuel type (no LCVs)



Alternative Fuel Passenger Car Sales



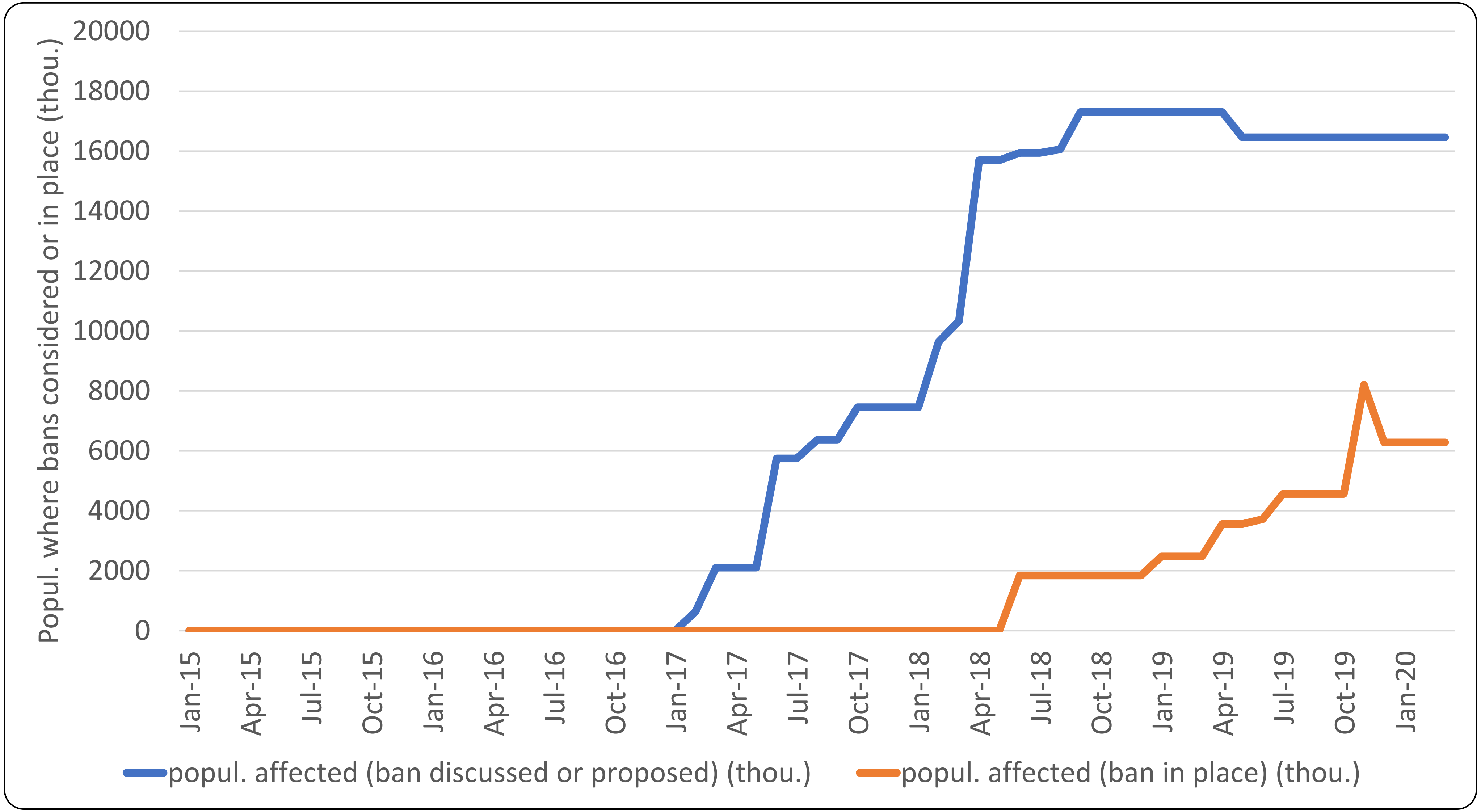
Sales-weighted average CO_2 emissions rate



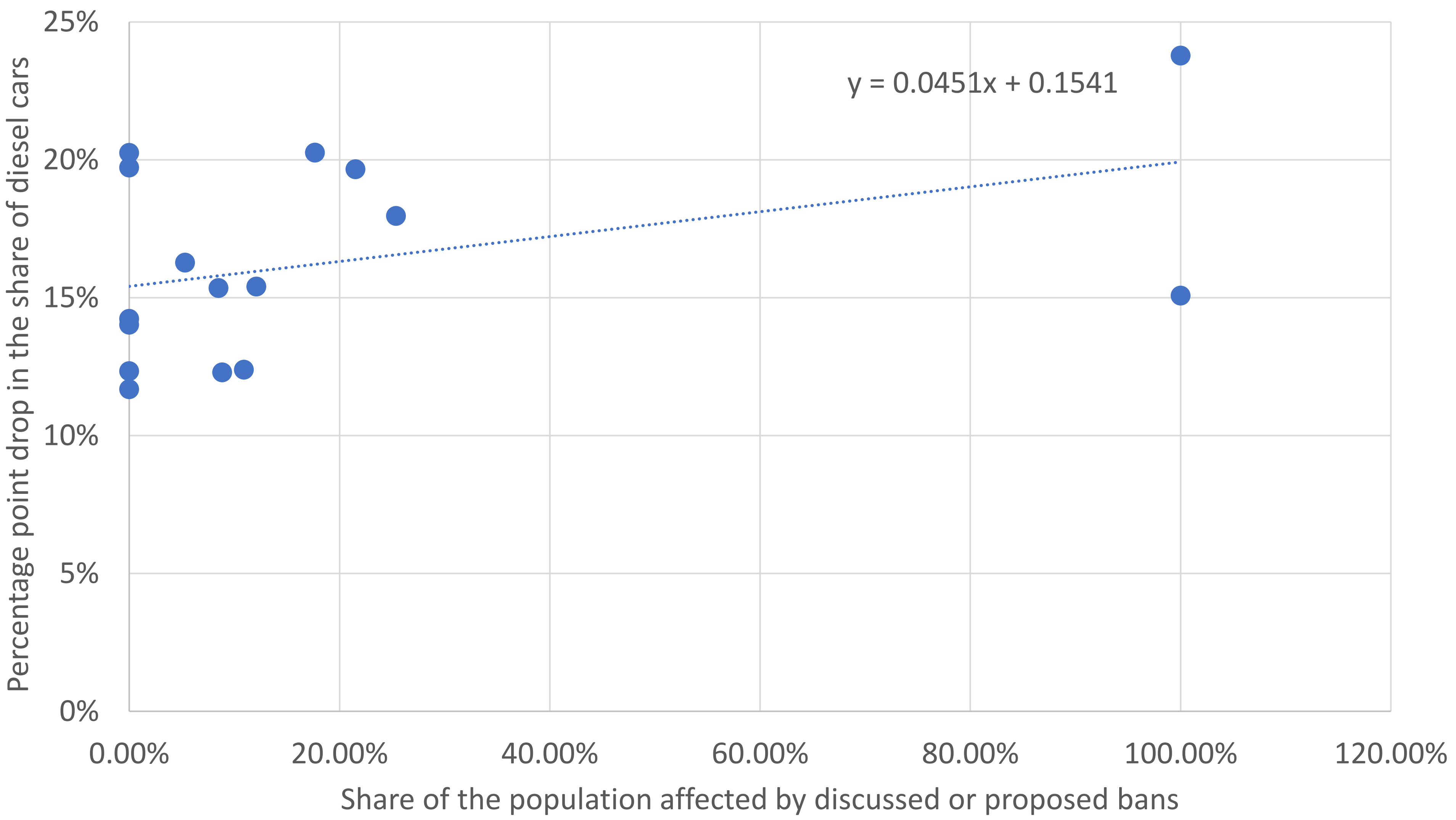
Diesel Bans

- Discussions, proposals, adoptions, repeals:
  - start in 2017
  - much action in spring 2018
- Diesel vehicles $\leq$ 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



Drop in diesel share 2015-2019

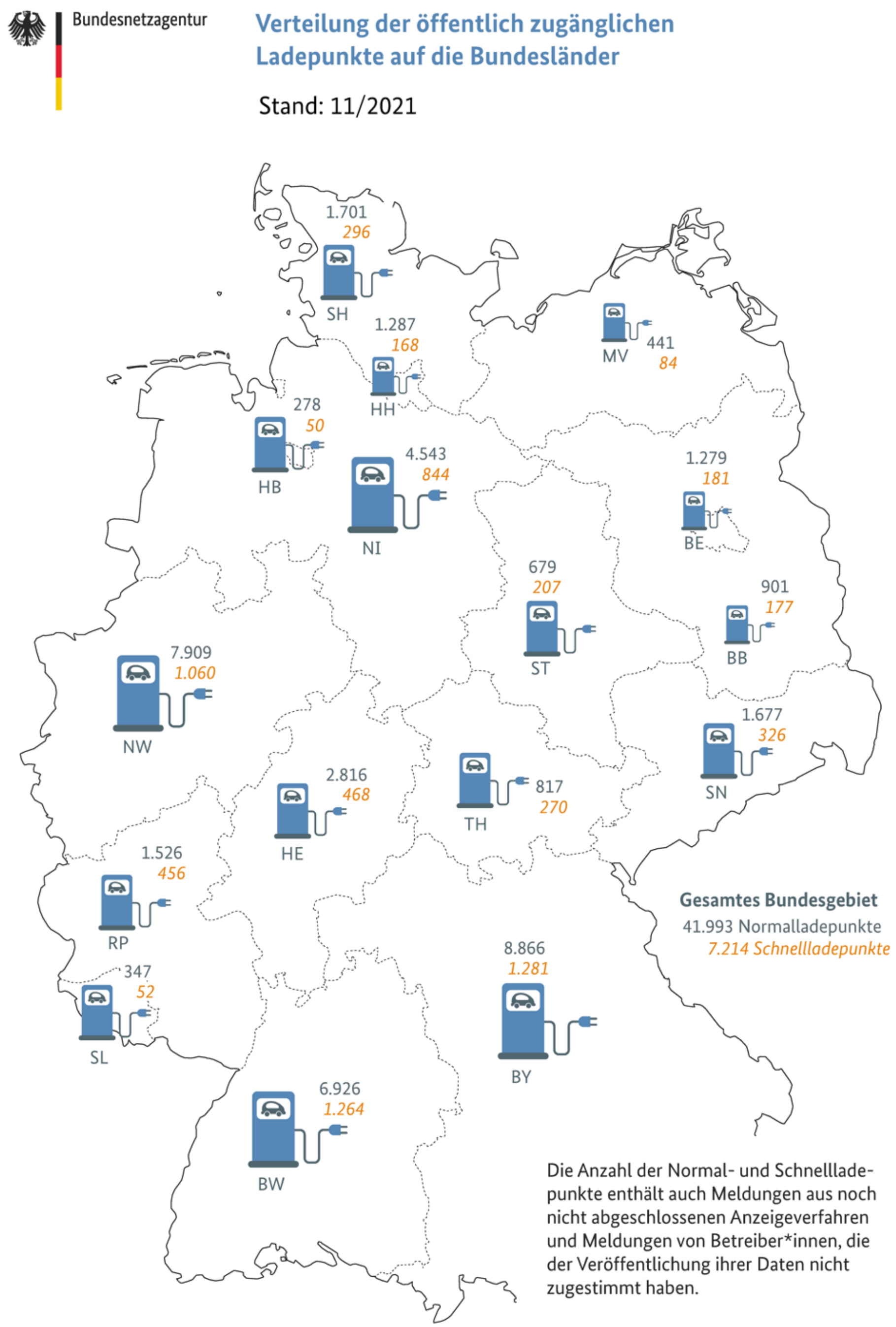


Bonus for the purchase of an EV

- 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)

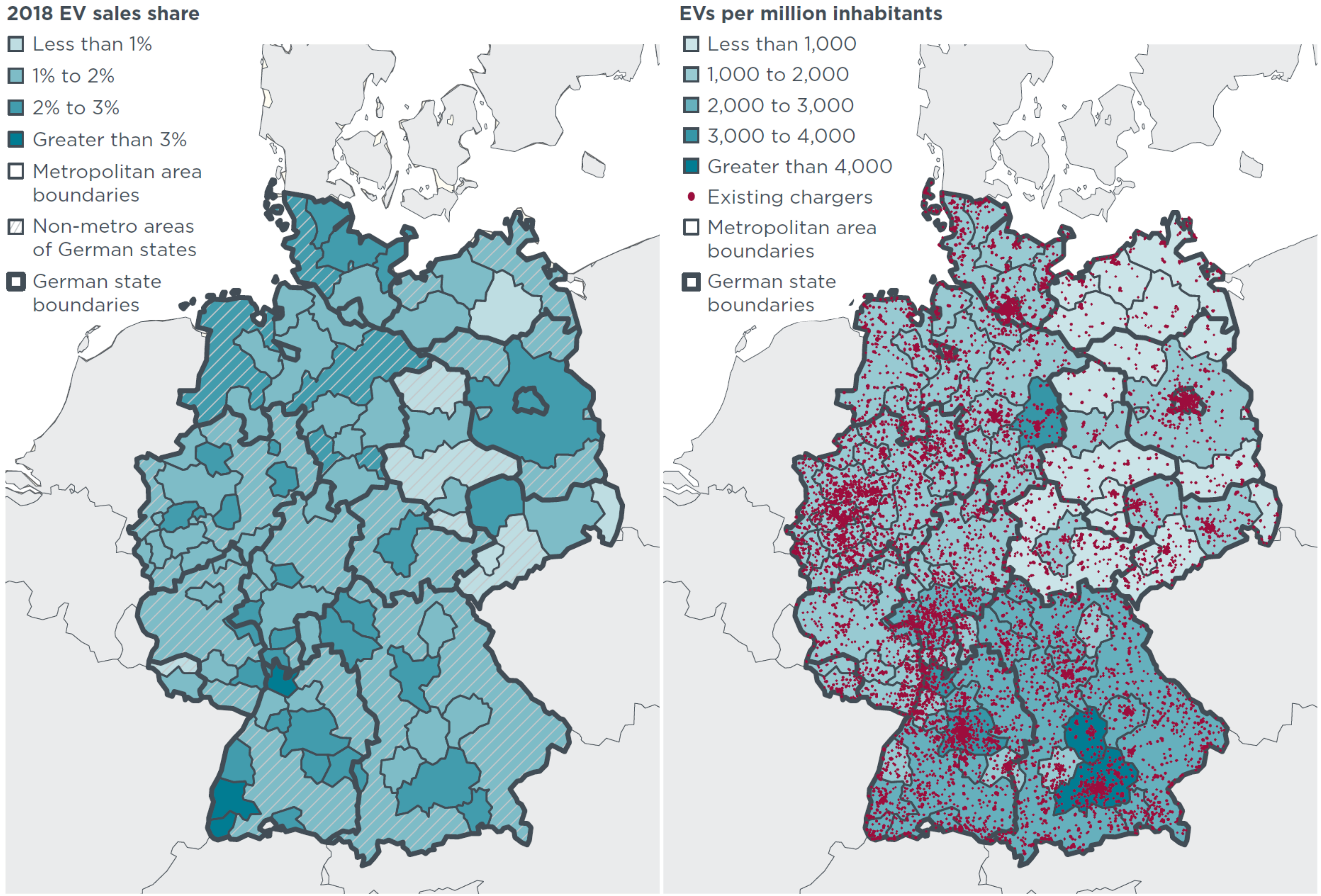
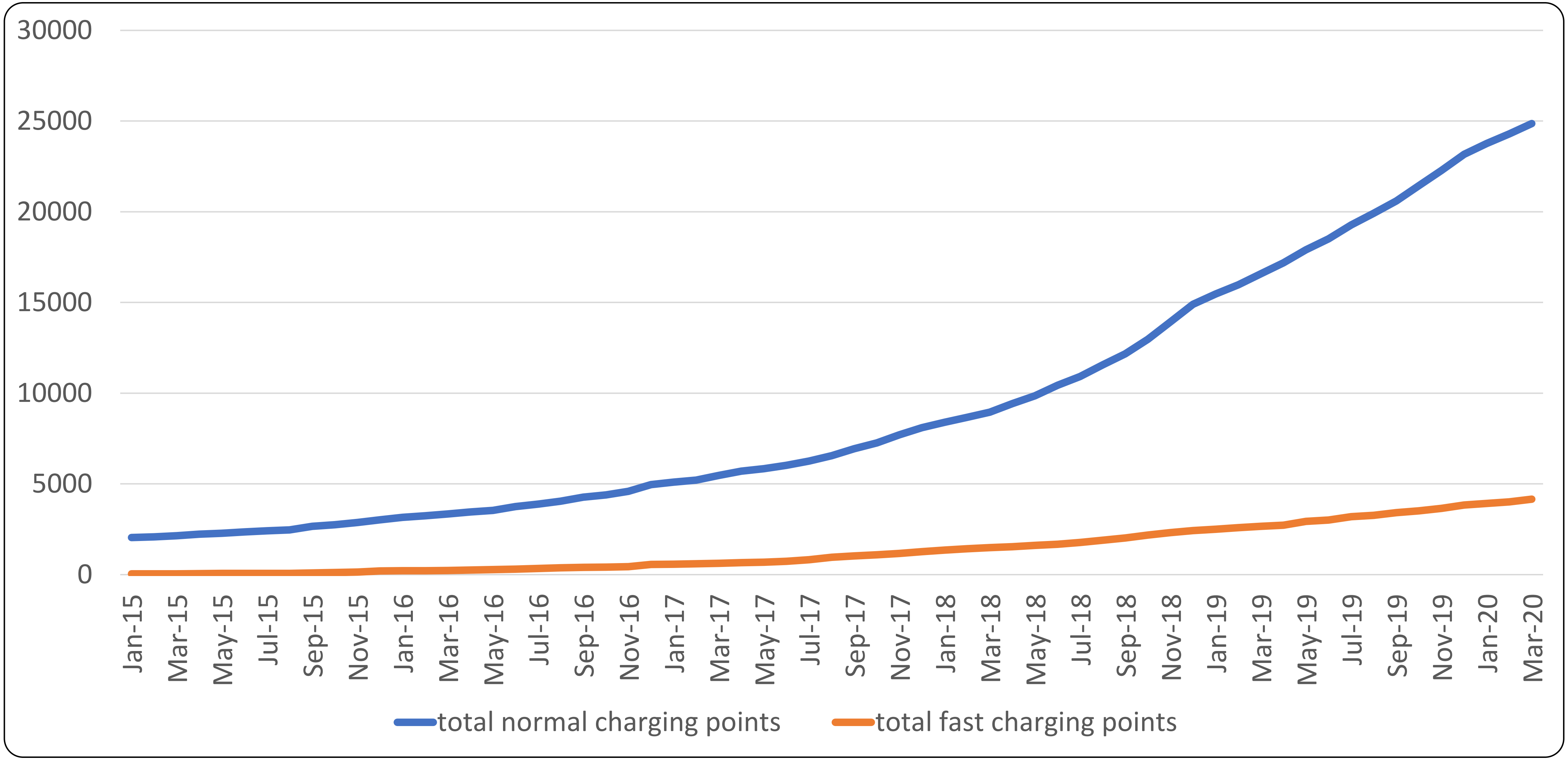


Figure 1. Electric vehicle share of new passenger cars in 2018 and cumulative electric vehicles per million inhabitants overlaid with charging station locations. Metropolitan and nonmetropolitan areas are based on Eurostat (n.d.).

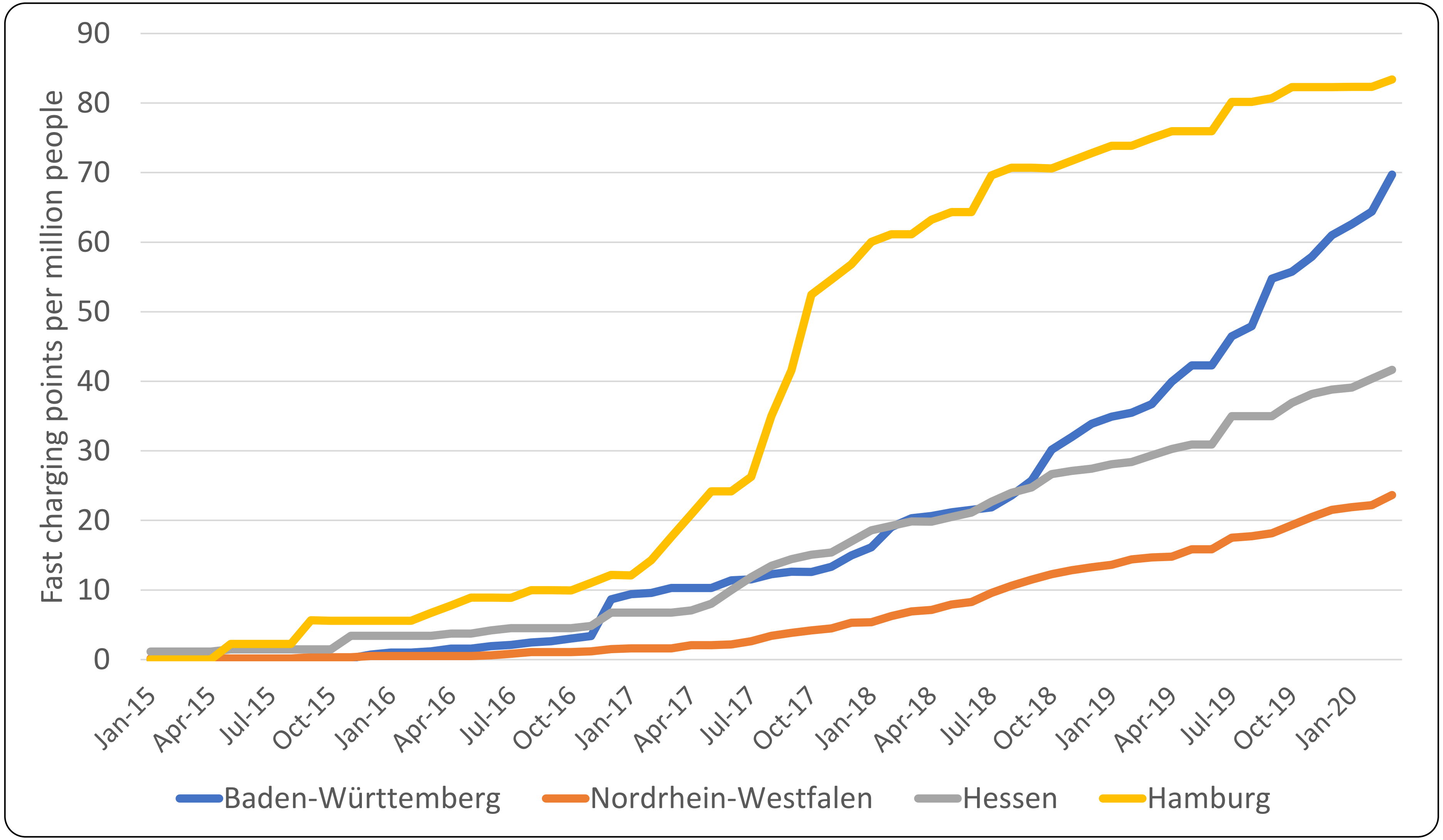
EVs and charging stations in Germany in 2018

Source: Nicholas & Wappelhorst, ICCT, 2020

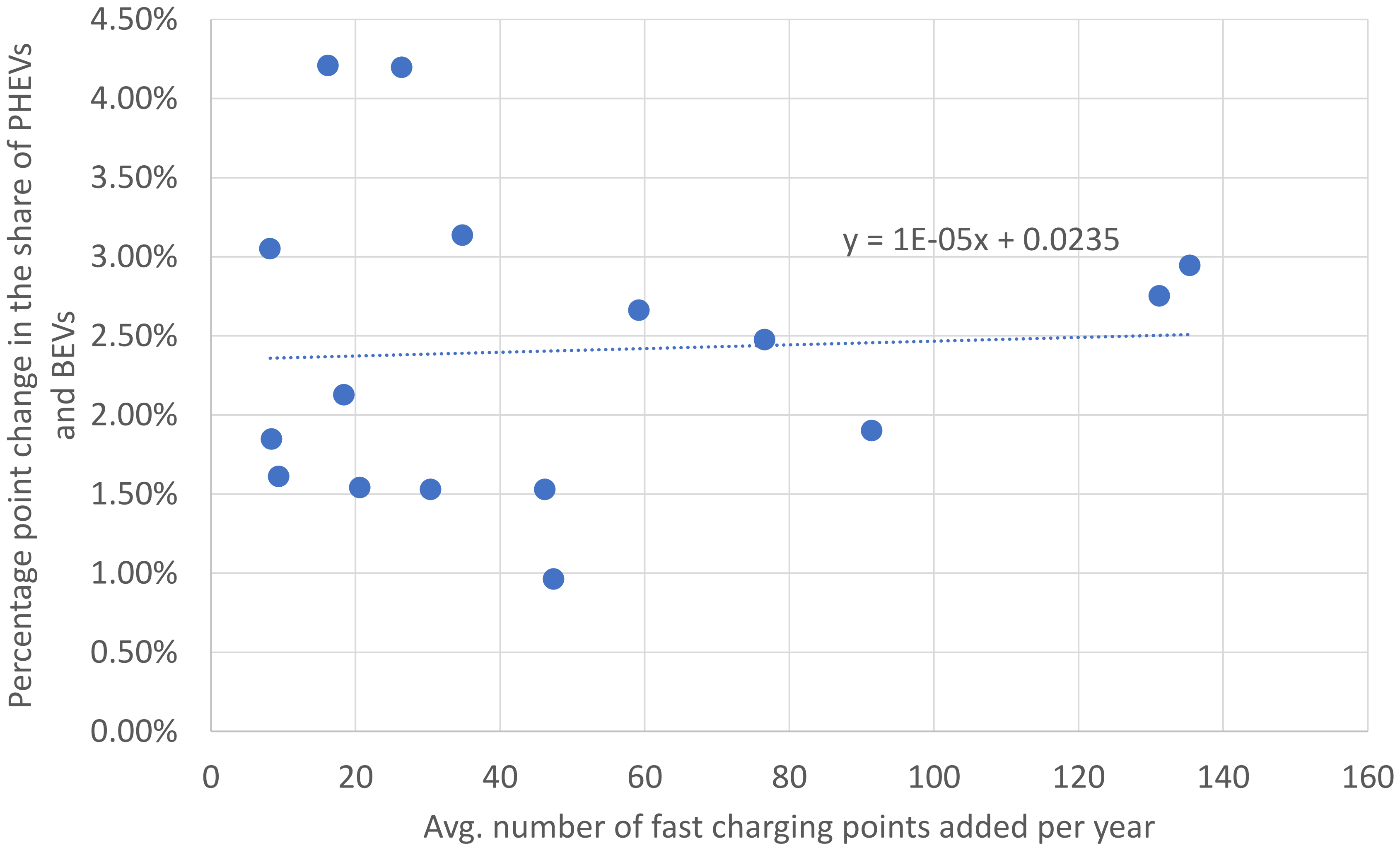
Publicly Accessible Charging Infrastructure



Fast charging density in selected Bundesländer



Change in BEV/PHEV share 2015-2019



The Model – 1

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

(1) $$V_j = -\alpha \cdot P_j + \mathbf{x}_j\boldsymbol{\beta} + \varepsilon_j$$

where P denotes the price of the vehicle, **x** is a vector of vehicle attributes, α is the marginal utility of money and β the marginal utilities of the attributes of the vehicle. ε 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

(2) $$\Pr(k) = \exp(\mathbf{w}_k\boldsymbol{\gamma})/[1 + \sum_j \exp(\mathbf{w}_j\boldsymbol{\gamma})],$$

where **w** contains P and **x**, and γ contains -α and β. 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

(3) $$\ln \text{Sales}_k - \ln \text{Sales}_{OOMG} = \mathbf{w}_k\boldsymbol{\gamma}.$$

On appending an error term, equation (4) is thus a linear regression model.

The Model – 2

$$\ln Sales_{imbt} = \mathbf{x}_{imbt}\boldsymbol{\gamma} + \boldsymbol{Z}_{imbt}\boldsymbol{\delta} + \alpha_{ib} + \tau_{mt} + \lambda_{bt} + e_{imbt}$$

where:

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

$\mathbf{x}$ = car attributes that change over time and/or across Bundesländer (e.g.. fuel costs per km)
$\mathbf{Z}$ = policy variables <u>interacted with car attributes</u>

α_{ib} = exact vehicle × Bundesland fixed effect
τ_{mt} = make-model × quarter-year fixed effect
λ_{bt}= Bundesland × 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) $\times$ (diesel car)

- Charging infrastructure:

  (density of fast charging points in Bundesland) $\times$ (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 × Share of sales at original value of policy variables =

$$= \text{N} \times \Pr(\text{k}) = \text{N} \times \left(\exp(\mathbf{w}_k \boldsymbol{\gamma}) / \sum_j \exp(\mathbf{w}_j \boldsymbol{\gamma}) \right)$$

- Sales of car k under different policy conditions =

$$= \text{N} \times \left(\exp(\mathbf{w}'_k \boldsymbol{\gamma}) / \sum_j \exp(\mathbf{w}'_j \boldsymbol{\gamma}) \right)$$

- 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

Least Squares Estimation Results

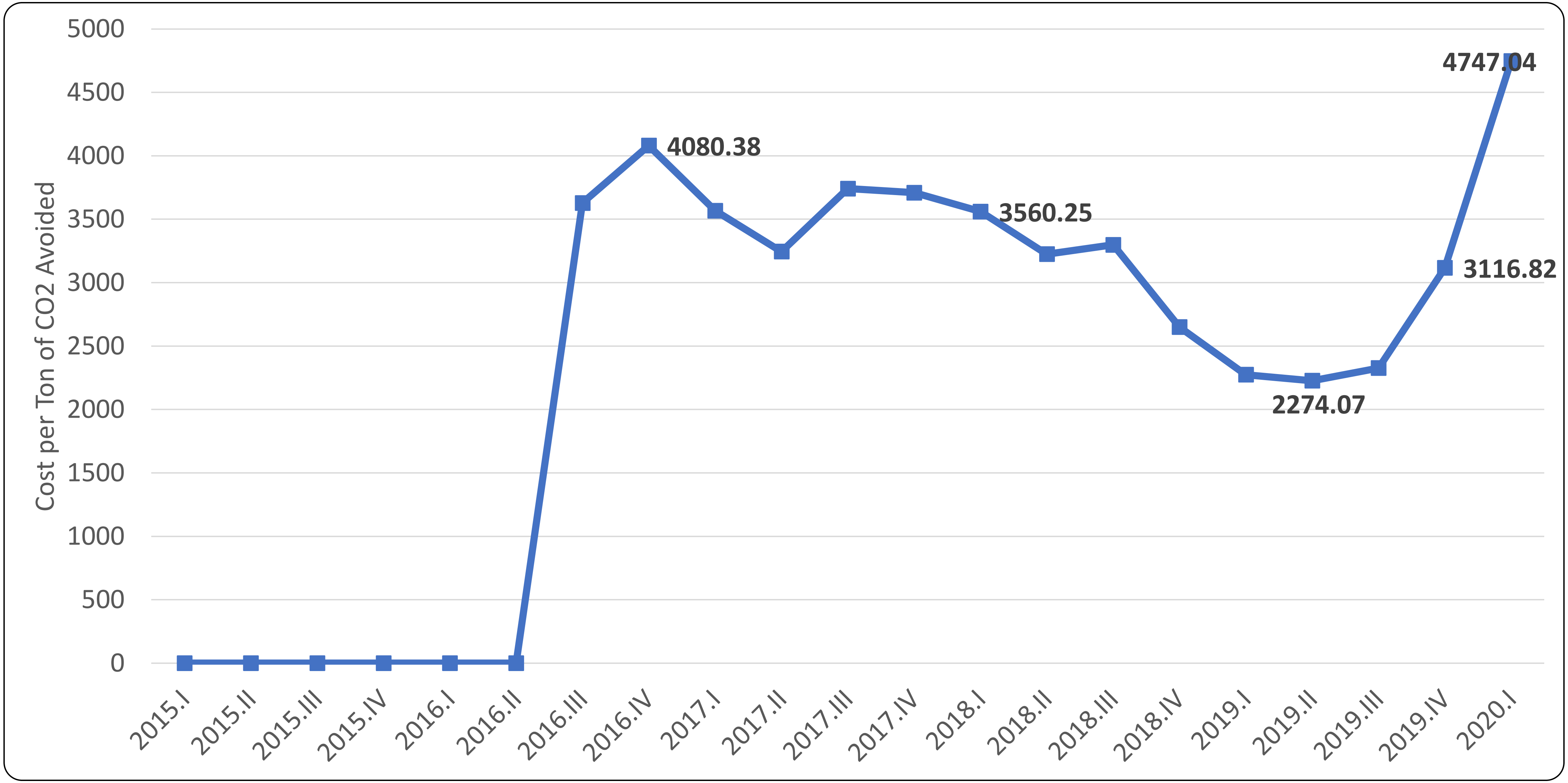
Variable	Coeff. (st. err)
Log annual circulation tax	--
Log fuel price per km	-0.3508*** (0.0269)
Diesel × share of popul affected by proposed bans	-0.3606*** (0.0111)
Log bonus	0.0105** (0.0039)
(BEV/PHEV) × density of fast charging points	0.0088*** (0.0006)
(BEV/PHEV) × Shannon index fast charging points	0.0659*** (0.0161)
Exact variant × Bundesland	Yes
Make-model × month year	Yes
Bundesland × month year	Yes
R square	0.7364
Nobs	1,592,999

Standard errors clustered at the Bundesland level.
** = significant at 5% level
*** = significant at the 1% level

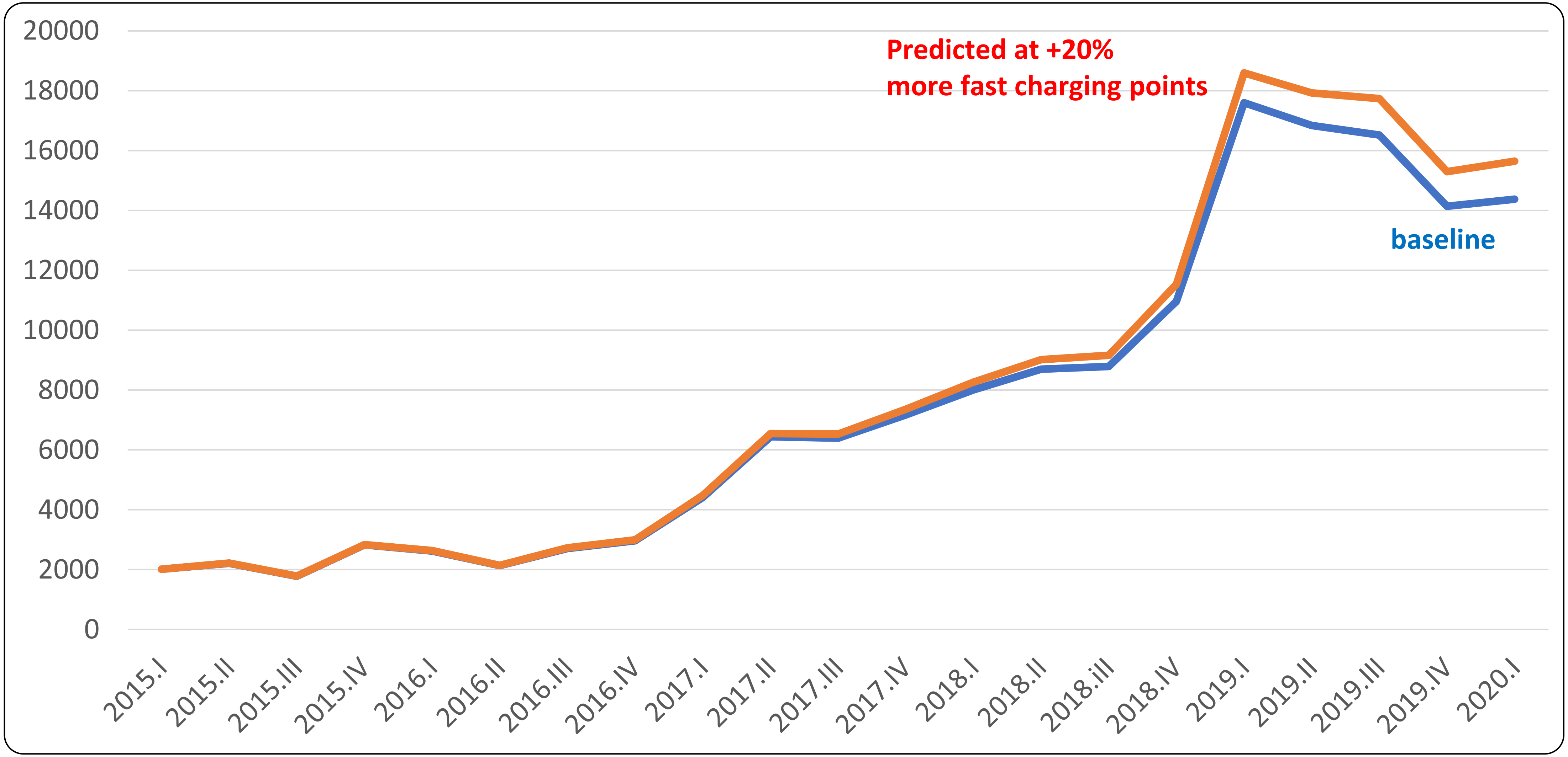
Summary: Effects of…

- 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

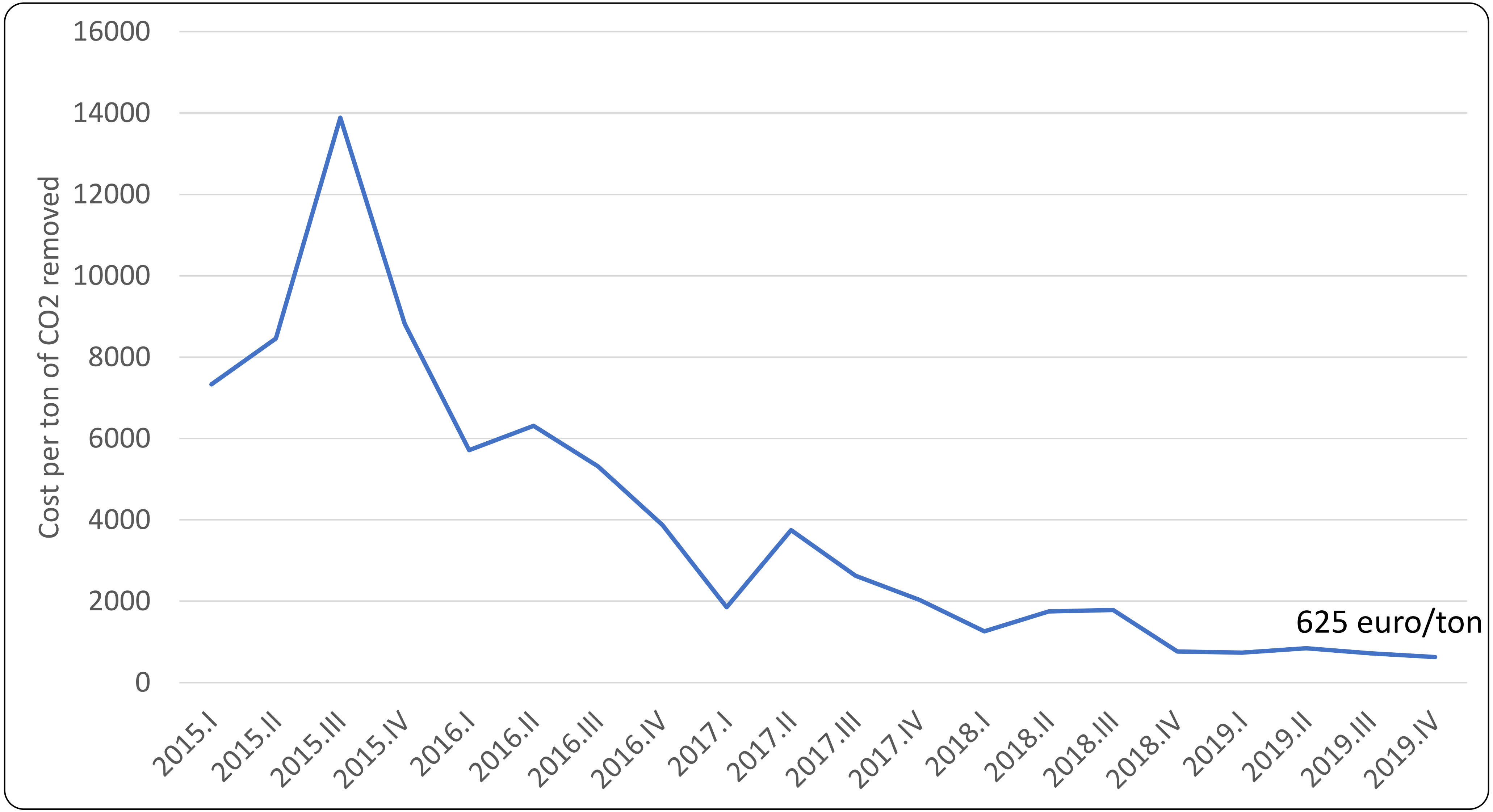
Cost-Effectivess of the EV Bonuses



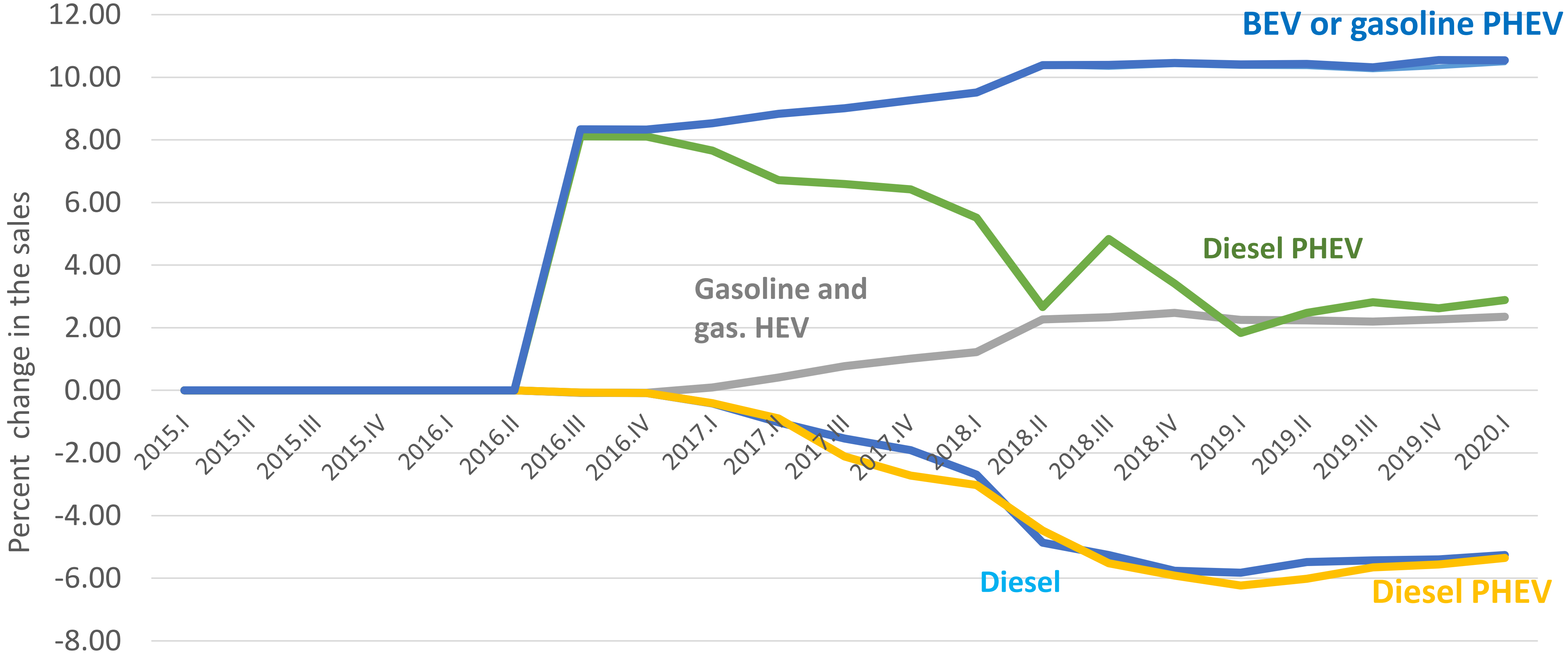
Sales of BEVs and fast charging points



Cost-effectiveness of a 20% increase in fast charging points w/ 4700 euro govt subsidy per newly added charging point



Effect of diesel bans + bonus on different types of cars



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 CO_2 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


GERMANY
Political Map
DENMARK
Baltic Sea
North Sea
Kiel
SCHLESWIG-HOLSTEIN
Rostock
Lübeck
MECKLENBURG-WEST POMERANIA
HAMBURG
Hamburg
Schwerin
Bremerhaven
BREMEN
Bremen
Oldenburg
LOWER SAXONY
BRANDENBURG
SAXONY-ANHALT
BERLIN
Potsdam
POLAND
Hanover
Wolfsburg
Braunschweig
Osnabrück
Bielefeld
Hildesheim
Salzgitter
Magdeburg
NETHERLANDS
Münster
NORTH RHINE-WESTPHALIA
Hamm
Dortmund
Paderborn
Göttingen
Cottbus
Halle (Saale)
Essen
Hagen
Düsseldorf
Kassel
Leipzig
SAXONY
Dresden
Erfurt
Cologne
Siegen
Jena
Gera
Chemnitz
Aachen
Bonn
THURINGIA
BELGIUM
HESSE
Koblenz
Frankfurt
Wiesbaden
Offenbach
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Darmstadt
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Erlangen
Fürth
Nuremberg
Mannheim
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Heidelberg
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Heilbronn
Karlsruhe
BAVARIA
Regensburg
Stuttgart
Ingolstadt
FRANCE
Reutlingen
Ulm
Augsburg
SLOVAKIA
BADEN-WÜRTTEMBERG
Munich
LEGEND
International Boundary
State Boundary
National Capital
State Capital
Freiburg im Breisgau
AUSTRIA
HUNGARY
0 30 60 120 Miles
SWITZERLAND

The Data - 1

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Gasoline Prices in Germany, Jan. 2015-Mar. 2020