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## Effectiveness and heterogeneous effects of purchase grants for electric vehicles

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# 2032

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Opinions expressed in this paper are those of the author(s) and do not necessarily reflect views of the institute.

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# Effectiveness and Heterogeneous Effects of Purchase Grants for Electric Vehicles\*

Peter Haan<sup>†</sup>      Adrián Santonja<sup>‡</sup>      Aleksandar Zaklan<sup>§</sup>

February 7, 2023

We evaluate German purchase subsidies for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) using data on new vehicle registrations in Germany during 2015-2022. We account for confounding time trends and interacting EU-level CO<sub>2</sub> standards using neighboring countries as a control group. The program was cost-ineffective, as only 40% of BEV and 25% of PHEV registrations were subsidy-induced, and had strong distributional effects, with greater uptake in wealthier and greener counties. The implied abatement cost of 870 euro per ton of CO<sub>2</sub> for BEVs and 2,470 euro for PHEVs suggests that subsidies to PHEVs were especially cost-ineffective.

**JEL codes:** Q54, Q58, H23, R48

**Keywords:** Decarbonizing road transport, electric mobility, purchase subsidies, policy effectiveness, distributional effects of climate policy

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# 1 Introduction

Decarbonizing transportation is an increasingly urgent goal for national and international climate policy, as the transport sector represents about one quarter of global greenhouse gas (GHG) emissions and lags behind other sectors with respect to abatement. Given that policymakers worldwide are increasingly accepting the target of climate neutrality by mid-century, the transport sector must be largely decarbonized by 2050. Passenger cars represent the greatest share of GHG emissions from transportation by far. Therefore, policies targeting emissions from cars are important planks in countries' climate policy packages. Consumer subsidies for the purchase of new electric vehicles have emerged as a central element in many countries' climate policy mix targeting the transport sector, and are being used around the world in major economies, including the U.S., China, Japan and Germany ([IEA, 2022](#)).<sup>1</sup> For example, the U.S. significantly expanded purchase incentives for electric vehicles in its 2022 Inflation Reduction Act ([Congress, 2022](#)). However, subsidies may be not effective and non-additional, e.g. if consumers would have bought the respective vehicles without the subsidy (e.g. [Mian and Sufi, 2012](#); [Hoekstra et al., 2017](#)) or if interacting policies – in our setting, especially EU-level CO<sub>2</sub> emission standards – also play an important role in driving the uptake.

Moreover, purchase subsidies are only relevant for customers willing and able to purchase a new car. Thus, the subsidy program may disproportionately benefit wealthier buyers with a greater concern for the environment (e.g. [Allcott et al., 2015](#)), which raises distributional concerns and may negatively affect the acceptance of purchase subsidies by the general population.

Therefore, in addition to analyzing the effectiveness of purchase subsidies understanding the distributional implications of this policy is crucial. However, so far there is only limited evidence about the effectiveness of purchase grants and even less evidence on its distributional effects.

This paper analyzes the effectiveness and heterogeneous effects of the purchase subsidy program for electric mobility in Germany, one of the most important car markets worldwide and

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<sup>1</sup>Cf. [Rapson and Muehlegger \(2021\)](#) for an overview of the economics of electric mobility.

the home market of some of the largest car manufacturers. The German federal government provides substantial consumer grants for the purchase of battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), with total subsidy amounts of up to 9,000 euro per purchased vehicle.

Our main contributions are twofold: First, we estimate the causal effect of a subsidy program on the uptake of BEVs and PHEVs using highly granular information on the universe of vehicle registrations in Germany. For the identification, we exploit time specific policy variation and account for confounding time trends and other relevant EU-wide policy using neighboring European countries as a control group. Second, we provide a detailed analysis of heterogeneous policy effects with respect to income, ideology – as proxied by the share of Green Party votes in federal elections – and degree of urbanization – proxied by population density. In this way we contribute not only to understanding whether purchase subsidies have distributional impacts but also to disentangling the main drivers of distributional effects.

For the empirical analysis, we combine highly granular data on monthly registrations of new vehicles at the vehicle model level from the German Federal Motor Transport Authority (*Kraftfahrt-Bundesamt*) with vehicle list prices from ADAC, the German motorists' association, to determine which vehicles are eligible for the subsidy and to perform a baseline analysis of the policy's average effectiveness on the registration of eligible vehicle models, normalized by county population.

Our results show that the purchase grant program was effective at increasing the sales of both subsidized BEVs and PHEVs. The data suggest that county-level BEV registrations rose by around 1,400% over time, and by about 600% for PHEVs. However, based on our identification strategy, we find that only a fraction of new BEV and PHEV registrations can be attributed to the German subsidy scheme. In particular, our results suggest that only 40% of BEV and 25% of PHEV registrations are subsidy-induced, implying that the rest of the increase in registrations is driven by general time trends and EU regulations on fleet-level CO<sub>2</sub> intensity. We further

find that the effects are highly heterogeneous with respect to income and “greenness”, although somewhat different patterns emerge for BEVs and PHEVs. For BEVs, heterogeneity is very pronounced. We find that the purchase subsidy for BEVs was disproportionately taken up by individuals in wealthier counties and with a higher share of Green Party votes. For PHEVs, heterogeneous effects are also present but muted compared to BEVs. In contrast, differences in the degree of urbanization, as proxied by population density, does not play a strong role in the adoption of either BEVs or PHEVs, suggesting that concern regarding vehicle range is not a major driver of BEV/PHEV uptake. Based on the empirical results, we provide an estimate of the environmental effectiveness of the subsidy program. The abatement costs are substantial. We find an implied abatement cost of about 870 euro per tonne of  $\text{CO}_2$  for BEVs and almost 2,470 euro per tonne of  $\text{CO}_2$  for PHEVs.

Using our empirical findings, we can draw three main policy conclusions. First, despite the sizable positive effect of the reform, our results call into question the overall cost-effectiveness of the subsidy program, given the substantial financial commitment involved and the program’s limited additional effectiveness. Second, the analysis of effect heterogeneity shows that the subsidy scheme involves a substantial transfer to individuals in high income regions, leading to distributional concerns over policy acceptance among the general population. Third, we show that the implied  $\text{CO}_2$  abatement costs of the program are much higher for PHEVs compared to BEVs. The stark contrast in the relative performance of PHEV and BEV subsidies suggests that policymakers worldwide should strongly consider differentiating between the two technologies when designing climate policy in the transport sector. To the extent that limited public resources might be available to spur transport decarbonization, our findings clearly indicate that these should flow into the adoption of BEVs rather than PHEVs. Even though the calculated abatement costs for BEVs is still high in absolute terms, it may be justified given the goal of unleashing learning-by-doing and economies of scale effects by spurring consumption at a relatively early stage of technology development and the ambitious timeframe of largely decarbonizing the

transportation sector by mid-century. In addition, the ongoing decarbonization of the German power grid will further mechanically decrease abatement costs in the next years.

A sizable literature studies the effectiveness of subsidy schemes and concludes that subsidies are an important determinant of BEV uptake (e.g. [Jenn et al., 2018](#); [Clinton and Steinberg, 2019](#); [Münzel et al., 2019](#); [Azarafshar and Vermeulen, 2020](#)). While most of these studies provide descriptive evidence, only a few studies use quasi-experimental variation based on granular data on vehicle uptake to identify causal effects. Our paper is related to this stream of the literature, in the vein of [Muehlegger and Rapson \(2022\)](#), who analyze the effectiveness of a BEV purchase program in California targeting low and middle-income buyers, and [Chen et al. \(2021\)](#), who examine the impacts of a purchase program in China. We contribute to this literature by carefully investigating the heterogeneity of policy effectiveness, which allows us to pin down some of the main drivers of the baseline effect. Moreover, we extend this literature by analyzing the effectiveness of purchasing subsidies in Europe’s most important car market.

Our paper is also related to a complementary literature studying the role of policy choices on decisions by players in the car market using a more structural approach. A range of papers address the indirect network effect on the two sides of the BEV market, charging infrastructure and BEV adoption ([Li et al. \(2017\)](#); [Springel \(2021\)](#); [Li \(2019\)](#)). This leads to a “chicken-and-egg” problem, where vehicle adoption depends on the availability of sufficient charging infrastructure, while investment in charging infrastructure becomes more attractive with an (expected) larger BEV fleet. By exploiting variation induced through subsidy implementations or grocery store density, these authors derive similar conclusions. They find that, despite both subsidies for vehicle purchases and charging infrastructure being effective, the latter are consistently more relevant. In a somewhat distinct contribution, [Remmy \(2022\)](#) also estimates a structural model of the vehicle market, using an aggregate version of the data from Germany used in this paper, and investigates the effects of subsidies on decisions of car manufacturers with respect to price and range of vehicles.



Finally, we also contribute to the subset of the literature focusing on the environmental effectiveness of purchase incentives. [Holland et al. \(2016\)](#) provide an estimate of the environmental benefits and costs due to air pollution and GHG emissions of EV purchase support schemes in the US. They conclude that the net benefits are modest in terms of GHG emissions and highly heterogeneous across space, with low-income areas receiving net environmental costs due to air pollution ([Holland et al. \(2019\)](#)). Thus, whether EV support programs are welfare-enhancing strongly depends on local conditions across the US. In a related study, [Xing et al. \(2021\)](#) consider substitution patterns using U.S. survey data on new vehicle purchases and conclude that the environmental effectiveness of current support schemes for EVs is limited, as EVs typically substitute for relatively low-polluting vehicles. Our own calculations focus on the environmental effectiveness of the German subsidy with respect to GHG emissions. Thus, we not only provide estimates of abatement costs for a European subsidy scheme, but we also document the stark difference in environmental effectiveness between BEV and PHEV subsidies. However, due to our setting we cannot take different substitution patterns into account in line with [Xing et al. \(2021\)](#).

## 2 Background

### 2.1 Subsidy policy

Germany's federal government implemented a package of support measures with the goal of establishing Germany as a lead market for electric mobility. A major component is the introduction of consumer grants for the purchase of battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

The consumer purchase grant program was initiated in 2016, with vehicles newly registered after May 18, 2016, being eligible for subsidies ([BMW, 2016](#)). Subsidies are shared by the federal government and by vehicle manufacturers. The government paid out 2,000 euro for the

purchase of an BEV and 1,500 euro for a PHEV, conditional on the purchase receipt documenting a manufacturer rebate of an equal amount. Vehicles with a list price of up to 60,000 euro were eligible for the grant program.<sup>2</sup> As the mandated manufacturer rebate is likely to interact with other purchase incentives offered by manufacturers, we consider the government amount as the baseline treatment intensity.<sup>3</sup> The initial grant program had a total budget of some 600 million euro (BMF, 2021).

The purchase program became progressively more ambitious. In February 2020, both the government grant and manufacturer rebates increased by 50% for vehicles with a listed price of up to 40,000 euro, reaching a total value of 6,000 for BEVs and 4,500 euro for PHEVs. Cars newly registered after November 5, 2019, were eligible for the increased grants (BMWi, 2020a). For vehicles with a listed price between 40,000 and 65,000 euro, government grants and required manufacturer rebates increased by 25% each, to a total value of 5,000 euro for BEVs and 3,750 euro for PHEVs. Moreover, the federal government extended the duration of purchase program (at the original grant level prior to 2019) through the end of 2025, with a total budget commitment of 2.09 billion euro for the 2020-2023 period (BMF, 2021). Shortly after, in June 2020 the government increased the subsidy even further. The amount of the government share of purchase grants was doubled compared to the level set in November 2019, while the manufacturer share remained unchanged (BMWi, 2020c), bringing the total grant amount up to 9,000 euro per BEV for vehicles with listed prices below 40,000 euro and 7,500 euro for those with listed prices between 40,000 and 65,000. A further 2 billion euro was also added to the total budget of the program (BMF, 2021). In late 2020, the doubling of the government share was extended through 2025 (BMWi, 2020b).<sup>4</sup>

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<sup>2</sup>For the purpose of this paper, list price refers to the base list price of a model, i.e. the list price of the version of the model without optional equipment and add-ons.

<sup>3</sup>As transaction prices are not available to us, the extent to which the manufacturer rebate substituted for other rebates normally provided during the purchase negotiation cannot be analyzed.

<sup>4</sup>According to estimates in the grey literature, the current level of the subsidy is making BEVs in the lower (below 40,000 euro) and middle (40,000 - 65,000 euro) market segments competitive with comparable internal combustion models, while highly priced BEVs were already competitive without receiving subsidies (Agora Verkehrswende, 2021).

	No policy	Reform 1	Reform 2	
		Introduction	1 <sup>st</sup> increase	2 <sup>nd</sup> increase
	Jan 2015	May 2016	Nov 2019	June 2020
<b>BEV</b>				
< €40.000				
Govern. share	NA	2,000	3,000	6,000
Total subsidy	NA	4,000	6,000	9,000
€40.000-€65.000				
Govern. share	NA	2,000*	2,500	5,000
Total subsidy	NA	4,000*	5,000	7,500
<b>PHEV</b>				
< €40.000				
Govern. share	NA	1,500	2,250	4,500
Total subsidy	NA	3,000	4,500	6,750
€40.000-€65.000				
Govern. share	NA	1,500*	1,875	3,750
Total subsidy	NA	3,000*	3,750	5,625

Table 1: Overview of subsidy scheme levels and their evolution over time

Note: The table shows the tiers of the German subsidy scheme for BEVs and PHEVs including the subsidy levels and their evolution over time. \*The maximum list price for eligibility during Policy 1 was 60,000 euro.

In Table 1 we summarize the key facts of the different policy changes. Given the short interval between the introduction of the two policies we cannot separately identify the effects of Policy 2 and Policy 3 in the empirical analysis. Instead we estimate the joint effect of the two policies, which we define as Reform 2.

In addition to purchase grants, the government also supports electric mobility in additional ways. One major point of intervention is support for the installation of charging infrastructure, a requirement for the viability of BEVs and PHEVs. Stations for rapid charging are of particular interest, as, due to the high charging speed, these represent the closest substitute for traditional gas stations. The government is also deploying its own purchasing power, by setting the target that 20% of its own vehicle fleet shall consist of BEVs. As government agencies are not eligible for subsidies, government purchases generate additional demand for BEVs without crowding out demand for subsidies from other market players, while depressing demand for vehicles with internal combustion engines. Moreover, owners of BEVs receive further privileges, such as freedom

from the federal vehicle tax for 10 years for each vehicle, tax incentives for charging vehicles at their owners’ work location and privileged parking spaces.

## 2.2 Potential for heterogeneous effects

Our setting of a rather untargeted policy scheme offers a lot of potential for heterogeneity in the uptake of subsidy payments. Analyzing such heterogeneity can shed light on some key mechanisms behind the uptake of electric vehicles. In this paper, we explore effect heterogeneity along three dimensions, starting with income – a canonical dimension along which to delineate effect heterogeneity (Muehlegger and Rapson, 2022). Second, the literature shows that energy efficiency subsidies are especially taken up by individuals with an environmentalist orientation (Allcott et al., 2015). We test for these patterns by considering attitudes toward environmental issues, proxied by the share of the Green Party voting in the 2017 federal election, which is the federal election closest to the introduction of the subsidy policy. Third, we consider the extent to which subsidy take-up depends on the degree of urbanization, which we view as an indication of the extent to which range anxiety (Li et al., 2017) may be a factor in EV take-up in our setting.

To explore heterogeneity, we map each German county into the quartile of the distribution it belongs to with respect to income, green vote share, and population density. It is important to note that the categorization of the regions according to the different dimensions is correlated. In Table 2, we present pairwise correlations of our three dimensions of heterogeneity. Income and Green Party share are positively correlated, with a correlation coefficient of 0.43, while income and population density are almost uncorrelated. Moreover, population density and Green Party vote share are also positively correlated, with a correlation coefficient of 0.41.

	HH Income	Population density	Green party vote share
HH Income	1.00	-0.08	0.43
Population density	-0.08	1.00	0.41
Green party vote share	0.43	0.41	1.00

Table 2: Pairwise correlations of heterogeneity dimensions

Figure 1 shows the geographical distribution of the counties according to the these three variables. A comparison of the income and Green Party vote share variables is especially instructive: one factor common to these variables is the geographic location of counties between East and West Germany. Most counties in Eastern Germany belong to the bottom quartiles according to both average household income (Figure 1a) and share of the Green Party vote (Figure 1b), with the exception of some (sub-)urban areas. Many Eastern German counties are also in the bottom quartile according to population density, although the picture here is less clear-cut than with income distribution and Green Party vote share. Therefore, the former division in Germany is an important source of variation in all three of the variables used for heterogeneity analysis.

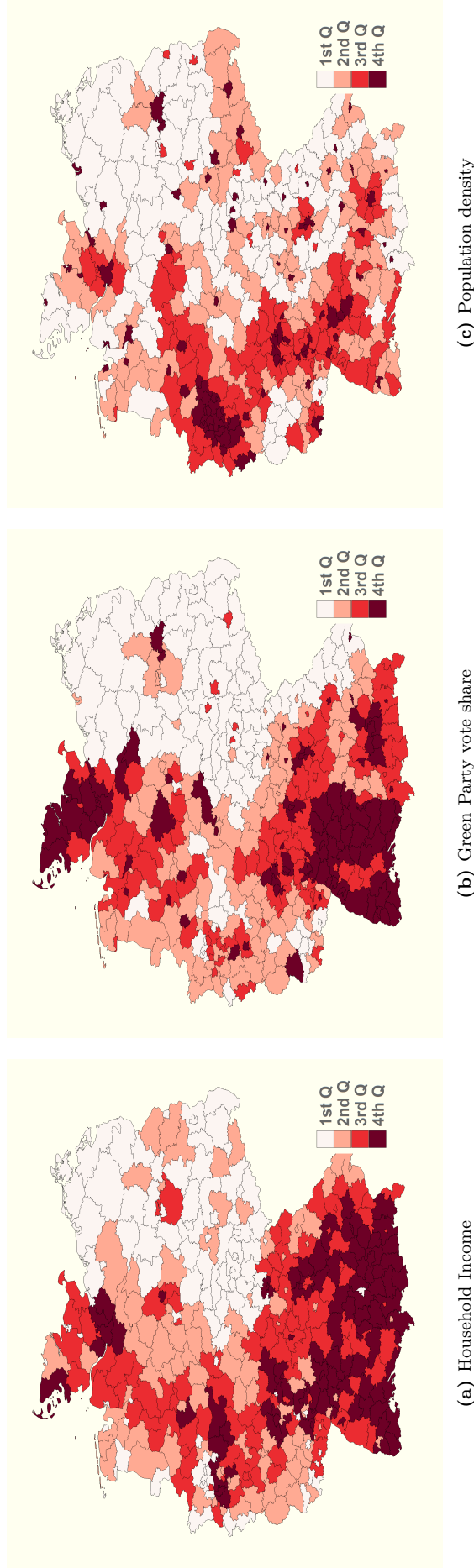


Figure 1: Maps of distribution quartiles along heterogeneity dimensions

Sources: Federal Institute for Research on Building, Urban Affairs and Spatial Development (Bundesinstitut für Bau-, Stadt- und Raumforschung).

Note: The figure shows county-level maps of Germany, showing the distribution of average household income (panel a), Green Party vote share in the 2017 federal election (panel b), and population density (panel c) by county. Counties are grouped into quartiles, with higher quartiles indicated in darker shades of red.

## 3 Data

### 3.1 Data sources

The main data source used in this paper is a dataset from the German Federal Motor Transport Authority (*Kraftfahrt-Bundesamt*). It contains the monthly number of the universe of newly registered vehicles at the vehicle model level aggregated for 399 German counties.<sup>5</sup> The data includes information about the engine type, i.e. about different classes of internal-combustion engines like gasoline or diesel, plug-in hybrid engines, or battery electric vehicles. Additionally, registrations are distinguished by ownership type, i.e. whether a vehicle is commercially or privately owned.

For our analysis, we use the monthly information for the January 2015 to February 2022 period. Thus, we observe the number of registrations before and after the different policy reforms.

We map registrations of vehicle models into the subsidy policy framework using data on list prices for each model from ADAC (*Allgemeiner Deutscher Automobil-Club*), the German motoring association. Specifically, each BEV or PHEV model is matched to one of three different price segments: vehicles with a list price below 40,000 euro, vehicles with a list price between 40,000 euro and 65,000 euro, and vehicles with a list price exceeding 65,000 euro. Thus, we can identify which vehicles were eligible for the different subsidy levels.<sup>6</sup> In addition, we match county level information to our dataset. This includes population density information from the German Statistical Office (destatis) and county socio-economic characteristics from the Federal Institute for Research on Building, Urban Affairs, and Spatial Development. This allows us to classify counties by income, population density, and political preferences, all of which are key dimensions for the heterogeneity analysis.

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<sup>5</sup>The data consists of cars newly purchased in Germany and cars brought into Germany from abroad. However, the vast majority are newly purchased vehicles.

<sup>6</sup>We do not observe if the owners of the vehicle actually applied for the subsidy. Given the generous financial incentive of the policy and its public salience, we consider any vehicle registration eligible for the subsidy as treated.

The original datasets includes more than 20 million registrations over our sample period, of which 1.8% are dropped during the data cleaning process.<sup>7</sup> In order to reduce the dimensionality of our dataset, we aggregate all relevant information to the county by month level. Thus, we end up with a balanced panel of 399 counties over 86 months. We normalize the information about registrations to 100,000 inhabitants to account for variation in the size of the different counties.

### 3.2 Descriptive overview

Before turning to the econometric analysis, we first provide a descriptive overview of our data. Figure 2 shows overall registrations in Germany by engine type over time. The vertical lines mark the introduction of the reforms. In addition, we highlight in grey the lockdown periods due to Covid-19, which had a large effect on production across the entire economy.

In the pre-reform period, until mid-2017, almost all vehicles in Germany were based on internal combustion engine (ICE) technology: The lines indicating total registrations and total ICE registrations overlap almost perfectly. After the first reform, in May 2016, we see a small increase in the registration of hybrid vehicles and, to a lesser extent, EVs. While registration of hybrids becomes dynamic before the introduction of the new policies in 2019 and 2020, the demand for BEVs stays at very low levels. Only after these reforms do we see a clear increase in registrations for both PHEVs and BEVs. By the end of our sample period, in late 2021 and early 2022, PHEVs and BEVs have reached similar registration numbers as vehicles with diesel engines, which were on a downward trend for much of our sample period. Finally, we also observe synchronized drops in registrations that affect all engine types during the two lockdown periods due to Covid-19.

In order to gain a better understanding of the evolution of total BEV and PHEV registrations, Figure 3 describes this evolution by price segment. As seen in Figure 3a, the total increase in

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<sup>7</sup>We only keep registrations with no missing information on any key variable. Furthermore, we drop registrations from eight PHEV and BEV models that at some point changed price segment between the 40,000-65,000 euro and above 65,000 euro price segments.



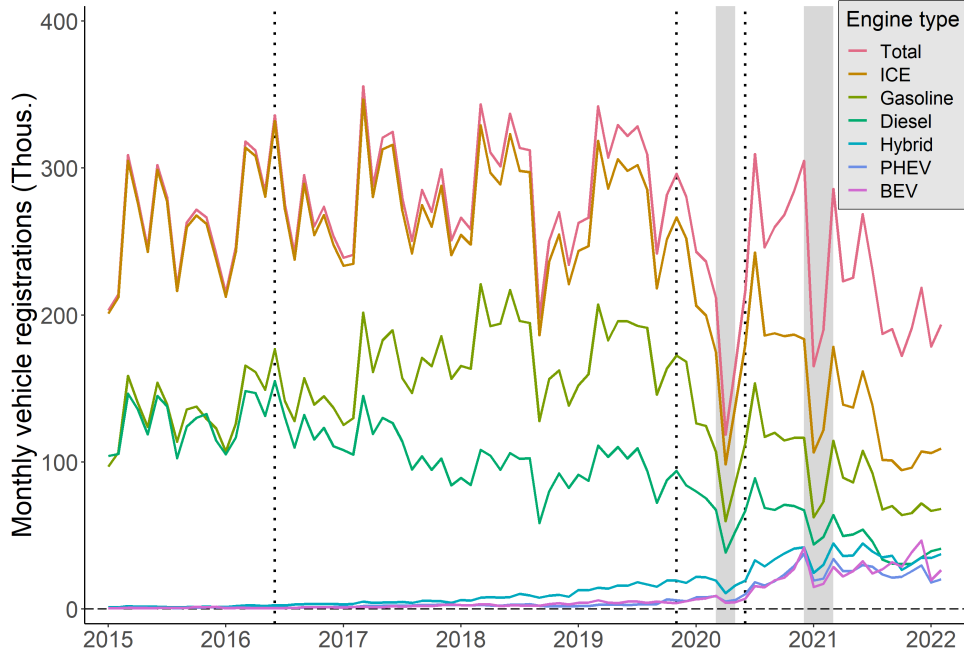


Figure 2: Total number of registrations, by engine type

Sources: German Federal Motor Transport Authority, own calculations.

Note: The figure is based on monthly vehicle registration data from January 2015 through February 2022. The first dotted line indicates the introduction of the subsidy system in May 2016. The second and third dotted lines show the eligibility cutoff of the amendments to the subsidy scheme in November 2019 and June 2020. Grey shaded areas indicate periods of lockdown due to Covid-19.

BEV registrations is mostly driven by vehicles with a list price below 40,000 euro. Registrations in this price segment steadily increase after the implementation of the subsidy scheme in May 2016, but they rise dramatically in 2020 and reach the level of more than 20,000 monthly registrations. In contrast, registrations of vehicles with list price above 40,000 euro increase more slowly, never reaching the threshold of 5,000 monthly registrations. When shifting focus to PHEV, Figure 3b presents a similar but slightly different picture. At the beginning of the sample period, total PHEV registrations for all three price segments are comparable to BEV registrations. However, in this case the total increase over time is driven by both the price segment of vehicles below 40,000 euro and of vehicles between 40,000 and 65,000 euro.

Finally, we present evidence of the heterogeneous developments across counties in Figure 4. Figure 4a shows the market share of BEVs in all price segments in the year 2021 (the last complete calendar year in our sample period) for all 399 German counties of Germany, while

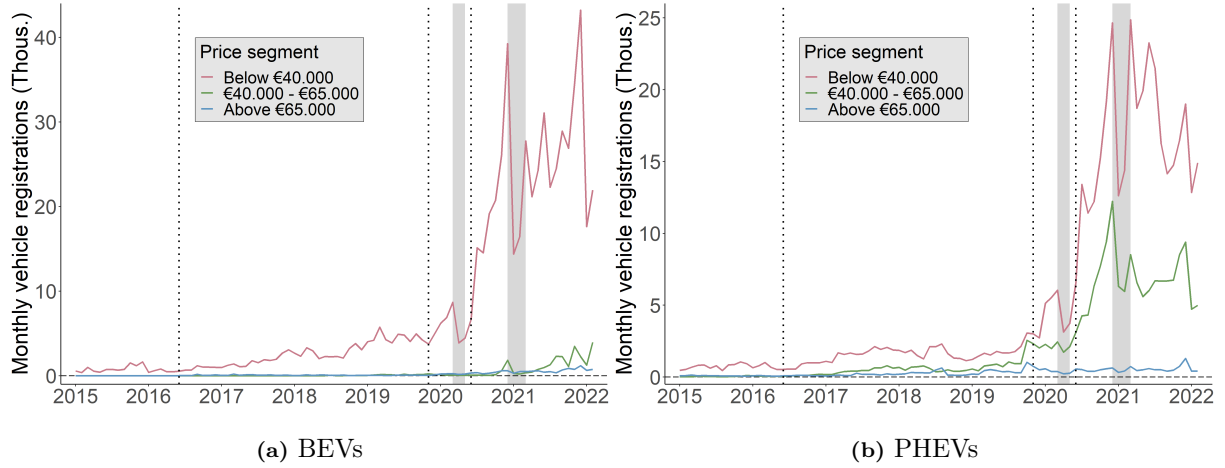


Figure 3: Number of registrations, by engine type and price segment

Sources: German Federal Motor Transport Authority, ADAC, own calculations.

Note: The figures are based on monthly vehicle registration data from January 2015 through February 2022. The first dotted line indicates the introduction of the subsidy system in May 2016. The second and third dotted lines show the eligibility cutoff of the amendments to the subsidy scheme in November 2019 and June 2020. Grey shaded areas indicate periods of lockdown due to Covid-19.

Figure 4b shows the equivalent information for PHEVs. While market shares for both BEVs and PHEVs often exceeded 20%, it is noteworthy that considerable between-county variation exists. In particular, counties in the former East Germany exhibit substantially lower market shares compared to most Western counties.

## 4 Research design

### 4.1 Identification

The aim of the empirical analysis is to identify the effect of purchase subsidies on registrations of eligible BEVs and PHEVs. We propose two approaches. First, we specify a simple event study as a linear model with time and county-level fixed effects focusing on the registrations of BEVs and PHEVs in price segments that were eligible for the subsidy (all models with a list price of less than 65,000 euro). The results of this approach would only be informative about the effectiveness of the subsidy in the absence of time-varying confounders that would have also impacted registrations in the counterfactual scenario without the German subsidy scheme. However, as discussed above, other German and European climate policies targeting

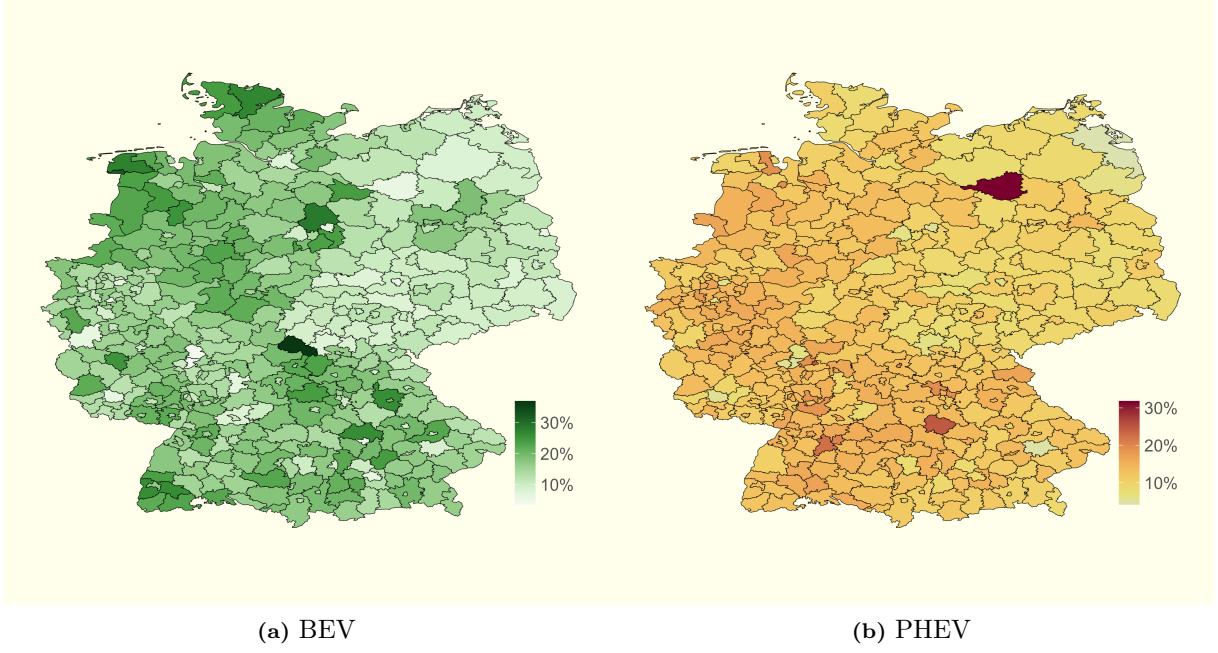


Figure 4: Market share by county in 2021

Sources: German Federal Motor Transport Authority, own calculations.

Note: The maps show the share of BEV and PHEV registrations of all price segments amongst the total registrations per county in 2021.

transport decarbonization might represent such a threat to identification. In particular, in 2020 the stringency of  $CO_2$  emissions standards mandated by the European Union increased substantially. This policy imposes fleet-level carbon intensity limits on all manufacturers, increasing the incentives to introduce new BEV and PHEV models to the European market and lowering purchase prices. Therefore, we propose a second identification strategy. We address the potential threat to identification due to other confounding time specific variation by leveraging BEVs and PHEVs registration data from other European countries provided by the European Alternative Fuels Observatory (EAFO) of the European Commission. In this data, we observe total BEV and PHEV registrations at the national level for all European countries and every month throughout our sample period. We use this information to construct a control group to approximate a counterfactual evolution of German registrations at the national level in the absence of its subsidy scheme. Since we observe the registrations of the control group on the national level, we perform a two step procedure. In the first, step we construct the trend of the control group and, with this information, we de-trend the registrations over time in the German

counties. In the second step we use the de-trended data in an event study approach with time and county-level fixed effects focusing on the registrations of BEVs and PHEVs in price segments that were eligible for the subsidy (all models with a list price of less than 65,000 euro).

In more detail, we first normalize the time series by dividing monthly registrations by the average monthly registrations in 2019. In this way, we can compare the evolution of registrations between countries with different market sizes. We construct the counterfactual normalized trend by taking the unweighted average trend of neighboring countries (specifically, Austria, Belgium, Denmark, France, Luxembourg, Sweden, and Switzerland),<sup>8</sup> as they are likely to be most similar to Germany and, therefore, best capture the evolution of German registrations without a subsidy scheme. Note, even though we do not observe registrations by price segment for other European countries, we consider the trend in total registrations to be a good proxy for the trend in registrations of models below 65,000 euros, as the market share of BEVs and PHEVs models above 65,000 is close to zero and negligible. Figure 5 illustrates this first step by showing the evolution of monthly BEV (5a) and PHEV (5b) registrations in Germany and the sample of neighboring countries normalized to the average monthly registrations in 2019. Normalized registrations for both Germany and the neighboring countries follow a very similar trend before 2020 and are similarly affected by shocks like the Covid-19 related lockdowns. Normalized registrations also increase substantially in other European countries in 2020, as would be expected given the introduction of strict  $CO_2$  emissions standards. However, the increase is stronger in Germany than in the remaining countries. This suggests that the two subsidy increases in November 2019 and June 2020 drove additional demand for BEVs and PHEVs.

In a second step, we take the absolute difference between the original and counterfactual trends (green line in Figures 5a and 5b). This difference captures the unexplained variation in

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<sup>8</sup>We exclude registrations from the Netherlands, as they follow a registration pattern that is unique amongst European countries: registration numbers for both BEVs and PHEVs concentrate in the month of December and are very low for the remaining months of the year.

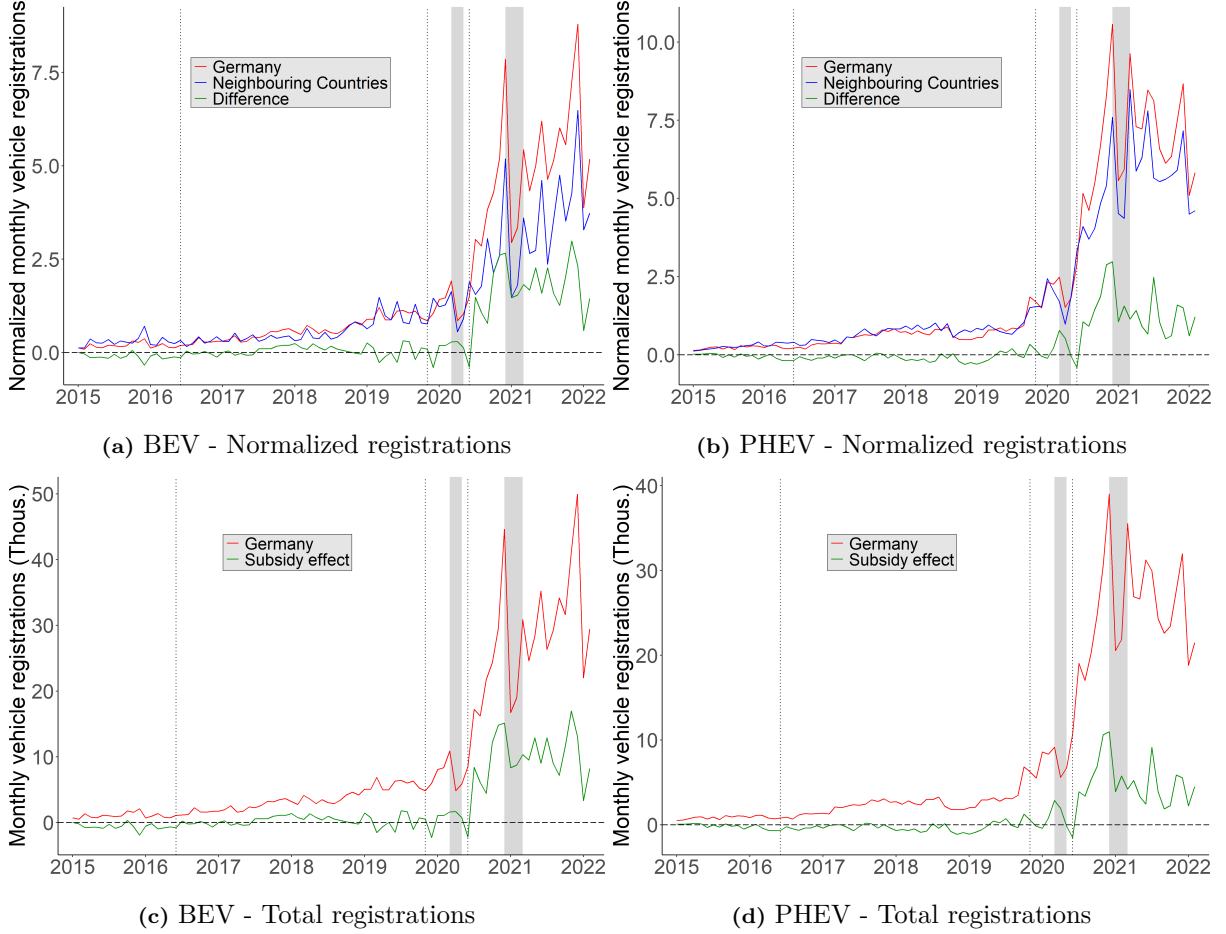


Figure 5: Evolution of normalized, total and counterfactual registrations in Germany

Sources: European Alternative Fuels Observatory (EAFO), own calculations.

Note: Panels (a) and (b) show the evolution of monthly registrations normalized to the average number of monthly registrations in 2019 for Germany and an unweighted average of neighboring countries (Austria, Belgium, Denmark, France, Luxembourg, Sweden, and Switzerland). Panels (c) and (d) show the evolution of total registrations in Germany as well as the total subsidy effect as discussed in Section 4.1. The first dotted line indicates the introduction of the subsidy system in May 2016. The second and third dotted lines show the eligibility cutoff of the amendments to the subsidy scheme in November 2019 and June 2020. Grey shaded areas indicate periods of lockdown due to Covid-19.

the German time series that we attribute to the subsidy. To map this unexplained variation into absolute registrations, we interact the monthly differences in trends with the base value of the German observed time series (average monthly registrations in 2019). This allows us to differentiate between monthly total registrations and the monthly registrations attributed to the subsidy program as reflected in Figures 5c and 5d. The subsidy effect in these figures is simply the differential trend from Figures 5a and 5b scaled to the German market size.

## 4.2 Empirical model

The baseline estimation for the two approaches relies on the same event study model:

$$y_{kit} = \sum_{j=-m}^q \delta_j T_{z,z=0+j} + \lambda_i + \epsilon_{it}, \quad (1)$$

In the first approach,  $y_{kit}$  records the total number of registrations of vehicles in price segment  $k$ , county  $i$ , and month  $t$  per 100,000 inhabitants.  $\delta_j$  is the coefficient of interest, the point estimate on a pre/post indicator  $T_z$ , which tracks periods relative to the start of the post-treatment period in May 2016. We estimate  $\delta_j$  at the trimester frequency, with  $\delta_0$  being the coefficient in the first post-treatment trimester, and  $\delta_m$  and  $\delta_q$  the earliest pre-treatment and latest post-treatment trimester, respectively. Our current dataset contains five pre-treatment trimesters and 23 post-treatment trimesters. Estimates of  $\delta_j$  for the pre-treatment periods capture anticipation effects, while  $\delta_j$  in the post-treatment period estimate the policy's effectiveness. We further include county fixed effects  $\lambda_i$  and cluster standard errors at the region (*Bundesland*) level.

In the second approach, the outcome  $y_{kit}$  is not based on total number of registrations but on the de-trended number of registrations. As mentioned above, each county by price segment time series is de-trended based on the trend of neighboring countries presented in Figure 5.

In order to move beyond the mean effect and to analyze the heterogeneity of the subsidy across different subsamples, we develop Equation 1 by aggregating the time variation and introducing group-specific interactions:

$$y_{kit} = \sum_{j=0}^2 \delta_j T_j + \sum_{j=0}^2 \sum_{d=2}^4 \delta_{jd} (T_j \times H_d) + \lambda_i + \epsilon_{it}, \quad (2)$$

Equation 2 is defined similarly to Equation 1. The time grouping indicators are aggregated so that we distinguish between the "No policy" period ( $j=0$ ), the "Reform 1" period ( $j=1$ ), and the "Reform 2" period ( $j=2$ ). This specification additionally includes an interaction term between the time grouping indicator  $T_j$  and a subsample indicator  $H_d$ . As mentioned in Section 3.1, subsamples of interest are defined along three different dimensions of heterogeneity at the regional level: mean household income level in 2019, share of votes for the Green Party in the 2017 German Federal elections, and population density. For each heterogeneity analysis of interest, we split our 399 counties into four groups of equal size. The indicator  $H_4$  is equal to 1 if county  $i$  belongs to the 100 counties with higher values of, for instance, average household income and 0 otherwise.  $H_3$  is equal to 1 for counties above the median but below the 75th percentile and  $H_2$  is equal to 1 for counties below the median but above the 25th percentile.

## 5 Results

Section 5.1 presents the results of the average effect of the German subsidy scheme on the uptake of BEVs and PHEVs. In Section 5.2, we then consider the distributional impact of the subsidy by studying the program's heterogeneous effects along several relevant dimensions. Finally, based on the empirical results, we calculate in Section 5.3 the environmental effectiveness of the subsidies for BEVs and PHEVs.

### 5.1 Main results

Figure 6 shows point estimates and 95% confidence intervals for our estimates of the German subsidy scheme's average effectiveness using Equation 1. Figure 6a shows results for BEVs, while Figure 6b contains the analogous results for PHEVs. For each of the two market segments, we present results using only the times series for Germany (Approach 1) and using the de-trended data for Germany (Approach 2), as outlined in Section 4.1.

In both cases, point estimates prior to the introduction of the subsidy scheme in May 2016

are close to zero and not significant. After the introduction of the reform, the results of the two approaches strongly differ. This demonstrates the importance of accounting for concurrent confounding time trends and policy changes at the European level. Using the German data only (dashed lines in Figure 6a), we estimate that the subsidy scheme caused increases in the uptake of BEVs in 2016 already, with effects strengthening progressively to about 5 additional registrations per 100,000 inhabitants and month after the first increase in the amount paid after November 2019. Effects escalate after the second increase in per-unit subsidy amounts in mid-2020 to more than 30 units registered per 100,000 inhabitants and month.

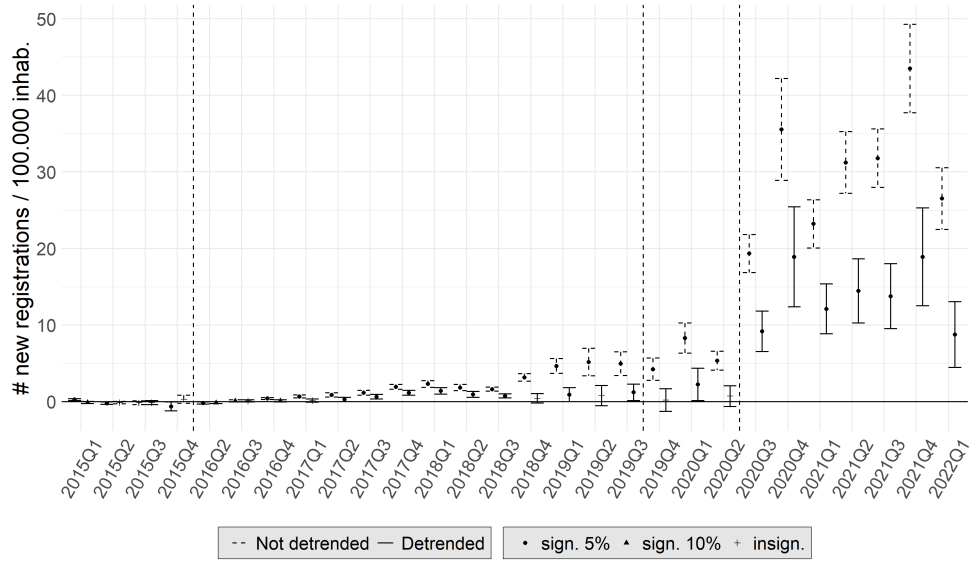
When accounting for other time variation, including the EU CO<sub>2</sub> standards (continuous lines in Figure 6a), the effects are markedly lower. Point estimates are much closer to zero between the introduction of the subsidy scheme in mid-2016 and prior to the second increase in mid-2020 and are rarely statistically significant. However, even with the de-trended data, we find significant and positive effects after the introduction of the more generous subsidies. Subsidies lead to an increase in BEV registrations of about 10 registrations per 100,000 inhabitants. The effect for PHEVs is of slightly lower magnitude (Figure 6b). In the following, given the importance of the confounding time variation, we focus only on the de-trended analysis.

In Table 3, we focus on the average effects of the different policy reforms. Specifically, we estimate Equation 1, but instead of deriving quarterly effects, we estimate the effect of the reform periods defined in Table 1, Reform 1 (2016-2019) and Reform 2 (2019-2022) – on the number of registrations. The results for BEVs (Table 3, columns (1) and (2)) confirm the findings of the more disaggregated analysis. The first reform, which introduced modest subsidy levels (see Table 1), had a small but significant effect on registrations of BEVs. We find that the introduction of purchase subsidies increased monthly registrations of BEVs by 0.81 vehicles per 100,000 inhabitants<sup>9</sup> in each county and month, which represents an increase of 115 %

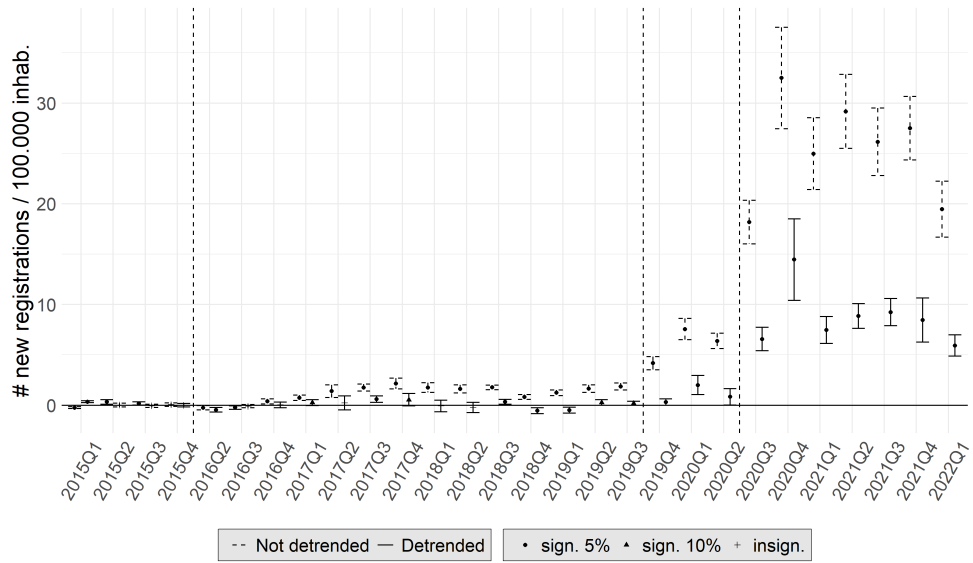
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<sup>9</sup>As all registration numbers are normalized by population and all point estimates represent registrations per 100,000 inhabitants, for shortness we henceforth omit the reference to population-normalization when interpreting coefficients





(a) BEVs



(b) PHEVs

Figure 6: Subsidy effect over time

Note: Regression results based on Equation 1 estimated on the observed (dashed lines) and detrended (cont. line) data. Confidence intervals are based on standard errors clustered at the regional level (Bundesland). The first dotted line indicates the introduction of the subsidy system in May 2016. The second and third dotted lines show the eligibility cutoff of the amendments of the subsidy scheme in November 2019 and June 2020.

compared to the average number of registrations per month during the pre-reform period. The magnitude of the coefficient for the first reform stage is unchanged, no matter whether we only consider the sample of BEVs with listed prices of up to 40,000 euro or also include vehicles with prices up to 65,000 euro. The effect of the second reform stage, with much-increased subsidy payments, is much larger, at about 10 registrations per month, or about 1400% compared to the pre-treatment period. Again, the effects are broadly similar irrespective of the sample choice.

The effects for PHEVs are much smaller and only significant for the second reform stage (Table 3, columns (3) and (4)). We estimate that subsidies for PHEV purchases resulted in additional PHEV registrations of 6.49 (all eligible vehicles) and 5.51 (vehicles below 40,000 euro) per month. This implies an increase in eligible PHEV registrations of 600% compared to the pre-treatment period. The comparison of all price segments that received the subsidy (vehicles with listed prices of less than 65,000 euro) with the sample of vehicles with listed prices below 40,000 euro shows again that the overall effect and the effect for vehicles below 40,000 euros hardly differ.

	(1)	(2)	(3)	(4)
	BEVs		PHEVs	
	<65	<40	<65	<40
Reform 1	0.81*** (0.10)	0.81*** (0.10)	-0.09 (0.13)	-0.05 (0.14)
Reform 2	10.41*** (1.68)	9.83*** (1.72)	6.49*** (0.61)	5.51*** (0.49)
County FE	Yes	Yes	Yes	Yes
N	34314	34314	34314	34314
Pre-Reform Mean	0.71	0.71	0.93	0.89

Table 3: Main results

Note: Estimated coefficients based on Eq. 1 estimated on detrended data separately for BEVs registrations (columns 1-2) and PHEV registrations (columns 3-4). Registrations include all models below 65,000 euro (columns 1 and 3) and only models below 40,000 euro (columns 2 and 4). The coefficient Reform 1 refers to the time period May 2016 - Oct 2019 and Reform 2 to the time period Nov 2019 - Feb 2022. Coefficients have to be interpreted with respect to the pre-reform period (Jan 2015 - April 2016) and represent the average change in registrations per 100,000 inhabitants. Standard errors clustered at the regional level (Bundesland) in parenthesis. \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels, respectively.

Finally, we replicate the previous results but focus on the outcome of absolute total registra-

	(1)	(2)	(3)	(4)
	BEVs		PHEVs	
	<65	<40	<65	<40
Reform 1	1.46*** (0.30)	1.46*** (0.31)	-0.38 (0.24)	-0.29 (0.22)
Reform 2	20.70*** (4.13)	19.26*** (4.01)	11.84*** (3.45)	10.55*** (2.89)
County FE	Yes	Yes	Yes	Yes
N	34314	34314	34314	34314
Pre-Reform Mean	2.0	2.0	2.0	1.9

Table 4: Main results - absolute detrended registrations

Note: Estimated coefficients based on Eq. 1 but estimated without population normalization separately for BEVs registrations (columns 1-2) and PHEV registrations (columns 3-4). Registrations include all models below 65,000 euro (columns 1 and 3) and only models below 40,000 euro (columns 2 and 4). The coefficient Reform 1 refers to the time period May 2016 - Oct 2019 and Reform 2 to the time period Nov 2019 - Feb 2022. Coefficients have to be interpreted with respect to the pre-reform period (Jan 2015 - April 2016) and represent the average change in registrations. Standard errors clustered at the regional level (Bundesland) in parenthesis. \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels, respectively.

tions per county instead of normalized registration per 100,000 inhabitants. In contrast to the coefficients based on the normalized specification, these coefficients can be aggregated across counties into a total subsidy effect. Thus, this specification will become relevant for the calculations on environmental effectiveness in section 5.3. Table 4 presents the results analogously to Table 3. Starting from an average of two registrations per month and county during the pre-treatment period, the increase in absolute registrations amounts to 20.7 (BEV) and 11.8 (PHEV) additional registrations per month and county during the Reform 2 period.

## 5.2 Heterogeneous effects

So far, we have focused on average effects of the policy reforms. In this section we turn to the estimation of Equation 2 to test if the effects vary between regions in a systematic way. Specifically, we rank the regions by income, voting shares for the Green Party, and population density, and defining groups according to quartiles of the respective variables. As base category, we define regions in the lowest quartile. Thus the point estimates refer to  $\delta_{jd}$  in Equation 2 and are interpreted as the difference in registrations per 100,000 inhabitants relative to the base

	(1)	(2)	(3)	(4)	(5)	(6)
	BEV			PHEV		
	HH income	Green party	Pop. density	HH income	Green party	Pop. density
Reform 1	0.66*** (0.09)	0.51*** (0.05)	0.62*** (0.10)	0.09 (0.06)	0.08* (0.04)	-0.11 (0.17)
Reform 2	3.18 (4.28)	8.12*** (0.87)	10.39*** (1.00)	4.84*** (0.51)	4.70*** (0.56)	4.86*** (0.49)
Reform 1 x 2nd Q	-0.06 (0.12)	0.21** (0.09)	0.26*** (0.08)	-0.16* (0.08)	0.17 (0.18)	0.23 (0.18)
Reform 1 x 3rd Q	0.10 (0.16)	0.49*** (0.11)	0.32*** (0.11)	-0.61 (0.42)	-0.57 (0.43)	0.21 (0.25)
Reform 1 x 4th Q	0.55*** (0.13)	0.49* (0.23)	0.15 (0.17)	0.06 (0.21)	-0.25** (0.10)	-0.36* (0.18)
Reform 2 x 2nd Q	8.78* (4.22)	5.74*** (1.54)	1.60* (0.77)	1.33* (0.64)	4.16** (1.54)	1.32 (0.81)
Reform 2 x 3rd Q	9.58** (4.33)	-0.39 (4.63)	3.55** (1.29)	2.07** (0.71)	1.78** (0.78)	3.32 (1.98)
Reform 2 x 4th Q	10.57** (4.63)	3.85** (1.40)	-5.07 (4.57)	3.16 (2.90)	1.22 (1.28)	1.87** (0.69)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
N	34314	34314	34314	34314	34314	34314

Table 5: Heterogeneous effects of the consumer subsidy

Note: All results based on detrended data of registrations of models below 65,000 euro. All columns are based on Eq. 2. Baseline coefficients represent the effect of the two reforms (Reform 1 and Reform 2) on the lowest quartile. Interacted coefficients represent the effect of one of the two reforms in counties belonging to one of the three other quartiles of the respective distribution (Quartile 2, Quartile 3, Quartile 4). Coefficients are interpreted as average change in registrations per 100,000 inhabitants. Standard errors clustered at the regional level (Bundesland) in parenthesis. \*, \*\*, and \*\*\* indicate significance at the 10%, 5%, and 1% levels, respectively.

category.

In Table 5, we show results for the registrations of BEVs (columns 1-3) and PHEVs (columns 4-6). For BEVs, registrations strongly vary with household income, averaged at the county level, and differ by reform stage (Table 5, column (1)). For the first reform, statistically significant heterogeneity is only present for regions in the top income quartile: we find that registrations increase by 0.55 for counties in the top quartile of the income distribution. For the second reform stage, the differences between income groups are much more pronounced. The baseline effect of the reform, which measures the effect for regions in the first quartile, is statistically not different from zero, i.e. we estimate that demand for BEV in low-income counties does not react to the purchase subsidy. However, already for regions in the second quartile point estimates are markedly higher and significant, suggesting that registrations increase by 8.72 per

month for counties in the second quartile of the county-level income distribution, compared to the baseline category. This effect further increases for higher quartiles. Our estimates suggest that registrations in regions in the highest income quartile increase by more than 10 per 100,000 inhabitants relative to regions in the lowest quartile. For PHEVs, there is no clear evidence of heterogeneity during the Reform 1 period. Regarding Reform 2 and in contrast to BEVs, we observe a positive subsidy effect already in the counties belonging to the first income quartile. As with BEVs, the point estimates become larger with higher county-level income, although differences by quartile are less extreme than for BEVs and the estimate for the richest counties (quartile 4) is not statistically significant.

We also find heterogeneous effects in the other two dimensions, although baseline effects for BEVs are much higher and always significant, while differential effects in different quartiles are less pronounced. For BEVs, the policy effect is stronger in regions with a high share of votes for the Green Party, our proxy of pro-environmental attitudes. The baseline effect is strongly significant and, in the second reform stage, it is economically large, at about 8 registrations per month (Table 5, column (2)). The 25% "greenest" counties account for an additional 3.85 registrations per month, about one third of the magnitude found for richest counties. In combination, these results showing that higher income and "greener" counties drive the uptake of BEVs is consistent with the existing evidence (e.g. Allcott et al., 2015). Patterns with respect to our greenness proxy for PHEVs are similar to those for income. The baseline effects are almost identical, at 4.7 registrations per month. Registrations increase in "greener" counties, except for the quartile of particularly green counties, where we do not observe a significant policy effect on the registrations of PHEVs.

Population density also matters for the uptake of BEVs, with patterns showing some similarity to our proxy for pro-environmental attitudes. The baseline effect is high, at 10.39 registrations per county and month (Table 5, column (2)). Policy effects tend to be stronger in more densely populated counties, presumably areas with shorter commutes and a denser charging network.

Interestingly, according to our estimates, the effect of the subsidy in the most densely populated regions is not different from the effects in the least populated regions, while additional registrations are peaking in the third quartile, with an additional 3.55 registrations per county and month. This result suggests that the uptake of BEVs is driven by sub-urban areas rather than metropolitan centers. With respect to "range anxiety", this evidence suggests that BEVs are preferred in less rural counties with more charging options and shorter trips, with the exception of highly urbanized counties, where other forces – possibly the higher opportunity cost of owning vehicles and more viable transportation alternatives – appear to be counteracting it. Overall, in our setting, range and charging concerns, as proxied by population density, do not seem to be a strong driver of the reaction to BEV subsidies, at least compared to income and environmental attitudes. Of course, in a generally densely populated country like Germany such concerns are likely to be muted compared to a setting like the U.S. Regarding PHEVs, we only observe a statistically significant additional subsidy effect in the most densely populated counties. With an increase of 1.87 additional PHEV registrations per 100,000 inhabitants, this pattern is qualitatively opposite to the results for BEVs.

### 5.3 Environmental effectiveness

In the final section, we use the empirical results to calculate the environmental effectiveness of the subsidy scheme, similar to [Chen et al. \(2021\)](#). We place a particular emphasis on comparing relative effectiveness between BEVs and PHEVs as well as on calculating abatement costs per tonne of CO<sub>2</sub> abated in the second reform period between November 2019 and February 2022, the period with high per-unit subsidy payments. We proceed in four steps. Table 6 presents an overview of these calculations. First, we calculate the amount of public funds (i.e. disregarding the manufacturer share of the subsidy payments) spent on the subsidy program between November 2019 and February 2022. Combining our data on registrations by vehicle price segment with the different subsidy amounts available over time, we arrive at a total sum of 3.2 billion euros for

BEVs (3.4 billion USD; 23.6 billion Chinese Yuan) and 2.2 billion euros for PHEVs (2.3 billion USD; 16.2 billion Chinese Yuan). Note that this first step assumes every eligible vehicle’s owner actually applied for the subsidy.

In a second step, we quantify the difference between actual and counterfactual (or infra-marginal) BEV/PHEV uptakes, i.e. how many registrations would not have occurred without the subsidy scheme. Note that we cannot directly scale the causal effects reported in Table 3 into total marginal registrations due to the population normalization. Therefore, in Table 4, we replicate the results shown in Table 3 using unweighted registrations. We can now scale the coefficients in monthly absolute levels reported in Table 4 of 20.7 (BEVs) and 11.84 (PHEVs) to 399 counties and multiply the result by the number of months over the Reform 2 period (28 months). We end up attributing a total of 231,260 BEV registrations and 132,276 PHEV registrations to the subsidy. Consistent with the evidence reported in Figure 6, we document that a large share of BEV and PHEV registrations were not induced by the subsidy program and would have also occurred in the absence of the policy. According to our analysis, 59% of the observed BEV registrations and 75% of the observed PHEV registrations were non-additional. Consequently, the implied subsidy per induced registration is higher than the nominal subsidy per vehicle of the subsidy scheme: the subsidy per additional registration amounts to around 14,000 euro for BEVs and 16,500 euro for PHEVs. These implied subsidies per induced registration are in line with the calculation by [Rapson and Muehlegger \(2021\)](#) for the case of medium demand elasticity and non-Tesla BEVs.

In a third step, we approximate the CO<sub>2</sub> abatement of newly registered BEVs and PHEVs, respectively. In order to do this, we assume that both BEVs and PHEVs replace an internal combustion engine (ICE) vehicle with average fuel efficiency and that all vehicles drive 13,000 km per year<sup>10</sup> for 18 years (following [Held et al. \(2021\)](#)).<sup>11</sup> According to the information at

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<sup>10</sup>See estimates of the German Federal Transport Authority [online](#).

<sup>11</sup>It is likely that the vehicle will be used outside of Germany at some point during those 18 years. However, this is not relevant for a calculation regarding global CO<sub>2</sub> emissions and abatement.

the vehicle model level provided by ADAC, the average CO<sub>2</sub> emissions of an ICE vehicle over the second reform period in our dataset amount to 12.87 kgCO<sub>2</sub>/100km. For the same period, the average BEV consumes 14.3 kWh/100km, which given the average carbon intensity of the German power sector of 420 gCO<sub>2</sub>/kWh amounts to 6 kgCO<sub>2</sub>/100km.<sup>12</sup> For PHEVs, we combine the average direct CO<sub>2</sub> emissions of 3.93 kgCO<sub>2</sub>/100km with the emissions resulting from an average consumption of 14.5 kWh/100km. Altogether, the emissions from an average PHEV during the second reform period amount to 10 kgCO<sub>2</sub>/100km. Given the assumed total distance driven for all types of vehicles, our calculations yield that, over the course of 18 years, an average BEV would emit 16.06 tonnes of CO<sub>2</sub> less than an average ICE, while an average PHEV would emit 6.68 tonnes of CO<sub>2</sub> less than an average ICE. In a last step, we combine the previous results to calculate abatement costs for the BEV subsidy and PHEV subsidy scheme. The BEV subsidy scheme implied abatement costs of 866 euro per tonne of CO<sub>2</sub>, while the PHEV subsidy scheme implies 2,468 euro per tonne of CO<sub>2</sub>.

Two aspects are noteworthy. First, the absolute level of the calculated abatement costs are high if compared to recent estimates of the social cost of carbon ([Environmental Protection Agency, 2022](#)). However, high initial abatement cost can be justifiable given the goal of spurring consumption at an early stage of technology adoption and adopting an ambitious timeframe of largely decarbonizing the transportation sector by mid-century. Decarbonizing the electricity grid through subsidies to wind and solar power was relatively expensive in 2010, but levelized costs of electricity generation for these two sources have decreased by almost 70% and 90%, respectively, since then ([IRENA, 2021](#)). Second, the relative difference in abatement costs between BEVs and PHEVs is substantial and warrants a discussion on whether public subsidy schemes

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<sup>12</sup>The CO<sub>2</sub> intensity of the power grid is a crucial parameter in this calculation. In contrast to [Rapson and Muehlegger \(2021\)](#), we use average CO<sub>2</sub> intensity instead of marginal CO<sub>2</sub> intensity. [Rapson and Muehlegger \(2021\)](#) argue that “EV load becomes part of the baseline” as the fleet grows, so that average CO<sub>2</sub> intensity might capture EV emissions better in the long-term. Given that our calculation is based on the full vehicle life-span of 18 years, average CO<sub>2</sub> intensity is more suitable in our context. In addition, German CO<sub>2</sub> intensity is likely to decrease over the coming decades. In order to put this calculation into context, if Germany reached CO<sub>2</sub> intensity levels of 150 gCO<sub>2</sub>/kWh (comparable to the current Danish CO<sub>2</sub> intensity of the power grid), this would amount to 2.15 kgCO<sub>2</sub>/100km for a German BEV.



for PHEVs are an efficient policy instrument with respect to abatement costs, at least compared to subsidies to BEVs.

	BEV	PHEV
<i>Additionality of subsidy scheme</i>		
Total registrations	559,899	531,431
Total subsidy amount (mill. euro)	3,216	2,180
Subsidy causal effect (regs./county-month)	20.70	11.84
Subsidy-induced registrations	231,260	132,276
Share of marginal registrations (%)	41.3	24.9
Purchase grant per induced registration	13,908	16,486
<i>Parameters on environmental effectiveness</i>		
Average electric. consumption (kWh/100km)	14.3	14.5
Average tailpipe emissions (kgCO <sub>2</sub> /100km)	NA	3.93
Average total emissions (kgCO <sub>2</sub> /100km)	6.01	10.02
Average ICE emissions (kgCO <sub>2</sub> /100km)	12.87	
Electricity CO <sub>2</sub> intensity (gCO <sub>2</sub> /kWh)	420	
Yearly distance driven (km)	13,000	
Years until scrappage	18	
<i>Abatement results</i>		
Total abatement per vehicle (CO <sub>2</sub> tonnes)	16.06	6.68
Abatement cost (euro/CO <sub>2</sub> tonne)	866	2,468

Table 6: Overview of abatement cost calculation

Note: All calculations based on the November 2019 - February 2022 period (Reform 2 period). Subsidy causal effect taken from Table 4. Average electricity consumption and tailpipe emissions are calculated based on ADAC data for the Reform 2 period. We take the estimate of the German power grid CO<sub>2</sub> intensity from the German Environmental Office for the year 2021 (available [here](#)). Yearly distance driven is taken from calculations by the German Federal Transport authority (available [here](#)), while years until scrappage are taken from [Held et al. \(2021\)](#).

## 6 Conclusion

This paper analyzes the effectiveness and heterogeneous effects of the consumer purchase subsidy program for electric mobility in Germany, Europe’s largest car market and home market of some of the world’s premier car manufacturers. We estimate the program’s overall impact on the uptake of battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) using granular data on the universe of new vehicle registrations in Germany. For identification,

we exploit time specific policy variation and account for confounding time trends and potentially interacting EU-wide policy setting CO<sub>2</sub> standards at the manufacturer fleet level using registrations in neighboring European countries as a control group. We then conduct a detailed analysis of the policy’s heterogeneous effects with respect to income, ideology – proxied by the share of Green Party votes in federal elections – and degree of urbanization – proxied by population density. This helps us to understand both distributional impacts of the subsidy scheme and the main drivers of these distributional effects.

Our results show that the subsidy program increased new BEV and PHEV registrations by about 1,400% and 600%, respectively, compared to the pre-treatment period. However, we find that a large share of BEV and PHEV registrations was infra-marginal, as only about 40% of BEV and 25% of PHEV registrations are subsidy-induced. The remainder was driven by general time trends and EU regulations on fleet-level CO<sub>2</sub> intensity. We further find that effects are strongly heterogeneous and that the purchase subsidy for BEVs was disproportionately taken up by individuals in wealthier counties and with a higher share of Green Party voters. For PHEVs, heterogeneous effects are less pronounced. Interestingly, concern with respect to vehicle range does not seem to be a major driver of BEV/PHEV uptake in our setting. Finally, we calculate an implied abatement cost of about 870 euro per tonne of CO<sub>2</sub> for BEVs and almost 2,470 euro per tonne of CO<sub>2</sub> for PHEVs.

Three main policy conclusions emerge from our analysis. First, our results cast doubt on the overall cost-effectiveness of the subsidy program. Second, the program leads to significant transfers to individuals in high-income regions and, therefore, to concerns over general policy acceptance. Third, the implied abatement cost of the program is especially high for PHEVs, suggesting that subsidies for PHEVs should be discontinued. Subsidies to BEVs may be justified despite the high initial abatement cost given the ambitious timeframe of transportation sector decarbonization by mid-century and the expected medium-term cost savings once learning effects accumulate and as the power sector continues to decarbonize.

One limitation of the present analysis is that our data do not allow for a separate investigation of the role of charging infrastructure in the adoption of BEVs and PHEVs, respectively. We consider such an analysis – in the German and in other settings – to be a worthwhile avenue for future research.

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