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Lavan T. Burra, Stephan Sommer, and Colin Vance[1]

Free-Ridership in Subsidies for Company- and Private Electric Vehicles

Abstract

Consumer subsidies are commonly employed to incentivize the purchase of battery electric vehicles (BEVs), but free-ridership potentially undermines their effectiveness. The present study investigates BEV subsidies in Germany, distinguishing their effect between company- and private cars. Drawing on a panel of high-resolution car registration data, we use the estimates from a Poisson pseudo-maximum likelihood model to predict BEV registrations in the absence of the subsidy. We calculate aggregate free-rider rates of 19% for private cars and 43% for company cars. We further find that the cost of the subsidy per induced BEV among private consumers is €5,400, while it is €7,215 among companies. Overall, the estimates suggest that the subsidy is considerably less cost effective among company cars, which comprise 55% of new BEV sales.

JEL-Codes: H23, L91, Q58

Keywords: Electric vehicles; consumer subsidy; company cars; free ridership

April 2023

1 Lavan T. Burra, RWI and University of Maryland; Stephan Sommer, RUB and Bochum University of Applied Sciences; Colin Vance, RWI and Jacobs University Bremen. *– We thank participants of the Transport Research Board (TRB) conference 2023 for very helpful discussions. This work is supported by the European Union's Horizon 2020 programme under the Marie Sk lodowska-Curie Actions, Innovative Training Network, Grant Agreement No 101003757. Moreover, we gratefully acknowledge financial support by the German Federal Ministry for Education and Research (BMBF) in the framework of the Kopernikus project Ariadne (grant 03SFK5C0).* *– All correspondence to: Colin Vance, RWI, Hohenzollernstr. 1-3, 45128 Essen, Germany, e-mail: colin.vance@rwi-essen.de*

1 Introduction

For more than a decade, the passenger car market has been in turmoil, as policymakers and the automobile industry endeavor to decarbonize the transportation sector. In Europe, where total CO_2 emissions are declining, transportation is the only sector where they are on the rise, increasing by almost 30% since 1990 (EC, 2020). The electrification of the car fleet is seen as one path toward bucking this trend, and is a key pillar in the European Union's (EU) effort to meet its climate neutrality objectives (EEA, 2022). Already, the share of battery electric vehicles (BEVs) in the European car market has increased from 2% in 2019 to 12% in 2022 (ACEA, 2023), and legislation is planning to ban sales of new cars with an internal combustion engine by 2035.

Germany, which is home to the largest car market in Europe, is among several EU Member States that have relied on consumer subsidies to increase the uptake of BEVs, spending roughly €3 bn on the subsidies between 2016 and 2021. Sales of BEVs increased nearly 20-fold over this period, but the extent to which this increase is attributable to the subsidy remains an open question. The present paper addresses this question by estimating panel models on car registration data from the German car market between 2014 and 2021, an interval that straddles the introduction of the subsidy in 2016. Our aim is threefold: (1) to provide estimates of the subsidy scheme on BEV registrations that are distinguished by price- and consumer segments, (2) to estimate free-rider effects across these segments, and, (3) ultimately, to calculate the cost-effectiveness of the scheme.

Our work thereby contributes to a growing literature that has attempted to identify the impact of various promotional measures, including purchase rebates, tax credits, and sales tax waivers, on electric vehicle (EV) registrations (see Hardman et al., 2017, for a review). Estimates from this literature present a mixed picture of policy effectiveness. Among multinational studies, Sierzchula et al. (2014) analyze the market share of plug-in electric vehicles (PEVs) across 30 countries globally in 2012 and find relatively modest effects: all else equal, a $1,000 increase in financial incentives leads to a 0.06% increase in a country's PEV market share. Münzel et al. (2019) analyze the impact of purchase incentives on PEV sales in 32 European countries from 2010 to 2017 and find markedly higher effects: an additional $1,000 incentive increases PEV sales shares by 5-7%.

Country-level studies likewise reveal a wide range of estimates (Li et al., 2017; Mersky et al., 2016; Narassimhan and Johnson, 2018; Vergis and Chen, 2015; Yan, 2018). From North America, Jenn et al. (2018) and Wee et al. (2018) both analyze state-level vehicle registration data from 2010 to 2015. Jenn et al. (2018) find that a $1,000 increase in the purchase incentive leads to an average 2.6% increase in electric vehicle sales, while Wee et al. (2018) find a considerably larger effect of 5-11%. Using quarterly US state-level data from 2010 to 2014, Clinton and Steinberg (2019) estimate a 7% per capita increase in EV registrations for every $1,000 of incentives. Azarafshar and Vermeulen's (2020) analysis of province-level vehicle registration data from Canada finds that a C$1,000 increase in incentives would increase sales of new electric vehicles by 5-8%. Analyzing municipal-level data from China between 2015 and 2018, Li et al. (2022) estimate the cost of inducing consumers to buy one EV through consumer subsidies to be roughly $15,000.

Numerous other studies have investigated the impact of purchase subsidies and rebates on EV adoption using microdata of new car buyers (DeShazo et al., 2017; Jenn et al., 2020; Linn, 2022; Muehlegger and Rapson, 2022; Sheldon and Dua, 2019; Springel, 2021; Xing et al., 2021). Springel (2021), for example, shows that registration tax exemptions in Norway of roughly $1239 per vehicle increase EV sales by 3%. In one of the few papers to examine free-ridership, Xing et al. (2021) estimate a consumer demand model for the US market, estimating that 70% of buyers are free-riders.

To date, most studies of EVs treat the demand side of the market as having a singular consumer base comprised exclusively of private consumers, without recognizing the prevalence of company cars that characterize many markets. In Europe, 60% of new cars are registered through the corporate channel, with the share reaching as high as 70% in Germany (TE, 2020). A recent survey by AMO (2022) shows that 36% of German companies that have at least one company car in their fleet already use PEVs, while 26% report using BEVs. In addition, 17% of the companies plan to use BEVs within the next three years. Notwithstanding their prominence, company cars have largely escaped notice in studies that estimate the effect of subsidies on BEV uptake.

This would be of little consequence if companies were to apply the same purchasing rationales as private households, but this seems implausible. For starters, studies have shown that while private households tend to focus on the sticker price and underestimate operation and maintenance costs (Andor et al., 2020), companies are more orientated toward the total cost of ownership (TE, 2020). This literature further demonstrates that private consumers fail to fully consider future fuel costs when purchasing a new car (Allcott and Wozny, 2014; Busse et al., 2013; Leard et al., 2022), leading them to underestimate the potential cost savings from EVs (Liu et al., 2021; Wu et al., 2015). This myopic calculus would presumably increase the importance of the subsidy in their purchase decision (Hardman et al., 2017).

By contrast, other factors are at play that may reduce the importance of the subsidy to companies. In general, companies can apply for VAT returns as well as depreciation write-offs, and often the drivers of company cars can deduct its use from their income taxes. Moreover, charging on the company's site is not subject to individual taxes of the car user, and the user gets a non-taxable lump-sum payment if they charge their cars privately. Taken together, the private consumer's stronger focus on immediate costs along with the company's access to a broader package of incentives would lead us to expect a weaker effect of the subsidy among companies. To explore the implications of this possibility, we partition the car registration data then estimate separate models to identify the effect of the subsidy on BEV registrations among private- and company cars.

Our data distinguishes car registrations by model, county, and quarter. This fine granularity results in a high proportion of zeros, creating a positively skewed distribution of vehicle registrations. We consequently employ a Poisson pseudo maximum likelihood (PPML) regression, which has been used in a wide range of economic applications (Guceri and Liu, 2019; Oksanen et al., 2015; Powell and Seabury, 2018; Todtenhaupt et al., 2020) as a way to deal with non-negative data with potentially many zeros (Silva and Tenreyro, 2006). A key advantage is that the PPML does not require a distributional assumption for the dependent variable, making it a suitable technique to apply to our granular vehicle registration data.

Our results suggest that a €1,000 increase in the subsidy for purchasing a BEV increases the uptake of a specific vehicle model per quarter and county by 18.6%, but with a large disparity seen between private consumers and companies. Specifically, we find that raising the subsidy by €1,000 increases the registrations of private BEVs by almost 20%, while the effect amounts to only 12% for companies. The estimates further reveal heterogeneity across price segments, with the effect of the subsidy being stronger among higher-priced cars.

We use the model estimates to predict counterfactual BEV registrations for all vehicle models in each county and quarter under the assumption that no subsidies are offered, which serves as a basis for calculating the free-rider share. For the sample as a whole, we find that one in three purchases are due to free-riding. The share reaches 43% for company cars compared with 18% for private cars. Moreover, our calculations suggest that the cost of the subsidy per induced BEV is €5,400 among private consumers and €7,215 for companies. Overall, the estimates suggest that the subsidy is considerably less cost-effective among the company cars that dominate the market.

The following section describes the vehicle registration data used for our analysis and the BEV subsidy structure in Germany. In Section 3, we describe the Poisson pseudo maximum likelihood approach and its advantages over the conventional modeling approach typically used in the literature. Section 4 catalogues the model estimates with which the counterfactual BEV market in the absence of the subsidies is simulated. This analysis is used to estimate aggregate free-ridership and the cost-effectiveness of the subsidies. The last section summarizes and concludes.

2 Data

Our data draws from IHS Automotive, which records all new passenger car registrations by year-quarter and by county across Germany between January 2014 and September 2021 at the vehicle make and model level (e.g., Volkswagen Golf, Tesla Model 3). We focus in this analysis on BEVs, which the data separately records as private registrations and those by companies. We observe a total of 615,216 BEV registrations during this period, about 45% of which are by private consumers, with the remaining 55% by companies.

Table 1 presents descriptive statistics for the main variables in our analysis. Overall, the data includes 89 different BEV models from 35 manufacturers. Due to the different introduction and phase-out schedules of vehicle models, we observe 17 BEV models in 2014, which increases to 61 models in 2021. Renault Zoe and Volkswagen ID.3 are the most common BEVs on the road in Germany, followed by the Smart Fortwo. In 2020, Renault Zoe, Volkswagen Golf, Tesla Model 3, Volkswagen ID3, and Hyundai Kona were the leading five EV models, with market shares of 15.9% (30,376), 9.2% (17,439), 8.0% (15,202), 7.6% (14,492), and 7.4% (14,007), respectively. Figure A1 presents the top five BEV models in terms of market share among new BEV registrations in Germany since 2019 across private and company markets. The Tesla Model 3 and Renault Zoe have captured the majority of private BEV registrations, while the Volkswagen ID.3 holds the largest market share among company BEVs. On average, 1.6 private and 1.8 company BEVs are purchased per county per quarter.

Our key explanatory variable is the subsidy paid to both companies and private consumers with the purchase of a BEV, which has changed over time and across price segments. When it was first launched in July 2016, the subsidy was set at €4,000 for BEVs with a list price not exceeding €60,000. The cost of the subsidy was split equally between the government and car manufacturers. In November 2019, the subsidy program was restructured to have two tiers: a subsidy of €6,000 for BEVs priced under €40,000 and a subsidy of €5,000 for BEVs priced between €40,000 and €65,000. Later, in response to the economic disruption triggered by the COVID-19 pandemic, the German government doubled its share of the subsidy in June 2020. The total subsidy in the lower price segment increased to €9,000, while the subsidy for vehicles priced between €40,000 and €65,000 rose to €7,500.

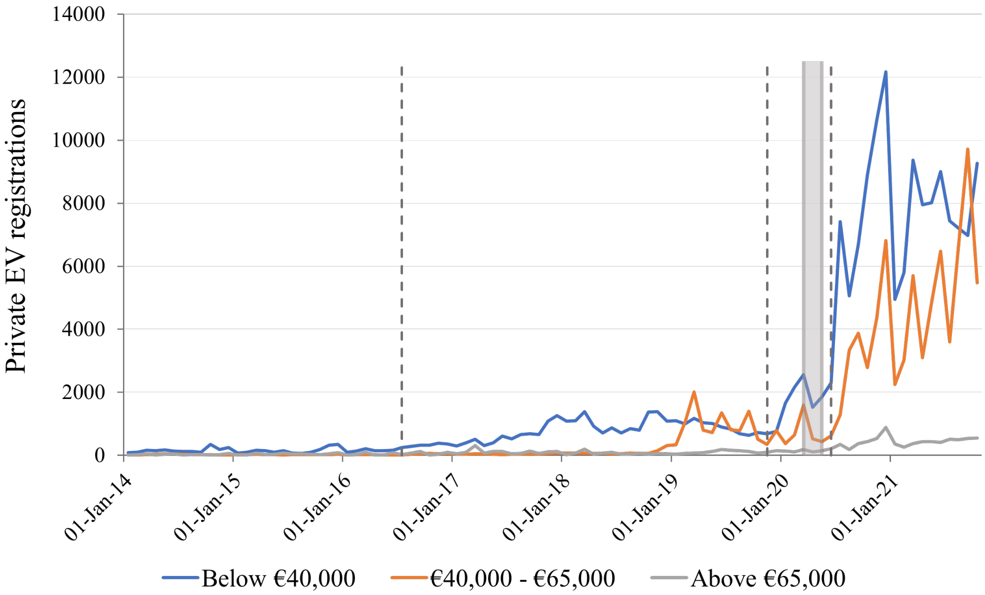
Figure 1 illustrates the growth of private and company BEV registrations starting from January 2014, categorized by vehicle price segments. While companies seem to be

Table 1: Descriptive statistics of BEV registration data and summary of BEV subsidies

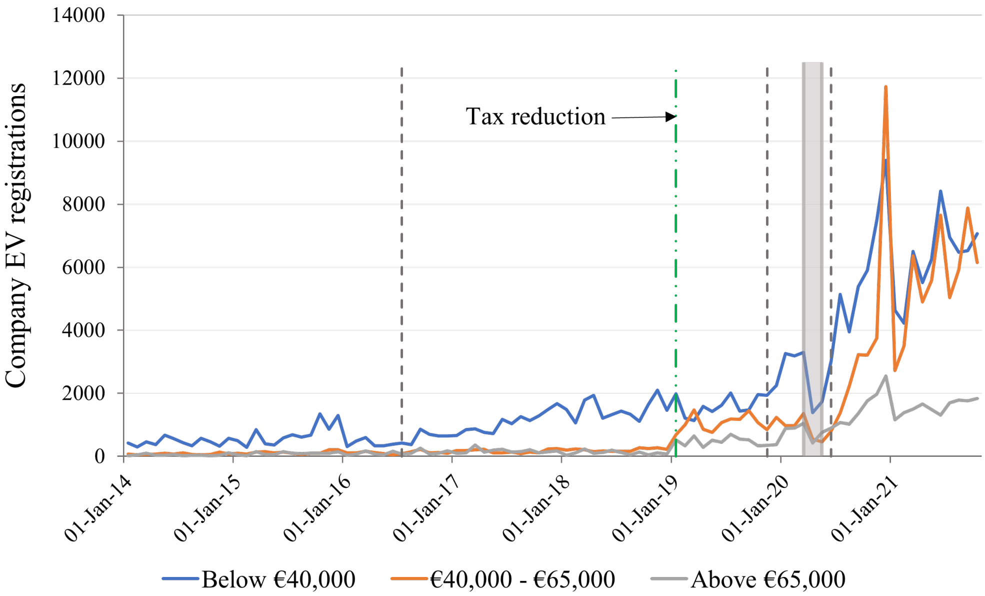
Variable	Description				
Analysis period	Jan 2014 - Sept 2021				
Total BEV registrations	615,256 (Private vs Company share: 45% & 55%)				
No.of BEV models	89				
No.of BEV manufacturers	35				
BEV purchase subsidy	Time period	BEV price (in €)	Overall subsidy		
	Jul 2016 - Oct 2019	<60,000	€4,000		
	Nov 2019 - Jun 2020	<40,000	€6,000		
		40,000 to 65,000	€5,000		
	from Jun 2020	<40,000	€9,000		
		40,000 to 65,000	€7,500		
	Segment	Mean	Std Dev	Min	Max
Quarterly BEV registrations	Private cars	8163.065	13358.57	230	46719
	Company cars	9988.903	12897.46	1309	46834
Quarterly county-model level BEV registrations	Private cars (N=154,052)	1.64266	4.601486	0	244
	Company cars (N=169,072)	1.831504	15.14232	0	2282

the early adopters with a larger number of registered BEVs, both private and company vehicles show similar patterns. Growth was modest until the federal share of subsidy was doubled for all BEVs priced below €65,000 in July 2020. This led to a sharp increase in average quarterly private BEV registrations, from 462 in 2016 to 16,931 in 2020 (a ∼35% increase) for vehicles priced below €40,000, and from 135 to 5,230 registrations (a ∼38% increase) for BEVs priced between €40,000 and €65,000. The average quarterly company BEV registrations rose from 1,396 in 2016 to 14,928 in 2020 (a ∼10% increase) for vehicles priced below €40,000, and from 288 to 5,722 registrations (a ∼19% increase) for vehicles priced between €40,000 and €65,000. These differences suggest that subsidies played a significant role in accelerating the uptake of BEVs, particularly in the private market. In the company car market, part of this growth may be attributed to the introduction of a reduced rate for the taxable income among company car drivers, amounting to 0.5% of the list price as of January 1, 2019. Since 2020, BEVs are subject to a rate of just 0.25% if the list price is below €60,000.

Last, the figure evidences a larger increase in BEV registrations among higher-priced cars, which applies to both the private and company car markets.



(a) Private electric cars



(b) Company electric cars

Figure 1: Number of BEV registrations by price segments

Notes: The three dashed lines indicate the introduction and changes in the subsidy program as presented in Table 1. The grey area represents the time when there were lockdown policies in place due to the Covid-19 pandemic.

3 Empirical Strategy

Most of the previous work that examines the effectiveness of consumer subsidies on EV uptake has modeled either market shares of EVs (Azarafshar and Vermeulen, 2020; Münzel et al., 2019; Sierzchula et al., 2014; Yan, 2018) or the number of EV registrations (Clinton and Steinberg, 2019; Jenn et al., 2018; Liu et al., 2021; Mersky et al., 2016; Narassimhan and Johnson, 2018; Wee et al., 2018) as a function of financial incentives and other attributes by specifying a high-dimensional fixed-effect regression model. Virtually all of the above-mentioned studies employ a linear regression applied to a log-transformed dependent variable.

The log transformation is mainly applied to normalize the heavily skewed distribution of the dependent variable, but this transformation can raise complications when there is a loss of observations that results from taking the log of zero. A common fix is to add one to the dependent variable. However, as Cohn et al. (2022) demonstrate, such "log1plus" regressions produce estimates with no natural interpretation that can have the wrong sign in expectation. Moreover, the estimates of log-linearized models fit by ordinary least squares (OLS) may be severely biased and inconsistent in the presence of heteroskedasticity (Silva and Tenreyro, 2006), and the bias may be exacerbated when controlling for fixed effects (Cohn et al., 2022).

As an alternative, we adopt the Poisson pseudo maximum likelihood (PPML) regression proposed by Silva and Tenreyro (2006) to deal with non-negative data that has a large number of zeros. This approach produces consistent estimates with a valid semi-elasticity and requires no distributional assumption for the outcome variable (Silva and Tenreyro, 2006, 2011). Further, as elaborated below, it can also be applied when the outcome variable is continuous. Assume there are $k = 1, ..., K$ BEV models available in a given market, which is defined as a county-quarter combination, $c \times t$. The number of registrations observed for a particular model k in a county c can be defined as a function of a consumer subsidy S, and fixed effects for model specific factors λ, market-specific factors μ, and model regional factors ϑ:

$$BEV_{kct} = exp\left(\beta_s S_{kct} + \lambda_k + \mu_{ct} + \vartheta_{kc}\right) + \varepsilon_{kct} \quad (1)$$
$$\text{with}\, BEV_{kct} \geq 0 \,\text{and}\, E\left[\varepsilon_{kct}|S\right] = 0$$

where BEV_{kct} is the registrations of model k (e.g., Renault Zoe, Tesla Model 3, etc.) in county c and year-quarter t. λ_k denotes vehicle model specific fixed effects that control for unobserved characteristics implicit in each car models (e.g., vehicle size, capacity, performance, range, etc.). County×year-quater fixed effects (μ_{ct}) control for all unobservables that change over time across each county (e.g., charging infrastructure, fuel price, and other set factors like purchasing power per capita, the unemployment rate, population density). The county*model fixed effects (ϑ_{kc}) capture time-invariant local preferences for green products and demand shocks for each model (e.g., a stronger consumer- or dealer preference for a particular model). In addition, ϑ_{kc} controls for factors like quality and brand loyalty in a particular county that may have an impact on vehicle demand. We assume that a given model has a constant list price across all markets. The parameter of interest, β_s, is interpreted as a semi-elasticity, which is identified from variation in the subsidy over time and across car models. While bias from omitted variables can never be completely ruled out, the specification's extensive coverage of fixed effects, including controls for time-varying regional effects, supports ascribing a causal interpretation to the estimate of β_s.

Under the assumption that the conditional variance is proportional to the conditional mean,

$$E\left[BEV_{kct}|S\right] = exp\left(\beta_s S_{kct} + \lambda_k + \mu_{ct} + \vartheta_{kc}\right) \propto V\left[BEV_{kct}|S\right], \quad (2)$$

β_s can be estimated by solving the following first-order condition:

$$\sum_{i=1}^{n} \left[BEV_{kct} - exp\left(\beta_s S_{kct} + \lambda_k + \mu_{ct} + \vartheta_{kc}\right)\right] S_{kct} = 0. \quad (3)$$

The estimator defined by equation (3) is numerically equivalent to the PPML estimator. The form of the above equation implies that all that is needed for the estimator to be consistent is the correct specification of the conditional mean i.e., $E\left[BEV_{kct}|S\right] = exp\left(\beta_s S_{kct} + \lambda_k + \mu_{ct} + \vartheta_{kc}\right)$. Therefore, the data do not have to have a Poisson distribution, and BEV_{kct} does not have to be an integer in order for the estimator based on the Poisson likelihood function to be consistent (Silva and Tenreyro, 2006).

4 Results

This section presents the results of the empirical analysis. We start with a model that pools company- and private cars to estimate the overall impact of consumer subsidies on the uptake of BEVs. Motivated by the patterns observed in Figure 1, we subsequently analyze the effect across consumer groups and price segments. We then assess the share of free-riders in the German car market using a counterfactual analysis based on the econometric model. Finally, we use our estimates to calculate the cost-effectiveness of the subsidy.

4.1 Model estimates

The top panel of Table 2 presents models that pool the data using alternative specifications of the fixed effects. Regressing BEV uptake solely on the amount of the subsidy in Model (1) yields a coefficient of 0.186, which is statistically significant at the 1% level. The estimate suggests that a €1,000 rise in the subsidy for the purchase of a BEV increases the uptake of a specific model per quarter and county by 18.6%.

Model (2) includes vehicle model fixed effects to control for all time-invariant characteristics of a model, such as the engine, fuel efficiency, etc., while Model (3) incorporates *county* × *time* fixed effects to control for temporal effects that have different regional consequences, such as economic development. Similarly, *county* × *model* fixed effects included in Model (4) control for model-specific attributes that vary by region. The sequential inclusion of these fixed effects bumps around the estimated effect of the subsidy

Table 2: Poisson estimation results for the effect of the subsidy on BEV uptake

	Model (1)	Model (2)	Model (3)	Model (4)
	Panel A. All Cars (N=220,070)			
BEV subsidy (in €1000)	0.186***	0.117***	0.167***	0.170***
	(0.010)	(0.009)	(0.015)	(0.011)
Constant	-0.075	0.922***	0.983***	1.245***
	(0.085)	(0.066)	(0.101)	(0.072)
County-time Fixed Effects	No	No	Yes	Yes
Vehicle model Fixed Effects	No	Yes	Yes	Yes
County-model Fixed Effects	No	No	No	Yes
	Panel B. Private Cars (N=154,052)			
BEV subsidy (in €1000)	0.243***	0.168***	0.193***	0.203***
	(0.003)	(0.004)	(0.011)	(0.010)
Constant	-1.038***	-0.176***	0.005	0.049
	(0.027)	(0.029)	(0.078)	(0.074)
County-time Fixed Effects	No	No	Yes	Yes
Vehicle model Fixed Effects	No	Yes	Yes	Yes
County-model Fixed Effects	No	No	No	Yes
	Panel C. Company Cars (N=169,072)			
BEV subsidy (in €1000)	0.114***	0.074***	0.106***	0.120***
	(0.013)	(0.011)	(0.023)	(0.016)
Constant	0.000	1.030***	1.139***	1.505***
	(0.105)	(0.069)	(0.139)	(0.094)
County-time Fixed Effects	No	No	Yes	Yes
Vehicle model Fixed Effects	No	Yes	Yes	Yes
County-model Fixed Effects	No	No	No	Yes

Notes: The dependent variable is quarterly BEV registrations in all model specifications. BEV subsidy is expressed in €1,000. All models include the same set of fixed effects: County-year quarter FEs, vehicle model FEs, and county-model FEs. Standard errors are reported in parentheses and are clustered at the county-model level. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level, respectively

somewhat, but ultimately the parsimonious specification of Model (1) is largely in agreement with the more saturated specification of Model (4). Taking (4) as our preferred model, we estimate that a €1000 increase in the subsidy increases the BEV uptake by 17%, a substantial effect size relative to the 0.06% to 11% range identified in the reviewed literature.

Panels B and C of Table 2 present results from applying the same specifications to the sample of private- and company cars, respectively. Among private cars, the coefficients on the subsidy are seen to be uniformly larger than those in the pooled model. Referencing Model (4), we find that raising the subsidy by €1,000 increases the registrations of private BEVs by 20.3%. The corresponding estimate for company cars in Panel C, at 12.0%, is significantly smaller in magnitude, supporting the hypothesis that companies are less responsive to the subsidy.

Moving beyond these average effects, we proceed with an augmented specification that includes the interaction of the subsidy with a dummy indicating cars in the lower price segment, i.e., priced below €40,000, the threshold below which the subsidy is at the highest level (see Table 1). Theory would suggest a negative estimate on the interaction term, reflecting a diminished effect of the subsidy with the price level. The results in Table 3, which are from models that include the interaction along with the full set of fixed effects, confirm this expectation. The first model, which pools private and company cars, indicates that each €1,000 spent on subsidies for vehicles in the higher price segment increases registrations by 23.3%, over five percentage points higher than for the less expensive vehicles.

This differential effect across price segments is more pronounced when partitioning the data by consumer type, presented in the second and third models. Among private cars, we find that an additional €1,000 spent on subsidies for high-priced cars increases the uptake of BEVs by 33.4%, almost 10 percentage points higher than the increase in the low-priced segment. The same pattern applies to company cars: the effect of raising the subsidy in the higher price segment is about ten percentage points higher compared to the lower price segment.

4.2 Quantifying free-riders

A likelihood ratio test indicates that the specification with the price segment interaction in Table 3 provides a significantly better fit than when omitting the interaction.[1] We

[1] The likelihood-ratio (LR) test is computed as: $LR = 2 \times (ln(L_{Tab.3}) - ln(L_{Tab.2}))$, where the test statistic follows a χ^2- distribution. The test statistic equals 799 for models with only private cars and

Table 3: Differential effect of subsidy across vehicle price segments

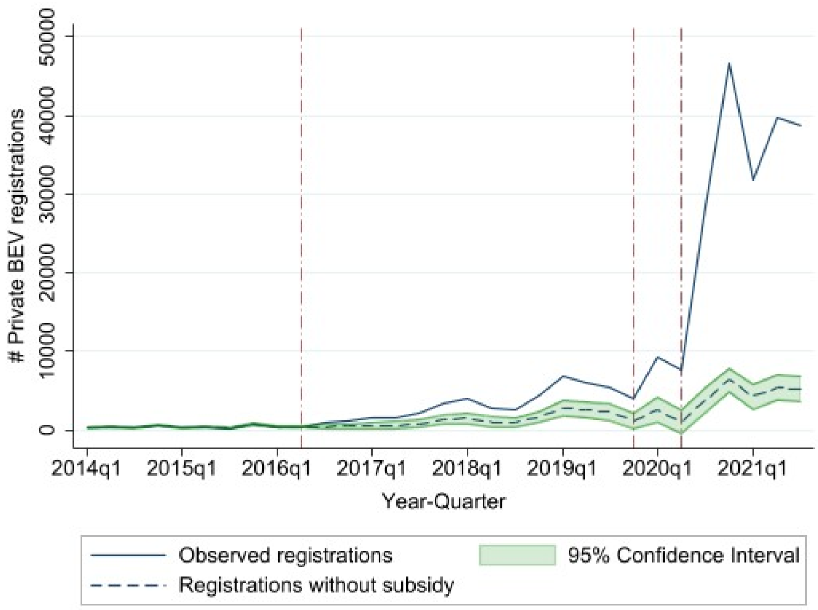
	(1) All cars	(2) Private cars	(3) Company cars
BEV subsidy (in €1000)	0.233***	0.334***	0.231***
	(0.019)	(0.015)	(0.026)
BEV subsidy*(Dummy for cars priced <€40,000)	-0.054***	-0.096***	-0.102***
	(0.013)	(0.010)	(0.021)
Constant	1.100***	-0.380***	1.282***
	(0.079)	(0.072)	(0.096)
Number of observations	220,070	154,052	169,072
County-time Fixed Effects	Yes	Yes	Yes
Vehicle model Fixed Effects	Yes	Yes	Yes
County-model Fixed Effects	Yes	Yes	Yes

Notes: The dependent variable is quarterly EV registrations in all model specifications. EV subsidy is expressed in €1,000. All models include the same set of fixed effects: County-year quarter FEs, vehicle model FEs, and County-model FEs. Standard errors are reported in parentheses and are clustered at the County-model level. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level, respectively

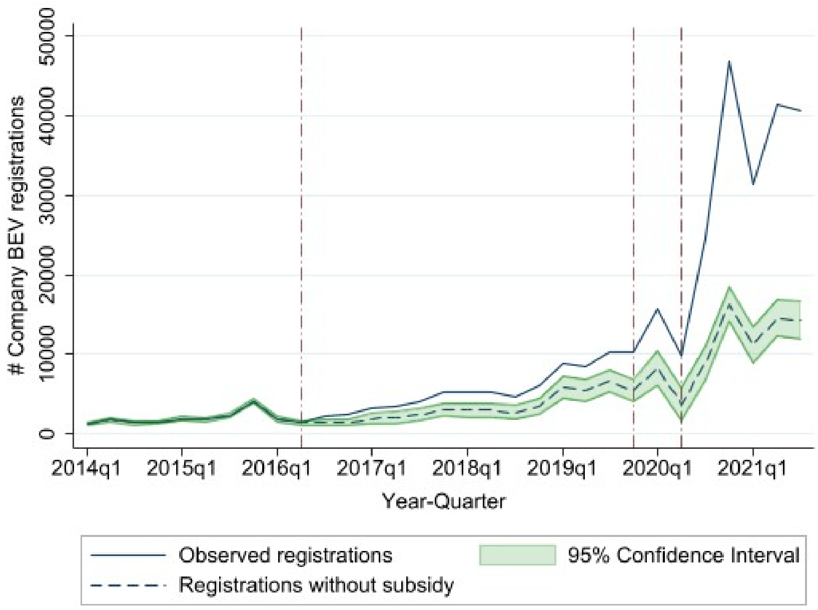
consequently use this specification to construct counterfactual scenarios under which the value of the subsidy is set to zero for both private and company cars. The resulting predictions are presented as the dashed lines in the top and bottom panels of Figure 2, which begin as of the first quarter of 2016 when the subsidy was first introduced. Each panel additionally includes a solid line indicating the observed vehicle registrations for the respective consumer type.

The differential between the observed and counterfactual lines provides a visual impression of the effectiveness of the subsidy. This differential is seen to be larger for private consumers, highlighting the bigger role that subsidies play in their purchase decision. We can estimate the free-rider share by dividing the area under the dashed curve by the area under the solid curve. The results of this estimation are presented in Table 4 for the different levels of the subsidy and the two consumer types. Two insights bear noting. First, the free-rider share is substantially higher among company cars, reaching 43% over the entire period compared with only 19% among private cars. Second, for both groups, the free-rider share decreases markedly with the level of the subsidy. Company cars see

1,223 for company cars, with a p-value of 0.000 in both cases.



(a) Private electric cars



(b) Company electric cars

Figure 2: Counterfactual BEV registrations: The absence of subsidy program

a 25 percentage point reduction in the share between the initial and final subsidy level, from 60.9% to 35.5%; the drop for private consumers is slightly higher at 26 percentage points. While this pattern makes intuitive sense – we would expect that a more generous subsidy would pull in more consumers who would not otherwise have purchased a BEV – it highlights that policymakers must reckon with higher budgetary outlays if they are to reduce the share of free-riders.

To probe further, it is of interest to calculate the total budget required to eliminate free-riders over the period of analysis. As a coarse estimate, we assume a linear relationship between the decrease in the free-rider share and the subsidy provided for each EV, which is evidenced by the figures in Table 4. Our calculations indicate that the government would have to have spent an additional €1.08 billion to subsidize private consumers and €2.79 billion to subsidize companies to achieve a 0% free-ridership rate, more than doubling the amount actually spent.[2] This corresponds to an average subsidy of €10,291 per private BEV and €14,355 per company BEV.

Table 4: Free-rider share across private and company cars

	All cars	Private cars	Company cars
	Interaction with price segments		
Subsidy level-1	51.9%	39.8%	60.9%
Subsidy level-2	42.8%	27.7%	53.0%
Subsidy level-3	25.6%	13.5%	35.5%
Overall	32.3%	18.8%	43.1%
BEV registrations due to subsidy	67.7%	81.2%	56.9%

We note that our estimates of free-riding are more conservative than those of Xing et al. (2021), who find that 70% of PEV buyers in the US would have bought a PEV even in the absence of federal tax credits. The disparity in findings may be due to the differences in the generosity of the programs between the two countries. The tax credits in the US, where Xing et al. (2021) conducted their study, are much lower compared to Germany, and the credit begins to phase out for a manufacturer after they have sold over 200,000 electric vehicles, among other reasons. This is consistent with the observation that lower subsidies correspond to a larger share of free-riders.

[2]The government spent a total of €2.28 billion from July 2016 to September 2021, with an equal split between private and company consumers.

4.3 Effectiveness of consumer subsidies

We finally turn to the question of the effectiveness of subsidies in stimulating the development of the BEV market. Based on our previous calculations, Germany's subsidy scheme resulted in 370,921 additional BEVs compared to a counterfactual scenario of no subsidies. This indicates that around 68% of total BEV registrations are due to the subsidies in the German market, and the remainder of consumers can be classified as free-riders. By way of comparison, Li et al. (2017) finds that tax credits contributed to 40% of PEV sales from 2011 to 2013 in the US, while Li et al. (2022) estimates that 55% of EV sales in China from 2015 to 2018 is explained by subsidies.

The German government spent a total of €2,280 million on subsidies between 2016 and 2021, with €1,090 million spent on private BEVs and €1,190 million spent on company BEVs. Dividing the total number of induced BEV purchases by these figures gives a measure of cost-effectiveness. We find that the subsidies resulted in 185 $\left(= \frac{202{,}144}{1{,}090}\right)$ additional private BEV registrations per million euros spent by the government compared with 138 $\left(= \frac{116{,}112}{1{,}190}\right)$ company cars. Taking the inverse, the cost of the subsidy per induced BEV is €5,400 among private consumers and €7,215 for companies. These estimates indicate a higher cost-effectiveness of subsidies in Germany than those reported for other countries. Among the three studies in the literature that implicitly account for free-riders when calculating cost-effectiveness, Li et al. (2017) estimated that purchase incentives cost about $16,300 per policy-induced EV purchase over the period from 2011 to 2013 in the US market. Springel's (2021) analysis of the Norwegian market using data from 2010 to 2015 shows that the cost per additional EV sale induced is about $25,000 (200,000 KR). Li et al. (2022), using data covering 2015 to 2018, found that inducing consumers to buy one EV through consumer subsidies in China costs the government about $14,250 (97,825 Yuan).

5 Conclusion

Using panel models on vehicle registration data from Germany spanning 2014 to 2021, we estimate the effect of a subsidy program on the uptake of battery electric vehicles. We differentiate the markets for private and company vehicles to allow for diverging purchasing rationales that might interact with the role of financial incentives. Company cars make up a large share of new car registrations in many markets, including in Germany, where the share approaches 70%. But to date, this consumer type has largely escaped notice in studies of promotional measures such as subsidies.

Our results suggest there is indeed a large difference in the response to the subsidy between these two market segments. We find that a €1,000 increase in the subsidy increases the registrations of private BEVs by almost 20%, while the effect amounts to 12% for companies. The free-rider share is correspondingly higher in the company segment, where it reaches 43%, compared with only 18% in the private segment. Expressed in terms of cost-effectiveness, we find that the cost of the subsidy per BEV is €5,400 among private consumers and €7,200 among companies.

While our results do not allow us to pinpoint the source of these differences between consumer types, they are consistent with two features that characterize the analyzed decision-contexts: (1) the well-documented myopia that private consumers typically apply to automobile purchases (Allcott and Wozny, 2014; Andor et al., 2020; Busse et al., 2013; Leard et al., 2022), which would increase the pull of the subsidy, and (2) the broad array of financial support measures that are already extended to the use of company cars, which would decrease its pull. These factors warrant consideration in policy design, particularly when the aim is to minimize free-ridership. This could be achieved by increasing the magnitude of the subsidy extended to both private and company consumers, but, as shown above, at over double the cost of the €3 billion actually spent on the program. Alternatively, the evidence presented here points to the scope for increasing the cost-effectiveness of Germany's scheme by targeting higher subsidies exclusively at the more responsive market segment, private consumers. In this regard, the government's recently announced plan to phase out the subsidy for companies completely by September of 2023 is a move in the right direction.

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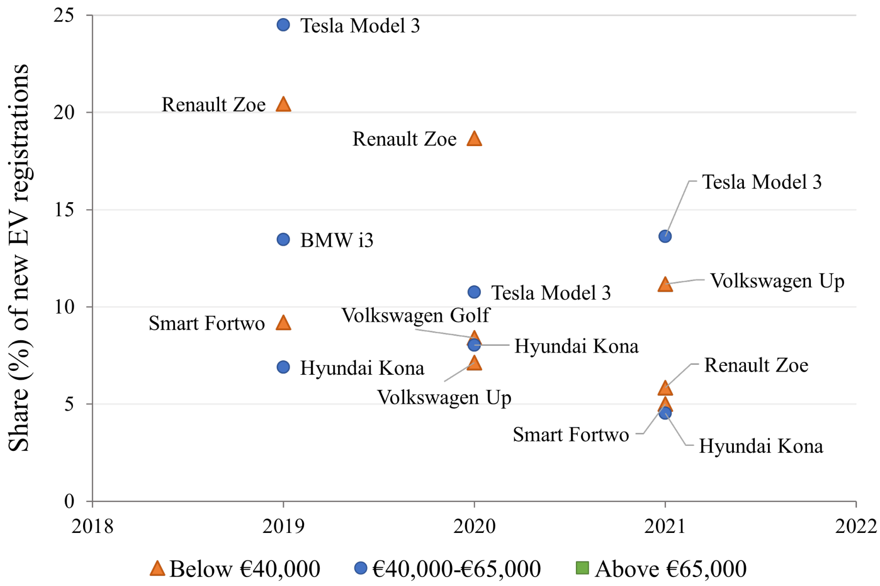
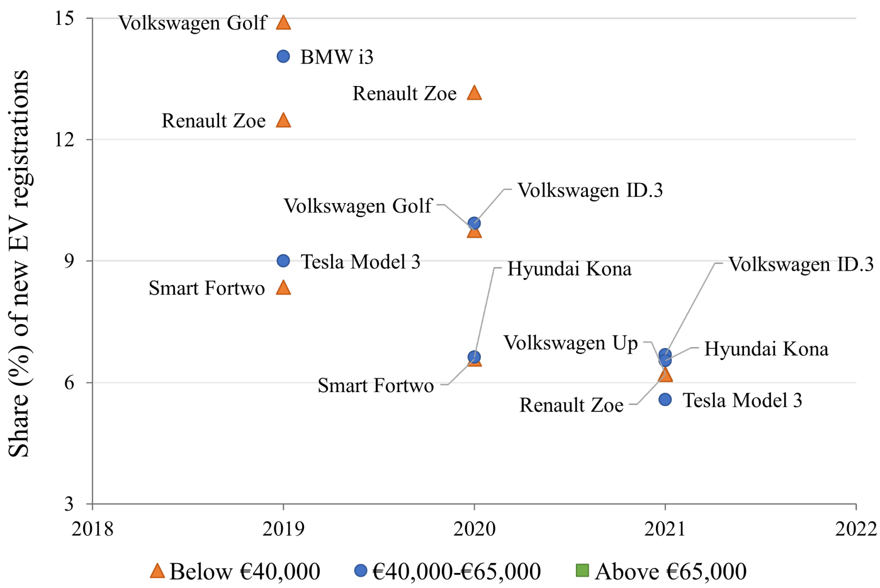
APPENDIX

A Tables & Figures



(a) Private-owned electric cars



(b) Company-owned electric cars

Figure A1: Major EV models in Germany with highest share of registrations