Electrifying company cars? The effects of incentives and tax benefits on electric vehicle sales in 31 European countries

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Original research article

Electrifying company cars? The effects of incentives and tax benefits on electric vehicle sales in 31 European countries

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ABSTRACT

Battery electric vehicles and plug-in hybrid electric vehicles have remarkable potential to reduce CO_2 emissions in road transport. Many governments have introduced incentives to accelerate the market penetration of these vehicles and several studies have shown their effectiveness. Vehicles owned by a company but allowed for private use by employees – so-called company cars – represent a large new car market in Europe. However, little is known about the effect of incentives beyond the early market stages and the effect of company car incentives. Here, we use panel data regression to estimate the effect of purchase incentives on battery and plug-in hybrid electric vehicle sales in 31 European countries from 2010 to 2022. We thus go beyond early market studies and obtain the first empirical estimate of the effect of company car incentives on electric vehicle sales. We find that a €1000 per year recurring incentive for company cars increases sales shares relatively by 50–90 % for plug-in hybrids and by 17–40 % for battery electric vehicles, e.g., from 10 % without incentive to 15–19 % or 12–14 %, respectively. Our results confirm the impact of purchase incentives and demonstrate the importance of company car taxation on electric vehicle sales.

1. Introduction

1.1. Motivation

For the European transport sector to stay within the carbon budget needed to reach the Paris Agreement, internal combustion engine vehicles need to be phased out by 2033 at the latest, even earlier than the 2035 target in Regulation (EU) 2019/631 (cf. [1]). Sales of plug-in electric vehicles (PEVs), including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), are increasing in Europe, reaching 23.4 % of the market in 2023 (EU, EFTA, & UK, cf. [2]). Sales shares vary by country, from more 80 % in Norway to <6 % in countries such as Poland, Slovakia, Cyprus, and the Czech Republic.

Several studies have provided an overview of PEV incentives. Hardman et al. [3] review the effectiveness of purchase incentives for PEVs. They primarily review market analyses and surveys and do not provide a quantitative assessment of the magnitude of the effects. In a later review, Hardman [4] focuses on recurring and indirect incentives. Specifically, parking incentives and high occupancy vehicle (HOV) lanes are found to have a positive impact on sales. National governments have had policies such as purchase incentives in place for over two decades, and differences in scale and approaches partially explain the variation in sales across countries [5].

More generally, Roberson and Helveston [6] survey American auto consumers to understand which type of incentives are most valued. They find that direct rebates are the most valued and effective incentives. Santos and Davies [7] interview experts in five European countries and find that charging infrastructure is considered to have the greatest impact, followed by purchase incentives. Rapson and Muehlegger [8] review the economics of PEVs. They find that in the US, incentives are not cost-effective due to a high proportion of consumers who would have purchased a PEV anyway. They also find that non-monetary attributes such as battery range, model availability, and charging station density are more important. However, they base this mainly on theoretical economic calculations without detailed empirical content.

Several econometric studies have quantified the impact of incentives. Positive effects are found in the US using panel data on model-level sales in US states [9–11]. A few studies also examine the different effects for BEVs and PHEVs, finding larger effects for BEVs than for PHEVs in the US [10,12]. In Canada, on the other hand, Azarafsahar and Vermeulen

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[13] do not find a significant difference in the effect for BEV vs. PHEV. Liu et al. [14] use city level data to assess the effect of incentives in China on sales of buses, commercial and private EVs. For the European market, Münzel et al. [15] study aggregated PEV sales, while Yan [16] studies only BEV sales. While the literature shows that different types of incentives can have different effects on PEV sales (see e.g., [3,4,6]), no analysis quantifies the effect of company car taxation. This is even though company cars play a major role in shaping new car sales in Europe [17], and company car taxation can affect the composition of new car sales [18,19]. There are no studies so far that examine the differential impacts on PHEV and BEV sales in the European market.

Company car incentives are a powerful tool for promoting PEV adoption in Europe due to their dual impact on corporate fleet decisions and the broader vehicle market. Beyond offering individual tax reductions, these incentives accelerate PEV integration into fleets, accelerate market diffusion and expand the pool of used PEVs. This increases affordability and accessibility for private buyers in the second-hand market, amplifying their impact across segments. Understanding this unique role is key to designing policies that maximize these long-term benefits. At the same time, company cars have gained more attention in the academic literature with analyses focusing on their welfare effects (e.g., [20,21]) as well as their environmental and car usage effects [19,22,115]. Company cars are cars that are owned by a company but assigned to an individual who can use them for private purposes as well [22]. Corporate cars now account for more than half of newly sold cars in the European Union [17]. However, only two studies explicitly discuss the role of incentives for company cars [23,116] and only one recent study analyses the impact of purchase incentives on company cars in Germany but without differentiation of company-owned vehicles with or without private usage and only for BEV [117]. Thus, company cars are an important part of the newly sold car-market with significant consequences for the economy and high relevance for PEVs, but existing PEV company car incentives have received little attention in the literature and there is no empirical estimate on the effect of company car benefits on PHEV sales so far.

In summary, empirical studies on the effect of purchase incentives on BEV and PHEV separately are rare for the European market, and company car incentives have received very little attention despite the importance of company cars in new car sales in Europe. The aim of the present paper is to fill these gaps. Here, we use panel data regression of PEV registrations from Europe including country fixed effects and purchase incentives.

Our work goes beyond existing studies in at least three aspects. First, we empirically study the effect of one-time and recurring incentives on BEV and PHEV sales separately. To the best of our knowledge, this has not previously been done for the whole European market. Second, we estimate the effect of company car incentives on BEV and PHEV sales in Europe. Third, we update the existing literature on the empirical effect of PEV purchase incentives in Europe by including more recent data, thus going beyond early market stages.

The outline is as follows. In the remainder of this section, we review the existing econometric studies on PEV purchase incentives and company car taxation. In Section 2, we describe the data for our analysis of European PEV sales, incentives, and the regression model used. Section 3 presents the results of our regressions, Section 4 a discussion of our findings, and we present conclusions and policy implications in Section 5.

1.2. Literature review

1.2.1. PEV incentives

The effects of incentives on PEV sales have been studied for different countries and geographical areas. Jenn et al. [9], Narassimhan and Johnson [10], and Clinton and Steinberg [11] use panel data of model-level sales and registrations in US states. All three studies find a positive effect of monetary incentives on PEV sales. Narassimhan and Johnson [10] find that monetary incentives have a larger effect on BEV sales than PHEV sales. One explanation is the smaller price difference compared to ICEV for PHEVs. Wee et al. [12], investigating state-level subsidies, also find a smaller effect for incentives on PHEVs than BEVs. Azarafsahar and Vermeulen [13] study point of sale incentives in Canadian provinces using monthly registration of BEV and PHEV models. They also find a positive effect with no significant difference between PHEVs and BEV models.

For Europe, Münzel et al. [15] use aggregated registrations of PEV in 32 European countries. They quantify one-time incentives, such as rebates, and recurring incentives, such as circulation tax exemptions. The effect of both types of incentives implies that, on average, an increase of incentives with 1000 Euros leads to a 5–7 % increase in PEV registration shares. Using model-specific sales data for 10 different BEV models in 28 European countries Yan [16] finds a 10 % increase in monetary incentives being associated with a 3 % increase in BEV sales shares.

Besides direct incentives, other factors influence the uptake of PEV, the availability of charging infrastructure being one of the most salient ones. Most studies analysing the effect of incentives thus include charging infrastructure as a control variable. However, there are issues regarding causality since more PEV sales also advance the investments in charging infrastructure. This is thus an example of indirect network effects that have been explicitly modelled by Li et al. [24,25], Zhou and Li [26], and Springel [27] for the US and Norway. All three studies find evidence of positive network effects between both markets. Li et al. [24,25], studying the early market for EVs (2011–2013), find that at this stage, mainly dominated by early adopters, charging station subsidies would have been more effective than vehicle purchase subsidies Springel [27] concludes that both sides should be subsidised. For a more mature market (Norway between 2012 and 2019), Koch et al. [28] find that in most municipalities in 2019, the charging infrastructure development had reached a level that does not justify more heavy subsidies.

Without explicitly modelling the indirect network effects between PEVs and charging stations, Sommer and Vance [29] and Dijk et al. [30] seek to identify the effect of the number of charging stations on electric vehicle sales within a national context and find charging stations to be an important driver of PEV sales. In line with theoretical predictions and empirical results from Meunier and Ponssard [31] as well as Zhou and Li [26], Dijk et al. [30] find that additional charging infrastructure has a larger effect on PEV sales when there is only a small number of charging stations available.

Most studies focus on the effect of PEV incentives or charging station availability while treating other determinants as controls. Austmann and Vigne [32], on the other hand, concentrate on the impact of environmental awareness on electric vehicle registrations in Europe. They extend the dataset created by Münzel et al. [15] with a measure of environmental awareness derived from a Twitter keyword analysis. Within their setting, Austmann and Vigne [32] find environmental awareness to not be a significant driver of the electric vehicle market. Instead, it has a stronger influence on the intention to purchase an electric vehicle as opposed to actual adoption. Bushnell et al. [118] focus on the relative impact of gasoline and electricity prices on the adoption of electric vehicles in California between 2014 and 2017. Using both fixed effects regressions and a regression discontinuity design, they find that gasoline prices have a larger effect on electric vehicle sales than electricity prices. Besides environmental awareness and energy prices, Sierzchula et al. [33], Münzel et al. [15], and Austmann [34] review other factors that the literature on PEV adoption has identified as influencing PEV uptake. These include characteristics of the national automobile sector, such as the existence of a car industry, socioeconomic factors, such as income and education, and additional psychological characteristics.

Lastly, different early studies investigate the determinants of PEV adoption using cross sectional data. These studies include Sierzchula et al. [33], Vergis and Chen [35], Mersky et al. [36], and Wang et al. [37]. However, as Münzel et al. [15] note, these studies are not well suited to evaluate the effect of policies due to unobserved country-specific factors.

To conclude, several studies investigate the effect of monetary incentives and other factors on electric vehicle sales. However, most articles focus on the early years of the PEV market. Newer studies, considering more recent years, focus on individual countries, in particular the US, Norway, and Germany. We therefore aim to contribute to this literature by updating the analysis of a large set of European countries from Münzel et al. [15] up to 2022. In addition to including recent years, we further investigate differences in the effect of monetary incentives regarding European BEV and PHEV registrations. While Münzel et al. [15] investigate aggregated PEV registrations, the studies by Narassimhan and Johnson [10] for the US and Haan et al. [38] for Germany indicate that there may be differences in response to monetary incentives for the two vehicle classes.

1.2.2. Company cars

Corporate cars, i.e., cars registered by a legal entity rather than a private person in the statistics of registered cars, include fleet cars, commercially leased cars, rental fleets, taxis, and company-provided cars. They account for about 57 % of newly sold cars in the European Union [17]. They thus make a large contribution to the fleet composition, and since many of these vehicles usually have a quicker turnover rate than private vehicles, they influence the used car market. There are no official statistics on the breakdown between the different categories of corporate cars.

In this paper, when discussing company cars, we refer to company-provided cars, i.e., cars that are given to an employee and that can be used both for work and private purposes. While employees do not have to pay for the car, they must add a corresponding benefit in kind to their taxable income, resulting in an increased tax burden, so-called fringe benefit tax.

The fringe benefit tax is a fixed percent of the price of the vehicle. In some countries, such as Austria, France, Ireland, and Portugal, the actual purchase cost of the vehicle is used as a base, while in other countries, such as Denmark, the Netherlands, and Sweden, list prices are used instead [18,20]. PEVs are incentivized mainly through a lower price on which the tax is calculated (Dimitropoulos, 2016). In Sweden, e.g., the list price has been the corresponding conventional vehicle until recently while it is now a fixed amount [39]. In Belgium, France, the Netherlands, and the UK, there is a formula that also considers the type-approval CO_2 emissions of the vehicle (Dimitropoulos, 2016). The number of countries that have provided some kind of tax benefit for PEVs in their company car taxation has increased from 5 countries in 2010, 11 in 2016, and 19 in 2022. By lowering the taxable income, the PEV becomes economically more attractive to the employee (Dimitropoulos, 2016).

Previous literature on company cars has studied the welfare effects of company car taxation [18,20,21,40]. These studies find that company cars are often under-taxed and thus represent a direct revenue loss for most countries. Another branch of literature looks at the effect on car ownership and travel behaviour. Most studies find that company cars lead to an increase in travel distance by car [19,41,42] and in car ownership ([21,22]; Dimitropoulos 2016).

The choice of the vehicle is normally up to the employee; however, many companies have policies that restrict the choice set. Restrictions may be based on vehicle cost, brand, or environmental performance (e.g., tail-pipe CO_2 emissions or fuel type). Policies may also differ on how fuel expenses are covered [43]. If the employer partially or totally covers the fuel costs, these can also be taxed, but only a low number of countries ask employees to account for the fuel given to them by the employer for private use. Instead, proxies are used [18]. Copenhagen Economics [18] finds that the fringe-tax benefit design incentivizes larger vehicles with higher CO_2 emissions and thus calls for a better alignment between company car taxation and climate objectives. Similar results are found in Germany [19]. Potter and Atchulo [44,45] study CO_2-based company car taxation in the UK and find that it mainly promoted diesel vehicles. However, after a reform in 2010, PHEVs were presumed to be the dominant vehicle technology. In Sweden, the taxation of company cars was a major driver for alternative-fuelled vehicle sales in new sold cars ([23]; Sprei 2018).

The registration shares of BEVs among all corporate cars (i.e., including fleets, rentals, taxis, etc.) differs between countries but the BEV share is lower in corporate sales than in private sales with 14.1 % compared to 15.6 % in 2023 [46]. For PHEVs, it is the opposite, with 77 % of all newly registered PHEVs being corporate, resulting in 10.3 % of corporate new registrations compared to 4.5 % of private. Countries with a high share of BEV uptake among corporate registrations are Sweden (39 %), Finland (33 %), and the Netherlands (30.9 %) [46].

To conclude, company cars are an important part of newly sold cars with significant consequences for the economy and high relevance for PEVs, but existing PEV company car incentives have received little attention in the literature.

2. Methodology

The aim of the present paper is to study the effect of purchase incentives on BEV and PHEV sales separately for the European market and analyse the impact of company cars incentives on PEV sales in Europe. To formulate this aim more specifically, we restate it in the form of two hypotheses to be tested empirically in the present study:

H1. Monetary incentives affect BEV and PHEV differently.

H2. Monetary incentives for PEV company cars increase PEV sales.

The remainder of this section explains the data and empirical approach used to test and elaborate these hypotheses empirically.

2.1. Data

We build on and extend the dataset of Münzel et al. [15] to cover the years 2011–2022. We cover all countries of the European Union, as well as the UK, Switzerland, Norway, and Iceland. As opposed to Münzel et al. [15], we excluded Turkey from the analysis, as it was not possible to obtain all the necessary data for most recent years. All data sources are listed below, additional details are available in Schub [47].

2.1.1. Dependent variable: BEV and PHEV sales shares

We study the (log of) BEV and PHEV sales shares as dependent variables. We use annual new registration of BEV and PHEV passenger cars from the respective country pages of the European Alternative Fuels Observatory [48] and collect total new passenger car registrations from releases of the European Automobile Manufacturers Association (ACEA) to calculate the share of new BEV and PHEV registrations [49–60]. For Cyprus and Malta, we collected total new registrations from their respective statistical offices. In line with Clinton and Steinberg [11] as well as Münzel et al. [15], we use information on new registrations as opposed to sales because incentives are usually tied to the time and place where a car is registered as opposed to where it is bought.

Fig. 1 displays the registration share of new BEVs (top panels) and PHEVs (bottom panels) clustered by regions. Fig. 2, for comparison, shows BEV (blue) and PHEV (red) sales shares over time for each country in one line plot. Registration shares differ significantly across and within regions. Except for the Baltic States, the largest registration shares are found in the northern countries, followed by countries in Western Europe. In eastern and southern countries, registration shares remained below 10 % over the whole period of study. With only some exceptions, BEV registration shares have increased consistently over the past years. In contrast to the BEV market, PHEV registration shares do not follow an equally steady upward trend. In multiple countries, the registration share of PHEVs has stagnated or declined between 2021 and 2022. A noticeably strong decrease in the registration share of PHEVs

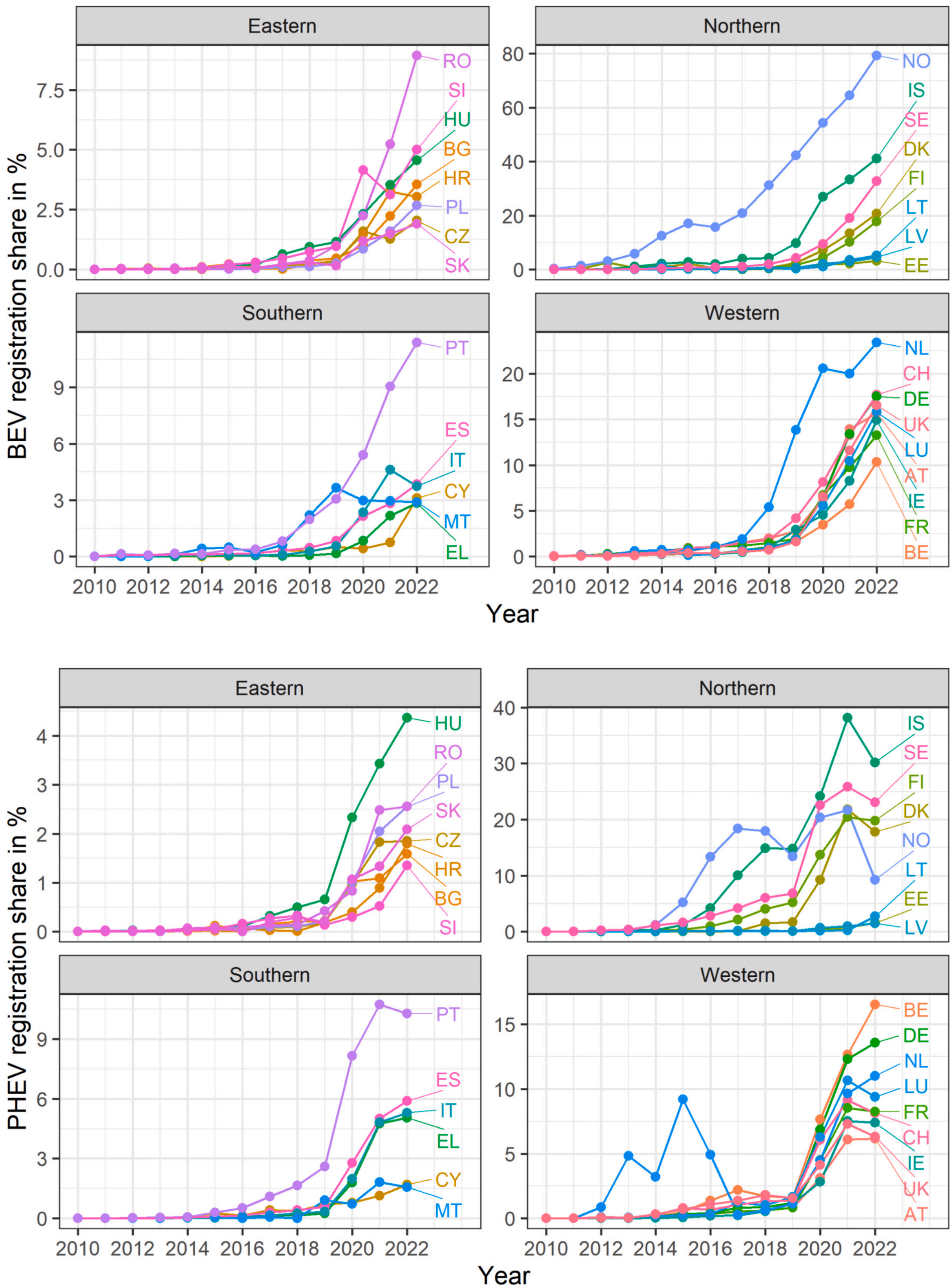

Fig. 1. BEV sales shares (top panel) and PHEVs sales shares (bottom panel) over time per country and by country cluster (Eastern, Northern, Southern, and Western Europe).

can be observed between 2015 and 2017 in the Netherlands after reducing company car incentives, being a strong example of the role of company car incentives in PHEV sales shares. Between 2010 and 2014, there were countries where no new BEVs or PHEVs were registered. In particular, the total number of observations without positive BEV (PHEV) registrations amounts to 33 (62). Therefore, during the earliest years in the sample, not every country had an existing market for PEVs.

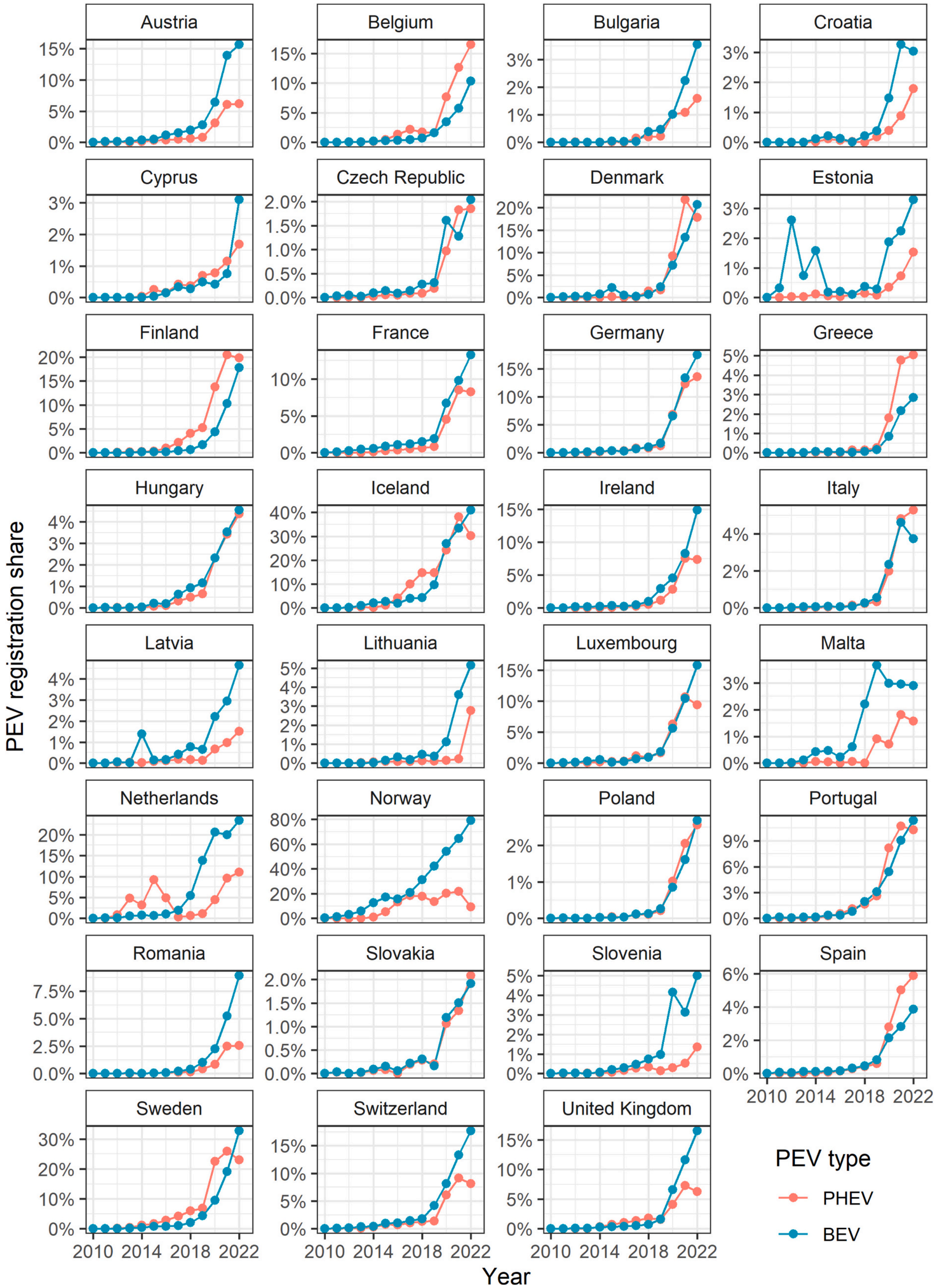

Fig. 2. BEV (blue) and PHEV (red) sales shares over time by country. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.1.2. Incentives

A wide range of incentives has been implemented in European countries to promote the uptake of PEVs. These include monetary incentives, such as rebates and circulation tax reductions, as well as non-monetary incentives, such as access to high-priority or bus lanes. We follow Münzel et al. [15] and classify monetary incentives into one-time incentives and recurring incentives. In addition, we focus on monetary incentives and do not collect information on non-monetary incentives. According to Hardman [4], non-monetary incentives can be important for the decision to purchase a PEV. However, as Münzel et al. [15] note, there is no comprehensive source of non-monetary incentives, and their importance is likely to vary on a regional as opposed to a national level. For example, access to high-priority or bus lanes would be more important for people living in urban areas. Furthermore, due to a lack of consistent sources, we did not collect information on subsidies for private charging equipment.

We gather information on monetary incentives from different sources (all sources are summarised in the appendix). Car taxes and incentives for PEVs are taken from tax guides and PEV incentive overviews published by ACEA (covering all 31 countries considered). In cases where the information is unclear, incomplete, or outdated, we complement the sources from ACEA with comparable tax guides published by PricewaterhouseCoopers (PwC), governmental sources, newspaper articles, and a database on historical taxes maintained by the European Commission [61].

As described by Münzel et al. [15], monetary incentives can be clustered into one-time and recurring incentives (see [3,4]). A one-time incentive refers to a financial benefit that a buyer enjoys only once, either directly upon purchase or after. Popular one-time incentives include rebates and registration tax reductions. Recurring monetary incentives, on the other hand, represent savings that a buyer benefits from several years after purchase. Recurring incentives include circulation tax reductions and reduced rates for the private use of company cars. In addition to recurrence, monetary incentives often vary between private and corporate buyers. For example, reduced company car taxes are only available for corporate cars. Rebates, on the other hand, can be available for both groups but may vary in size.

2.1.2.1. One-time incentives. One-time incentives include rebates, point of sales tax reductions, and VAT exemptions. Rebates are direct discounts that are granted upon or shortly after purchase. Various countries, including Germany, tie the size of the rebate to the car's purchase price. Rebates can also depend on other vehicle attributes. Different countries, such as the UK, condition PHEV rebates to the electric driving range. We focus on rebates granted to private and corporate buyers and do not include rebates for public bodies that were implemented in the Czech Republic and Bulgaria. In Austria and Germany, government rebates have been paid conditional on the manufacturer (or importer in the case of Austria) also giving the buyer a specified discount. It is possible that manufacturers or importers sacrifice discounts otherwise granted in response to their share of the official rebate (see [38]). Consequently, we only consider the component of the rebate granted by the federal government. Governments often define budgets for their rebate programs, and sometimes, these budgets are exhausted after some time. Croatia is an example of high rebates, but according to electrive.net [119], the budget was quickly used up. However, as the number of supported PEVs in Croatia was large relative to average PEV registrations in other years, we include the full subsidy value. Still, the possibility of limited rebate budgets should be kept in mind when interpreting the results below. Limited rebate budgets could lead to an underestimation of the unconstrained effect of monetary incentives. In some support programs, scrapping an old car increases the rebate. As Münzel et al. [15], we do not have information on the share of people handing in old cars. Thus, we do not include additional subsidies that are tied to the scrappage of an old car except for Romania. Romania is a special case as it has offered high rebates for PEVs only when scrapping an old car. While in 2012, rebates for BEVs amounted to 5000 Euro, they increased to 10,000 Euro in 2018. As Transport and Environment [62] note, Romania has a large fleet of old cars, and it is thus likely that most prospective buyers have had access to an old car. The rebate for Romania is therefore included. Over time, the number of countries providing rebates for BEVs or PHEVs has increased from four countries in 2010 to 11 countries in 2016 and 24 countries in 2022.

Points of sale (POS) taxes refer to taxes due upon purchase. Within this sample, POS taxes mostly comprise registration taxes. Additional POS taxes on expensive or imported goods with special treatment for PEVs have been implemented in Greece, Hungary, Norway, and Switzerland. In various countries, POS taxes are calculated based on vehicle attributes such as fuel consumption or emissions, which incentivize the purchase of cleaner cars. In other cases, incentives for PEVs emerge from direct exemptions. Out of the total number of 31 countries, 22 provided incentives for PEVs through POS taxes in 2022.

Value-added tax (VAT) exemptions have been offered only by a handful of countries. In Norway and Iceland, PEVs have been subject to reduced VAT rates for both private and corporate buyers. Austria, Portugal, and Slovenia, on the other hand, have introduced incentives for PEVs by giving companies the right to claim back VAT paid on BEVs or PHEVs but not for ICEVs.

2.1.2.2. Recurring incentives. Private income tax reductions have only been implemented in Belgium, Portugal, and Luxembourg for a limited number of years. Companies across Europe, on the other hand, can reduce their tax burden by deducting expenses related to the purchase of cars from their taxable profits. We document two types of depreciation incentives for PEVs, which we separate into one-time and recurring depreciation benefits. The UK and Austria allow companies to depreciate PEVs at a faster pace (the UK allows for a 100 % first-year depreciation, and Austria for degressive depreciation at a rate of 30 %). In addition, Luxembourg and the Netherlands have introduced special depreciation allowances in the year of purchase for PEVs in 2018 and 2020, respectively. These incentives represent immediate tax savings in the year of purchase and are thus one-time savings. In some countries, including Austria, the amount companies can write off from their profits depends on the proportion of corporate and private use. As we also quantify incentives related to the private use of company cars, we assume that company cars are used both privately and for business at an equal share of about 50 %.

2.1.2.3. Company car incentives. When employees are allowed to use company cars privately, they must add a corresponding benefit in kind to their taxable income, resulting in an increased tax burden. To quantify incentives from reduced company car taxes for PEVs, it is necessary to translate the size of the taxable benefit in-kind into its effect on the net wage. For this purpose, we update the marginal income tax rates used in Münzel et al. [15] based on updated reports on wage taxation from the OECD [63–66]. Following Münzel et al. [15], employees using company cars are likely to be above-average earners, and we use marginal tax rates for a single earner with a wage of 167 % of the average wage. The obtained marginal tax rates include employee contribution for social security and exclude cash benefits.

We calculate the monetary value of tax-based incentives for BEV and PHEV separately for the most common BEV model in Europe for the specific years (Nissan Leaf until 2018, Tesla Model 3 from 2019 for BEV, as well as Mitsubishi Outlander until 2020, and the Ford Kuga PHEV from 2021 for PHEV). As a sensitivity, we also include regression models with constant reference models for all years. Price and technical details for these models were taken from [67–77].

2.1.3. Additional control variables

We obtain data on public charging points from the country pages of the EAFO portal. EAFO [78] defines a charging point as an individual interface capable of charging one electric vehicle at a time. In line with previous research and official definitions [15,29,79], we specify normal charging points as those with a charging power up to 22 kW and fast charging points as those with a power output above 22 kW. If data on charging points for earlier years is missing on EAFO [78], we use ACEA reports from previous years that rely on earlier EAFO data as a secondary data source. For Sweden, the EAFO data on fast charging points appears unreliable, so we used Elbilstatistik [80] instead. As fast charging is relevant to long-distance travel, we follow Austmann and Vigne [32] in measuring the density of fast chargers as the number of fast charging points per 100 km highway. Slow chargers are measured as slow charging points per 1000 inhabitants.

Energy prices are also relevant in vehicle purchase decisions. As gasoline and diesel prices are highly correlated, we follow Münzel et al. [15] in only using electricity and diesel prices. We obtain electricity prices for medium-sized households with an annual consumption in the range of 2500–5000 kWh from Eurostat [81]. For Switzerland, average electricity prices for medium-sized households are calculated using data from Switzerland's electricity commission. In line with Münzel et al. [15], we use the ratio between electricity and diesel prices to reduce the number of regression variables. The ratio of electricity and diesel prices represents a measure of the relative attractiveness of operating an electric vehicle over a combustion engine vehicle.

We include total household consumption expenditure per capita as a measure of the economic condition of a country in a particular year. We also include information on the share of people living in detached or semi-detached houses as they have easier access to home charging. Lastly, information on the motorisation rate as measured by the ratio between car stock and the population is included. These further controls are taken from [61,81–92].

All prices have been corrected for country-specific inflation rates and converted to 2022 Euros.

2.2. Econometric approach

In our sample, almost all countries implemented incentives and changed the size of incentives over time. We use this variation to estimate the average effect of monetary one-time and recurring incentives on the registration share of BEVs and PHEVs. Our baseline model follows the approach of Münzel et al. [15] and reads:

$$\begin{aligned}\log(\text{PEV sales shares})_{it} = {} & \beta_1 \text{ One}-\text{time incentive}_{it} \\ & + \beta_2 \text{ Recurring incentive}_{it} + \beta_3 \text{ Trend}_t \\ & + \beta \text{ Controls}_{it} + \alpha_i + \varepsilon_{it}\end{aligned}$$

The natural logarithm of PEV sales shares is used as the dependent variable, i denotes the country and t the year. The panel is not balanced as we take the log of the dependent variable, and sales shares were zero in the early years in some countries. Incentives are monetary national-level incentives measured in thousands of Euros. The coefficients of interest, β_1 and β_2, represent the effects of additional one-time and recurring incentives. In particular, the coefficient of one-time incentives, β_1, should be interpreted as the average $100 * \beta_1\%$ increase in the registration share in response to increasing one-time incentives by 1000 Euro. The coefficient of recurring incentives, on the other hand, gives the average $100 * \beta_2$ percent increase in response to an increase in recurring incentives of 1000 Euro/year. We do not sum recurring incentives over an average holding period as this would require an additional assumption about the holding time, introducing uncertainty into the measurements. Instead, we include the recurring incentive value only in one year. An assumption about the holding time would be required if one wanted to make one-time and recurring incentives comparable in absolute Euros received. Yet, the results below indicate that several years of holding time can be expected on average as the coefficients for 1000 € one-time incentive are about four to five times larger than those for 1000 € per year (as, e.g., 200 € per year over five years amount to 1000 € in total).

We include country fixed-effects α_i to capture time-invariant differences between countries, for example, regarding culture or the existence of a car industry (see [15]). $Controls_{it}$ contains time-varying controls. Furthermore, we add a linear time trend $Trend_t$. The time trend captures time-varying drivers of the PEV market common to all countries in the sample. In particular, the time trend captures the increase in available PEV models and corresponding changes in attributes such as driving range (see [15]). In addition, the time trend may capture additional supply-side policies affecting PEV registrations in all countries and EU-wide fuel economy standards (see [38,93]). As discussed by Haan et al. [38], EU fuel economy standards tightened in 2020 leading carmakers to sell more cars with lower emissions. Lastly, the time trend may capture common macroeconomic factors across countries. For the baseline specification, we choose a time trend over year dummies as we use highly aggregated data and have thus only a limited sample size to estimate all parameters.

In line with Münzel et al. [15], we additionally estimate the model by further splitting up incentives by type, leading to the following alternative specification:

$$\begin{aligned}\log(\text{PEV sales shares})_{it} = {} & \beta_1 \text{ Rebate}_{it} + \beta_2 \text{ POS tax}_{it} + \beta_3 \text{ VAT reduction}_{it} \\ & + \beta_4 \text{ income tax}_{it} + \beta_5 \text{ Compay car tax}_{it} \\ & + \beta_6 \text{ other recurring incentives}_{it} + \beta_7 \text{ Trend}_t \\ & + \beta \text{ Controls}_{it} + \alpha_i + \varepsilon_{it}\end{aligned}$$

Using this alternative specification, we learn about the effects of individual incentive types. However, incentives across categories may be correlated and variation within each category only comes from a limited number of countries.

We used the plm package [94] in the statistical software R (R core team 2023) to estimate all models. The data and code are available upon request.

3. Results

The present section contains the results on the effect of purchase incentives on PEV sales shares. Section 3.1 describes our results on BEV sales, Section 3.2 on PHEV sales, followed by a more detailed analysis of company car incentives in Section 3.3, and we conclude with a discussion in Section 3.4.

Table 1
Regression results for log of BEV sales shares.

Model	(1)	(2)	(3)	(4)
One-time incentive	0.077**	0.073**	0.072**	0.073**
(in 1000 Euro)	(0.031)	(0.029)	(0.029)	(0.029)
Recurring incentive		0.142**	0.142*	0.142*
(in 1000 Euro/year)		(0.070)	(0.077)	(0.078)
lagged log of fast chargers			0.026	0.025
per 100 km highway			(0.054)	(0.056)
lagged log of slow chargers			−0.014	−0.015
per capita			(0.031)	(0.031)
log (electricity/diesel price)				0.064
				(0.326)
Trend	0.433***	0.415***	0.408***	0.408***
	(0.031)	(0.034)	(0.061)	(0.063)
Country fixed effects	✔	✔	✔	✔
Observations	356	356	356	356
No. of countries	31	31	31	31
Adjusted R^2	0.857	0.862	0.861	0.861
F Statistic	1081.2***	747.7***	446.7***	371.2***

Notes: Dependent variable log(BEV registration share). Clustered SEs in parenthesis.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

3.1. Effect of incentives on BEV sales shares

We performed panel data regression with the quantified incentives to estimate their effect on BEV sale shares. Table 1 displays our primary regression results for the (log of) BEV sales shares as the dependent variable. Columns (1) to (4) contain results for aggregated financial incentives with an increasing number of control variables in the different models. All F-statistics of our models are significant. The goodness of fit measures reveal a remarkably high explanatory value of FE estimation of our model (adjusted $R^2 > 0.85$, F-statistic > 350).

The impact of monetary incentives is of particular interest: The estimated relative effect of a 1000 Euro increase in one-time incentives on the registration share of BEVs is 7.2–7.8 % across model specifications (significantly different from zero at 5 % level, 95 % confidence interval 1.4–13.9 %). The coefficients on recurring incentives are approx. twice as large as those for one-time incentives. Please note that recurring incentives are given in the value for the first year. To make them comparable in absolute Euros received, an assumption about the holding time must be made. This also explains the difference between the coefficients, e.g., 250 € per year over four years amounts to 1000 € in total.

Regarding the included control variables, we find estimated impacts of charging points and energy prices close to zero. As the number of charging points increases over time in most countries, it is likely that the time trend already captures the development of the nationally aggregated charging infrastructure. In addition, lagging the number of charging points by one year reduces the correlation between BEV registrations and charging points, which has an additional dampening effect on the estimates. Due to the long-time frame of one year, the lagged charging points may be underestimated compared to current charging points.

3.2. Effect of incentives on PHEV sales shares

We analyse the effect of one-time and recurring incentives on PHEV sales shares in Table 2. All F-statistics of our models are significant. The goodness of fit measures reveal a remarkably high explanatory value of our model (adjusted $R^2 > 0.75$, F-statistic > 250).

Compared to the BEV results, the regression for the PHEV sales shares indicates a smaller effect of one-time incentives on registrations. The estimated change of sales shares in response to an increase in one-time incentives of 1000 Euro ranges from 0 to 3 %. In all specifications, we obtain standard errors of the estimated effect of one-time incentives exceeding the respective point estimate, leading to statistically insignificant estimates. The estimated increase in the registration share in response to an increase in recurring incentives by 1000 Euro per year, on the other hand, lies in the range of 53–56 % in the constant (changing) reference model case (significantly different from zero at 1 % level, 95 % confidence interval 15–95 %). Again, these estimates come with large standard errors of around 0.2 but are statistically significant at the 1 percent level. These findings are stable against the choice of constant or changing reference vehicle.

Overall, the results indicate that the recurring incentives matter more for PHEVs than BEVs. This could have different reasons. First, PHEV are particularly important as company cars in several European markets with several markets providing recurring incentives especially for company cars. In addition, PHEVs could be perceived as more suitable by company car users since company cars show higher average annual mileage and more frequent long-distance trips than privately owned vehicles. These driving patterns were easier to perform with a PHEV than a limited range BEV that was common during a large part of the years under consideration here (2010–2022). Second, BEVs had higher purchase prices than PHEVs for a long time, which could also contribute to a higher importance of one-time incentives upon purchase for BEVs than for PHEVs.

Contrary to the observation that most PHEVs cannot charge at fast charging stations (see, for example, Fastned [120]), the results show a statistically significant relationship between PHEV registrations and fast charging points. One explanation could be that PHEV attract more anxious consumers who also value charging infrastructure more [95]. In addition, the ratio of electricity to diesel prices is positively correlated with the PHEV registration share where a smaller correlation could have been expected given that PHEV can use both electricity and fossil fuels.

Table 2
Regression results for log of PHEV sales shares.

Model	(1)	(2)	(3)	(4)
One-time incentive	0.003	0.019	0.022*	0.023
(in 1000 Euro)	(0.030)	(0.030)	(0.033)	(0.034)
Recurring incentive		0.554***	0.567***	0.536***
(in 1000 Euro/year)		(0.203)	(0.198)	(0.189)
lagged log of fast chargers			0.169**	0.158*
per 100 km highway			(0.085)	(0.087)
lagged log of slow chargers			0.013	−0.005
per capita			(0.068)	(0.068)
log (electricity/diesel price)				0.759***
				(0.263)
Trend	0.592***	0.554***	0.439***	0.450***
	(0.024)	(0.026)	(0.053)	(0.055)
Country fixed effects	✔	✔	✔	✔
Observations	341	341	341	341
No. of countries	31	31	31	31
Adjusted R^2	0.789	0.807	0.814	0.816
F Statistic	652.7***	483.6***	304.5***	258.0***

Notes: Dependent variable log(PHEV registration share). Clustered SEs in parenthesis.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

3.3. Effect of recurring incentives and company car taxation

The different financial incentives can be further split up by type to provide additional insights into the impact of distinct incentive types on both BEV and PHEV (see Table 3). In Table 3, we include one-time incentives (Rebate, POS tax, and VAT reduction) in higher resolution than in Tables 1 and 2, as well as recurring incentives (income tax, circulation tax and depreciation, company car tax). In particular, the tax incentives for company cars could be a relevant lever for BEV and PHEV. To obtain robust findings, we include four models for each BEV and PHEV: (1) with a changing reference model as in the previous sections, (2) with additional controls for charging infrastructure and energy prices, (3) with constant reference model for comparison, and (4) without some influential countries that have seen large changes in incentives throughout the observation period (France, Greece, Denmark, the Netherlands) which also resulted in large sales share changes. For example, the Netherlands had strong purchase incentives for PHEV, including company car incentives, from 2010 to 2016 but completely abolished the PHEV company car incentives from 2017 onwards, which led to drastic changes in PEV and PHEV sales shares in the Netherlands. More specifically, we first estimated the model with all countries and then calculated the difference between the original coefficient estimates and the estimates when leaving out a particular country and secondly, we calculated the leverage and squared normalized residuals of each observation for the within-transformed model. These model variants have been estimated with log of BEV sales share (models 1–4) and log of PHEV sales shares (models 5–8) as dependent variables.

For BEVs, we observe statistically significant effects of rebates and company car taxation on BEV sales shares in all model specifications. The effect of rebates on BEV sales shares ranges from 13 to 15 % relative sale shares increase per 1000 Euro per year (significantly different from zero at 1 % level, 95 % confidence interval 7–20 %). For PHEV, the most interesting individually significant incentive that is highly significant across all model specifications is the company car tax reduction. We

Table 3
Regression results for recurring incentive on log of BEV and PHEV sales shares.

Model	BEV sales shares				PHEV sales shares			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rebate	0.144***	0.143***	0.148***	0.135***	0.027	0.029	0.030	−0.007
(in 1000 Euro)	(0.030)	(0.028)	(0.032)	(0.034)	(0.033)	(0.034)	(0.033)	(0.031)
POS tax	0.023	0.020	0.075*	−0.008	0.059*	0.066	0.068*	0.040
(in 1000 Euro)	(0.020)	(0.021)	(0.045)	(0.040)	(0.036)	(0.044)	(0.038)	(0.037)
VAT reduction	−0.077*	−0.080*	−0.082	−0.080	0.028	0.022	0.027	0.091*
(in 1000 Euro)	(0.047)	(0.048)	(0.052)	(0.050)	(0.053)	(0.047)	(0.055)	(0.042)
Income tax	−0.005	−0.010	−0.024	0.010	0.209	0.145	0.229	0.205
(in 1000 Euro/year)	(0.032)	(0.032)	(0.029)	(0.031)	(0.428)	(0.353)	(0.430)	(0.372)
Circulation tax and depreciation	0.181	0.176	−0.002	0.773***	−0.244*	−0.202	−0.293**	−0.246
(in 1000 Euro/year)	(0.366)	(0.366)	(0.366)	(0.246)	(0.133)	(0.126)	(0.147)	(0.296)
Company Car tax	0.227***	0.220***	0.398***	0.169***	0.881***	0.849***	0.859***	0.514***
(in 1000 Euro/year)	(0.059)	(0.064)	(0.111)	(0.064)	(0.245)	(0.230)	(0.246)	(0.197)
Trend	0.413***	0.426***	0.429***	0.419***	0.554***	0.450***	0.551***	0.563***
	(0.028)	(0.046)	(0.024)	(0.031)	(0.025)	(0.052)	(0.025)	(0.026)
Country fixed effects	✔	✔	✔	✔	✔	✔	✔	✔
Additional controls		✔				✔		
Constant reference model			✔				✔	
Without influential countries				✔				✔
Observations	356	356	356	309	341	341	341	296
No. of countries	31	31	31	27	31	31	31	27
Adjusted R^2	0.880	0.879	0.876	0.882	0.816	0.824	0.816	0.821
F Statistic	375.9***	262.4***	364.4***	332.9***	220.5***	163.2***	202.2***	198.1***

Notes: Dependent variable log(PEV sales share). Influential countries: France, Greece, Denmark, Netherlands. Clustered SEs in parenthesis.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

observe an effect on PHEV sales of 51–88 % relative sales share increase per 1000 Euro per year (significantly different from zero at 1 % level, 95 % confidence interval 30–137 %). Likewise, but with a smaller effect size, a 1000 € per year tax incentive for company cars increases BEV sales shares relatively by 17–40 % (significantly different from zero at 1 % level, 95 % confidence interval 4–62 %). These effects appear much higher than for one-time incentives but as the recurring incentives are measured on an annual basis and the typical vehicle holding times for first holders range between a few years for company cars to several years for private vehicles, these numbers should be higher as the monetary advantage adds up over several years. Please note that the company car benefit value is zero in countries that do not have this benefit (and likewise in all models for other incentives). Furthermore, the effect of company car incentives on company cars alone is likely higher than shown, as the dependent variable contains both private and company cars. Accordingly, the coefficients show the average impact across all PHEVs, although the impact for company cars alone would be higher and is zero for non-company cars.

The signs for circulation tax and depreciation incentives, as well as VAT, are unexpected for some models shown in Table 3. As only four countries have offered special depreciation allowances, the first is mainly an effect of the circulation tax reduction incentives (removing the four countries with special depreciation does not alter the coefficient sign). Concerning VAT, only two countries (Iceland and Norway) have VAT reductions as incentives and have further strong incentives in place. Thus, the non-zero values for VAT incentives might be not sufficiently identified. Altogether, as the sign is unexpected only for some models and only significantly different from zero for some models, this does not generally alter the robustness of the findings for rebates for BEV and company car tax reductions for PHEV, but further data and research are needed to better understand the effect of depreciation allowances and VAT reductions in combination with other incentives.

The large effect of reduced company car taxation is particularly relevant to the present analysis. To the best of the authors' knowledge, this is the first empirical analysis of the effect of tax reduction for company cars on BEV and PHEV sales in the empirical literature. Despite the uncertainty from different model specifications, we observe a strong, robust, and statistically significant large positive effect of reduced company car taxes for PHEV and BEV in Europe on their sales shares.

3.4. Robustness checks

We perform additional tests on the regression models to make sure the results are reliable and robust.

First, our sample contains many heterogeneous countries that have implemented a wide range of incentive schemes for PEVs. Our estimates might thus be sensitive to the exclusion of individual countries. As we estimate the effects of incentives, a strong influence on individual countries is not necessarily problematic. However, to evaluate the robustness of our findings, we still consider it informative to investigate whether individual countries drive the results. Also, outliers or influential observations may guide toward wrongly measured incentives. We identify countries with a strong influence on the regression outcomes by directly testing which individual observations have the largest influence on coefficient estimates when left out of the regression (using the 'influence' function in R). Second, we identify potentially influential countries by calculating leverage and squared normalized residuals of each observation for the within-transformed model [121,122,123]. However, excluding influential countries did not alter the main results.

Second, we perform additional robustness checks by (1) replacing time trends with year dummies and (2) by applying first-differencing as opposed to the within transformation. Both approaches eliminate country fixed effects but use different sources of variation (see [96]). In particular, the within estimator uses the deviation of a variable from the country average. The first-differencing estimator, on the other hand, uses variation between two adjacent time periods [47].

The point estimates of the effect of monetary incentives on the BEV registration share exhibit minimal variation when switching to year dummies instead of a time trend, and the changes of the coefficient estimates are within the one standard error around the estimates. Likewise, using first differencing alters the coefficient estimates only with one standard error of the estimate. Furthermore, all coefficients of interest stay significantly different from zero under these variations. Thus, the linear time trend appears to accurately capture the dynamics in the market, and the results are stable. However, one additional test revealed differences in the standard errors of the coefficients of interest observed between estimates obtained using the within and first-differencing transformation. In the constant reference model case, the standard errors decrease nearly by half compared to the results obtained from applying the within transformation. Following Wooldridge [96], the increased efficiency of the first-differencing estimates may be due to the serial correlation of the error terms. The point estimates, however, are stable against this additional check.

Similar tests are carried out for PHEV. Across specifications, the estimated effect of one-time incentives remains within the range of 1–4 % across specifications, and the estimated effect of recurring incentives stays within the range of 30–50 %. The estimated effects of monetary incentives exhibit slight variations between specifications with a linear time trend and year dummies. However, notable variation is observed when estimating the model using first-differencing. The estimated effect of recurring incentives declines in the full sample but stays within the reported range. This may indicate issues arising from the inclusion of influential countries, which justifies the previously reported estimates without influential countries.

4. Discussion

The results of this study are robust, reliable, and consistent with previous research. Furthermore, they are transferable to other data sets, i.e., different countries, times, and spatial or temporal scales. Overall transferability is ensured by fixed effects and a trend variable. However, our results are subject to several uncertainties discussed in the following.

The aggregation of sales data at the national level ignores variations at the city or regional level. In many cases, several major cities have introduced additional incentives for PEV users, which are not included here and may underestimate the true level of incentives. This may bias our results. However, consistent data sets on both sales and incentives are difficult to obtain at levels below the national level. Analysis at the local and regional levels is thus rather qualitative and not quantitative (cf. [97]).

Our results estimate the effect as an increase of BEV registration shares by 8–14 % per €1000 one-time incentives and by 10–20 % per €1000 per year for recurring incentives. The estimated average increase in the registration share of PHEVs in response is 1–5 % to one-time incentives of €1000 and 30–65 % for €1000 per year for recurring incentives. In comparison, [98] report an effect of 8 % sales shares increase per €1000 for private BEVs and 2.3 % for company owned BEV. Yan [16] reports a 3 % increase in BEV sales shares for a 10 % increase in incentives. As the mean incentive in this study is about €4000, this translates to about 7.5 % sales share increase for BEV per €1000 incentive and thus slightly higher than in our sample. Münzel et al. [15] found the introduction of €1000 to increase the registration share of PEVs by approximately 5–7 % for one-time incentives and around 30 % for recurring incentives. Accordingly, the estimated effects on aggregated PEV registrations in Münzel et al. [15] fall between our estimates for BEV and PHEV and are consistent with our results. The observed reduction in the impact of one-time incentives for PHEVs is consistent with the findings of Wee et al. [12] and Narassimhan and Johnson [10] for the initial stages of the US market. As the latter authors observe, this may be attributable to the lesser price differential between PHEVs and comparable conventional vehicles in comparison to BEVs. The smaller price differences between PHEVs and comparable conventional vehicles may result in greater sales of PHEVs in the absence of subsidies. Furthermore, our results indicate that recurring tax savings, particularly reductions in taxes for the private use of company cars, provide significant incentives for PHEV registrations. This aligns with Dimitropoulos et al. [99] as well as Burra et al. [98], who emphasise the importance of employer-provided company cars for the adoption of PEVs and new car models in the European market.

In summary, the comparison between our estimates and other existing studies is not always straightforward, as only some studies differentiate between BEV and PHEV as well as different types of incentives. Our results fall into existing ranges of incentive effects for PEV in the literature. Still the effect on only PHEV and on company cars has received little attention so far, such that our results are consistent with previous studies where comparable and add new findings on PHEVs and company cars.

Specifically, our results demonstrate that company car incentives lead to a significant increase in PEV sales shares, in particular for PHEV. We are therefore partially confirming Hypothesis H2 “Monetary incentives for PEV company cars increase PEV sales.” Our analysis cannot differentiate between the impact of one-time incentives on private and company cars as both buyer groups are merged in the dependent variables BEV and PHEV sales shares. However, the fringe-tax benefit is an incentive only applicable to company cars and is significantly different from zero for BEV and PHEV sales shares in all regression models. This indicates that specific incentives for company cars impact PEV sales and thus confirms H2. However, future research should apply similar methods to separate samples for private, fleet, and company car buyers to better understand the impact of the same incentives on the different buyer groups.

The dual decision-making process in the company car segment, involving both the individual user and the company’s policies, has implications for interpreting our results. Purchase incentives, such as reduced benefit-in-kind taxation or upfront subsidies, may have differing effects depending on whether they align more with user preferences or company priorities. For instance, while lower benefit-in-kind taxation directly reduces costs for users and may drive higher adoption rates, upfront subsidies might primarily influence company decisions by lowering fleet acquisition costs. Similarly, lower depreciation rates are interesting for the company to encourage PEV choice among their employees but are of no direct value to the users. This dynamic and interplay suggests that the observed impact of incentives on PEV market shares could vary depending on how strongly these incentives resonate with the priorities of each stakeholder. Therefore, the results may reflect not only the effectiveness of specific policy measures but also their ability to balance the interests of both users and companies in the decision-making process.

The dependent variables are the natural logarithm of the annual national registration shares of new BEV and PHEV. We chose registration shares over sales shares as purchase incentives are usually based on registration rather than sales location [124]. Furthermore, shares are chosen over total registrations because the current focus is on the evolution of PEV shares of total new vehicle registrations. Due to significant differences in PEV markets across countries, total numbers would have obscured this effect [15,36]. Finally, the logarithmic form is strongly recommended in the econometric literature when the dependent variable is a percentage, as it is useful to ensure the normality of the residuals [15,116,125,126].

The value of the incentives will depend on the choice of reference vehicle, their specifications, and prices. The direct incentive the individual consumer will receive will depend on the vehicle purchase and thus will deviate from the amount calculated here. The actual impact on the bias of consumer preference is hard to capture since the counterfactual, i.e., what vehicle would the consumer have chosen instead of a PEV, is hard to establish. We base our selection of vehicles on market share, which has changed over the observed period. We have thus performed our estimations with both the same model and a change of model to reflect the change in market shares. Our findings are robust for these changes.

Incentives are given equal weight, regardless of the recipient (private, corporate, or all customers), even if the incentive structures differ for these groups. In some countries, company-provided vehicles make up a significant portion of new car sales. Therefore, incentives for the other groups may be overestimated in markets where one group of consumers dominates. The impact of this will vary depending on the structure of the incentives and the distribution of sales between the different groups, making it difficult to establish an overall effect. Thus, specific results on company cars incentives are transferable to countries with noteworthy sales shares of company cars whereas results on one-time incentives for BEV purchase should be transferable to countries with similar market and incentive logic. For example, Norway and Denmark have high VAT for combustion engine vehicles and the strong VAT reduction in these countries showed significant impact. It can be expected that other global markets with exemptions on purchase taxes for BEV outside of Europe should also see a similar impact.

Methodologically, three potential sources of bias remain beyond the assumptions and robustness checks. Firstly, policy selection may be endogenous, as noted by Gallagher and Muehlegger [100]. This means that a country may choose benefits that are considered most effective in promoting PEV market penetration, given their policy setting. For example, Denmark and Norway have high registration taxes, so reducing or exempting these for PEVs results in a significant incentive. The effectiveness of certain incentive types may be overestimated if incentives are chosen endogenously. Secondly, the incentive values are calculated based on the assumption that all customers behave rationally and claim available incentives and that dealers pass on the entire incentive value to customers (Clinton and Steinberg 2016). Even this simplification may overestimate the effect of the incentives. However, Sallee's [101] investigation of the HEV market found evidence that the full incentive value was passed on, and the same would be expected here (Clinton and Steinberg 2016). Thirdly, if the incentive is in the form of a tax credit it must exceed the buyer's personal income tax liability. Purchasers of new PEV often have a higher income [102,103], we thus assume that the average PEV buyer (or employee offered a company car) earns above average and that partial eligibility should not be a problem in our sample.

The regression models presented do not allow for the influence of past registration shares on future registration shares. Narassimhan and Johnson [10] and Jenn et al. [9] extend fixed effects regression models comparable to ours with a lagged dependent variable. In both references, the authors motivate the use of a dynamic model, citing two key reasons: firstly, that past buyers may influence the purchase decisions of future buyers, and secondly, that the lagged registration share could capture natural technology growth. The estimated effect of monetary incentives is found to be smaller in their dynamic specifications. In this analysis, it is assumed that the common time trend or year dummies accurately capture the dynamics of the market. From a technical standpoint, the presence of serial correlation in the error terms may be indicative of the potential for country-specific dynamic effects. Conversely, the two cases of Estonia abolishing BEV rebates and the Netherlands reducing PHEV company car incentives cast doubt on the assumption of the natural growth of PEVs. Following the removal of incentives, registrations in both countries declined significantly. Furthermore, dynamic panel data models violate the strict exogeneity assumption, necessitating estimation using internal instruments [96]. Given the limited number of observations in our sample, estimating a dynamic model may be infeasible.

Furthermore, additional tests on how PEV types interact with incentives to further demonstrate that the effect of incentives varies significantly across PEV types would be useful. This would further establish differences in the reaction of different PEV buyers to different incentive types. However, as we have already performed many additional regression models and find the individual models to differ noteworthy in the coefficients for incentives for BEV or PHEV, we leave this to future work.

Other factors, such as consumer awareness of PEVs in general and subsidies in particular, have been found to be significant in explaining differences between states in the US [9]. However, due to a lack of reliable data for Europe, we exclude this in our study. On the other hand, consumers who would have bought a PEV anyway may be given an incentive anyway, so-called free riding, reducing the actual efficiency of the incentives. Several studies have found a strong free-ridership effect in PEV sales, with 50–80 % of buyers that would have purchased the BEV also in absence of the subsidy [104–107] with a mean of 70 % in a review of 7 studies [109]. This is comparable to free-ridership share in incentives for hybrid electric vehicles [110]. Some evidence indicates the effect is particularly strong at about 85 % among company-owned vehicles [98], although the study did not differentiate between fleet vehicles (company owned by not allowed for private usage) and company cars (company owned and available for private usage). From a governmental perspective, free-ridership per se is not a problem if the policy instrument increases PEV sales compared to a no-policy scenario (i.e., free-ridership is less than 100%). Yet it indicates that other instruments such as quota systems or an income-dependent purchase subsidy would result in similar PEV sales at lower budgetary costs. E.g. Sheldon et al. [105,106] found that subsidies in the US have become less effective and more expensive over time. However, they remain necessary to support low-income buyers. Model availability is another important factor for adoption and is part of the trend variable included in our regression models.

5. Conclusions and policy implications

We analyse the quantitative impact of financial incentives and a set of control variables on the adoption of BEVs and PHEVs in Europe, as measured by the share of PEVs in registered vehicles. The panel structure of the data considers country-level heterogeneity. Our findings show, like previous studies, a robust and positive relationship between PEV registration shares and financial incentives. Thus, financial incentives for PEVs in Europe continue to influence the market diffusion and the magnitude of the monetary incentive is important as well.

By performing our analysis on both BEVs and PHEVs, we find that the incentives have varying effects between the two types of PEVs. One-time incentives are more important for BEV registrations, while the reduction of company car taxation has a larger impact on PHEV registrations. Like previous research, the time trend continues to be significant and important in magnitude.

Our findings show that the reduction of company car taxation is a significant incentive for PEVs. This has important policy implications since company cars constitute a large share of the newly sold cars in Europe, and since they quickly enter the used car market, they open the possibility for other socio-economic groups to purchase a PEV. While company car taxation was significant for both BEVs and PHEVs, the magnitude of the effect was larger for PHEVs. Since PHEVs can be driven both on fossil fuels and electricity, it is important to ensure that these are driven as much as possible on electricity. Empirical evidence points quite often to the opposite, especially for company cars [111]. In summary, tax reductions for BEV or PHEV company cars are important to increase PEV sales shares, but special care needs to be taken to ensure high electric driving shares of PHEV.

While incentives influence sales, they can become costly especially with increasing market shares. However, discontinuation of all incentives might have a detrimental effect on market uptake, especially on groups with lower income [105,106]. One way to address this is through so-called bonus-malus (also called feebate) schemes, where highly polluting conventional vehicles must pay higher fees to finance BEV rebates [112]. Still, the exact design of the scheme needs to be carefully made to ensure a balance. The incentive could also be limited to only the most environmentally friendly BEV through, e.g., size or price limits. France in 2023 restricted their bonus based on price and environmental criteria [113]. These restrictions could also reduce the number of free riders since these seem to be more prevalent for more expensive PEVs [105,106,114].

CRediT authorship contribution statement

Hendrik Schub: Writing – original draft, Visualization,

Methodology, Formal analysis, Data curation. **Patrick Plötz:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization. **Frances Sprei:** Writing – review & editing, Methodology, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used "deepl write" in order to correct potential grammar mistakes and improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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