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Towards Green Driving – Income Tax Incentives for Plug-in Hybrids*

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Abstract

Fostering green driving has the potential to reduce the high CO_2 emissions in the transportation sector. We investigate a German policy reform in 2019 that provided preferential tax treatment for hybrid company cars and evaluate the effectiveness and efficiency of the reform. Using a difference-in-differences design, we find that the tax benefit increased the number of newly registered eligible hybrid cars, compared to non-eligible cars in Germany and pseudo-eligible hybrids in Austria. We find additional evidence for the effectiveness of the reform by comparing the German and the Austrian car markets in a triple-difference-in-differences setting. While the reform did help foster green driving, it was rather cost-inefficient, compared to other policy measures aiming to reduce CO_2 emissions. Conducting a cost-benefit analysis, we find that the cost per saved ton of CO_2 was 682€.

Keywords: green taxes, e-mobility, tax incentives

JEL Classification: H24, Q53, R41

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1 Introduction

Environmental protection and reducing greenhouse gas emissions are among the most pressing topics confronting all generations and nations. To achieve the climate goals codified in the Paris Agreement, governments are implementing many tax and non-tax measures to incentivize eco-friendlier behavior. However, implementing fundamental reforms to counteract the climate crisis can be complicated. In June 2022, for example, the US Supreme Court limited the Environmental Protection Agency's power to implement fundamental regulations like a carbon tax to regulate carbon emissions (New York Times, 2022). This is predicted to slow the transition to clean power in the United States (Harvard T.H. Chan School of Public Health, 2022). Decisions like these raise the question of whether less far-reaching and more specific regulations are more promising for reducing greenhouse gas emissions and confronting the climate crisis. We evaluate a German tax reform that specifically aimed to reduce greenhouse gas emissions in the transportation sector by fostering green driving.

The transportation sector is a key greenhouse gas emitter. In the United States, it accounts for the largest share of emissions (27%), and, within Europe, around 20% of total emissions relate to this sector (United States Environmental Protection Agency, 2022; European Environment Agency, 2017). Depending on the production of the batteries and the electricity sources, electric and hybrid cars have the potential to lower the sector's emissions (see, e.g., Orsi et al., 2016). However, several constraints, like higher acquisition costs for eco-friendly cars, individual preferences, and infrastructure issues, have so far discouraged consumers from choosing these cars. To overcome these constraints, governments have taken various tax and non-tax actions. With their policies, governments can address the whole value chain of eco-friendly cars: they can fiscally promote research and development of these cars as well as their production and consumption. Many countries incentivize buyers of eco-friendly vehicles by offering benefits to purchasers (van der Steen et al., 2015). These range from preferential parking to financial incentives, like reduced registration fees, lower vehicle taxes, and tax credits.

Not only governments care about transportation emissions. As sustainability reporting is on the rise and ever more companies must report their direct and indirect emissions, many companies are also striving to reduce their emissions. Prior literature verifies a behavior change when companies have to report non-financial figures (see, e.g., Chen et al., 2018). One incentive for companies to care more about non-financial, sustainability-related figures is that investors respond positively to the disclosed social benefits of investments (see, e.g., Martin and Moser, 2016). Transportation emissions, for their part, represent a substantial portion of companies' direct emissions, including those relating to a company's car pool. Anecdotal evidence from European Corporate Social Responsibility reports suggests that on average 30% of companies' direct emissions are attributed to their car pool. As investors and other stakeholders increasingly pay attention to non-financial reporting and sustainability, corporations have an incentive to reduce their transportation emissions.

We investigate a tax reform introduced in 2019 that aimed at incentivizing sustainability advances in the German car market. While most tax and nontax policies apply to eco-friendly cars used both for private and business purposes, this reform applies only to company cars and grants an income tax benefit for eco-friendly plug-in hybrid cars. In Germany, company cars account for over 60% of new car registrations, comprising a large part of the car market (see Sopp and Gast, 2020). The clean institutional setting of this policy reform allows us to precisely identify the effect of introducing this income tax benefit on hybrid car registrations. We investigate both whether the policy helped foster green driving and whether it was cost-efficient.

We evaluate the effectiveness of the reform by applying a difference-in-differences research design. In our baseline setting, we analyze the German car market and compare new registrations of eligible plug-in hybrids with non-eligible cars. To ensure that our results are not driven by a general increase in the hybrid car market, we additionally focus on the eligible hybrid car models and compare them in Germany and Austria. While the Austrian car market is highly comparable to the German car market, Austria did not change the tax treatment or subsidize hybrid company cars during our observation period. Therefore, we compare eligible hybrid car models in Germany with the same car models in Austria that did not receive preferential tax treatment (so-called pseudo-eligible hybrid models). Combining the first two analyses, we additionally conduct a triple-difference-in-differences design and compare the whole car markets of Germany and Austria.

We further investigate the efficiency of the preferential tax treatment with a cost-benefit analysis. We estimate the lost income tax revenue and the reduced carbon dioxide (CO_2) emissions of the reform and calculate a price per saved ton of CO_2. We then compare these estimated costs with other policy measures aiming to reduce transportation emissions.

We build our analyses on administrative data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), which contain monthly new registrations for all vehicle models on the German and Austrian car markets from January 2017 until March 2020. We combine these data with hand-collected information on several car model properties.

We find that introducing the preferential tax treatment for specific eco-friendly plug-in hybrids effectively fostered green driving in Germany. More specifically, the reform led to an economically sizeable increase in new registrations of eligible plug-in hybrids in Germany by 362% compared to non-eligible cars in Germany. We validate this positive and statistically significant increase by comparing eligible models in Germany with the same models in Austria. Additionally, we find a positive and significant effect in the difference between eligible versus non-eligible cars in Germany and pseudo-eligible versus pseudo-non-eligible cars in Austria. A heterogeneity analysis reveals that large and expensive car models, in particular, benefited from the reform. Our data reveals that these profiting car models are high CO_2 emitters when predominantly used with the internal combustion engine.

Conducting the cost-benefit analysis, we evaluate the preferential tax treatment as rather cost-inefficient. We estimate reform-induced costs of 5,008€ for each eligible hybrid car in the baseline analysis. Compared to estimated CO_2 savings of 7.35 tons for each eligible hybrid, we estimate reform-induced costs per saved ton of CO_2 amounting to 682€, which exceeds the costs of CO_2 credits trading on the European Climate Exchange over the observation period by a factor of 30 and the costs of previously studied policies, for example, by Chandra et al. (2010) or Metcalf (2008), by at least 50%. The very high reform-induced costs are mainly driven by the fact that plug-in hybrids are predominantly driven with their internal combustion engine.

Given the importance of the transportation sector for CO_2 emissions, there is a growing literature on taxation and e-mobility. One strand of literature evaluates different tax incentives to foster eco-friendly cars within and across countries. Damert and Rudolph (2018) discuss and evaluate a variety of policy instruments that aim at decarbonizing passenger cars in the European Union. They state that fuel taxes effectively incentivize consumers to buy eco-friendly cars and suggest levying vehicle purchase and vehicle circulation taxes based on a car's energy consumption. Analyzing the effect of fuel taxes separately, Giménez-Nadal and Molina (2019) find general evidence that higher fuel taxes reduce the use of private cars and increase the use of public transport in the United States.

Other studies evaluate different tax incentives for specific country groups. Investigating tax reforms in Germany, France, and Sweden, Klier and Linn (2015) compare a tax incentive that affects upfront car costs with a tax incentive that affects operating costs. They find that reducing the upfront costs by lowering the vehicle purchase tax is more effective than reducing annual costs by cutting circulation taxes. Bigler and Radulescu (2022) confirm these findings for Switzerland by investigating purchase subsidies and fuel costs. These results align with prior research showing that consumers tend to respond more to an upfront purchase tax than to the present discounted value of expected circulation taxes (Busse et al., 2006).[1]

A second strand of literature focuses explicitly on tax incentives for hybrid cars. Sallee (2011) studies the incidence of tax incentives for US Toyota Prius owners and determines

[1]In contrast, Ogunkunbi et al. (2022) find evidence of a negative relationship between registration tax benefits and electric car market share using data from 15 EU countries.

that primarily consumers gain from such policies. Comparing different US tax incentives for hybrids, Narassimhan and Johnson (2018) find tax rebates to work better than tax credits, while Diamond (2009) analyzes the effect of US state-level incentives on the hybrid car market, showing a weak link between the offered incentives and new registrations. He identifies a more pronounced effect for gasoline prices. Along these lines, Gallagher and Muehlegger (2011) show that 27% of hybrid car sales can be attributed to rising gasoline prices and only 6% relate directly to tax incentives. In addition, they find that sales tax incentives have a larger effect than income tax incentives, confirming that reducing upfront costs matters more than reducing running costs. Also, for sales tax incentives, Chandra et al. (2010), in their Canadian setting, detect an increase in the market share of hybrid cars resulting from sales tax rebates. Finally, studying the effect of gasoline prices and federal tax incentives on hybrid registrations in 22 US metropolitan statistical areas from 1999 to 2006, Beresteanu and Li (2011) find that tax credits can explain 20% of total hybrid sales.

Only one paper so far empirically investigates the effect of an income tax incentive for company cars on purchases of hybrids. Kok (2015) examines tax changes in the Netherlands between 2008 and 2013, including reduced taxation of privately used company cars. Combined with both a vehicle purchase tax reduction and an annual road tax reduction, he finds 11% lower average CO_2 emissions after the tax reforms. He also finds that the tax incentives for company cars contributed the most to the observed purchasing behavior.

Our contribution is twofold. First, our study provides recent evidence for the effectiveness of an income tax incentive on new registrations of eco-friendly cars. Investigating a more current policy change allows us to account for the substantial increase in environmental awareness in recent years (see Pew Research Center, 2020; Umweltbundesamt, 2021) and thereby update the findings of prior literature. Second, we specifically focus on an income tax incentive for hybrid company cars, a setting that has several advantages. Currently, the taxation of company cars in the US and most European countries hampers the use of eco-friendly cars (Berggren and Kågeson, 2017; Mandell, 2009; PricewaterhouseCoopers, 2007; Wesseling et al., 2015). However, since most newly registered cars are company cars, their taxation is a critical avenue for increasing the share of eco-friendly cars (see Sopp and Gast, 2020). By analyzing the effect of a policy that aims to foster the use of hybrid company cars, our analyses provide valuable insights for possible reforms. Electric and hybrid cars require a substantial consumer investment, as they are more expensive than traditional cars (see Section 2). When investigating company cars, the company makes this initial investment. While prior literature finds reducing upfront costs by, for example, reducing sales taxes to work better than reducing operating costs by, for example, granting a tax credit (see, e.g., Gallagher and Muehlegger, 2011; Busse et al., 2006), company cars might be a setting where granting a tax credit has advantages.

In contrast to prior research, our results suggest that income tax incentives that reduce the operating costs of a car can increase green driving in the context of company cars. However, our findings show that, despite the high share of greenhouse gas emissions attributed to the transportation sector, governmental actions that aim to reduce this sector's emissions may be cost-inefficient. This inefficiency is mainly driven by the fact that hybrid cars are predominantly used with their internal combustion engines. Since the German government does not require any particular sort of driving behavior to grant the preferential tax treatment, free-riding problems occur.

The following section discusses the institutional setting and derives our hypothesis. Section 3 introduces our empirical strategy. Section 4 outlines our data and discusses descriptive statistics. Section 5 provides our main results for the effectiveness and efficiency as well as several robustness checks. Section 6 concludes.

2 Institutional Setting and Hypotheses Development

While other sectors have succeeded in reducing greenhouse gas emissions in recent years, transportation emissions have risen slightly, contravening climate goals. For example, in 2017, greenhouse gas emissions caused by new passenger car registrations increased, compared to the previous year (Harendt et al., 2018). Since the transportation sector accounts for around 20% of greenhouse gas emissions in the EU (European Environment Agency, 2017) and 27% in the US (United States Environmental Protection Agency, 2022), fostering e-mobility is crucial for achieving climate targets.

Investing in an electric or hybrid car, however, comes with a substantial upfront investment for consumers. Even though the total ownership costs are comparable to those of a traditional car, the higher acquisition costs may prevent consumers from acquiring electric or hybrid cars (van der Steen et al., 2015). To overcome this constraint, Germany, like many other countries, has in the last decade implemented several measures to incentivize green driving. In 2011, Germany introduced a law that exempts purely electric vehicles from the motor vehicle tax for the first 10 years after the car's new registration.[2] In 2015, Germany implemented an e-mobility law that provides several benefits for electric vehicles, for example, preferential parking. In 2016, Germany additionally introduced an environmental bonus that directly subsidizes purchases of new electric or hybrid cars both for private and business use (see Bundesministerium für Wirtschaft und Energie, 2016). The

[2]The motor vehicle tax is an annual tax determined by the engine displacement of a car. The exemption for purely electric vehicles applies to cars that are newly registered before the end of 2025.

bonus amounts to 4,000€ for purely electric cars and 3,000€ for hybrids.[3] Car manufacturers and the federal government equally share the financial burden of the environmental bonus.

The rule we are investigating changes the tax treatment of privately used company cars and became effective in January 2019. In general, employees who also use company cars for private purposes must pay income tax on this non-cash benefit. Specifically, if the work-related use exceeds 50%, employees must pay taxes on one percent of the company car's domestic gross list price per month.[4] However, the tax reform implemented a preferential tax treatment for plug-in hybrids, i.e., vehicles whose batteries can be recharged by an external electric power source and its onboard combustion engine. A plug-in hybrid is eligible for the tax benefit if it was registered or provided to the employee after December 31, 2018, and either (a) emits a maximum of 50 grams CO_2 for each driven kilometer or (b) has a range of 40 kilometers or more with the exclusive use of the electric engine. If a plug-in hybrid is eligible, the employee must pay taxes only on 0.5% of the car's gross list price per month instead of 1%.[5] Apart from implementing this preferential tax treatment for hybrid company cars, there was no further tax reform that affected company cars during our observation period (January 2017 until March 2020).

The gross list price is the main driver of the employee's tax liability for the private use of a company car. Since eligible hybrid cars are, on average, more expensive than non-eligible cars, it is questionable whether the reform provides a real fiscal incentive for choosing an eligible plug-in hybrid, instead of a non-eligible car. Table 1 compares the average eligible plug-in hybrid with the average non-eligible car in our sample and shows that there is a net tax advantage of the preferential tax treatment.[6] Since the employer acquires the car, the choice of an eligible hybrid instead of a traditional internal combustion car is, on average, mainly associated with advantages for the employee. The only fiscal

[3] In February 2020, the German government increased the environmental bonus retroactively to November 1, 2019 (6,000€ for purely electric cars and 4,500€ for hybrid cars). Since the decision was made only in February 2020, we do not expect this amendment to affect the results in our observation period from January 2017 until March 2020. However, we conduct a robustness test in Section 5.1.5 where we exclude the months from November 2019 and find similar results.

[4] If the work-related use is 50% or less, the employee can deduct only actual costs incurred by the work-related use.

[5] The tax law change also incentivized the new registration of purely electric vehicles. The tax base of purely electric cars with a gross list price below 40,000€ was reduced to 0.25%. In Section 5.1.5, we extend the treated car models to the eligible purely electric car models in a robustness test and find similar results.

[6] We use a marginal personal income tax rate of 42% to calculate the tax liabilities. Company cars are most likely provided to employees with an above-average taxable income. Since the average income in Germany for 2018 (2019) is 55,980€ (57,810€), these employees at least pay a marginal tax rate of 42%. Some may even experience the top income tax rate of 45%, resulting in even higher net tax savings of 616€. In Table A2 in the Appendix, we calculate the tax advantage for a typical company car, the Mercedes S-Class.

disincentive is the potential infrastructure investment for charging the electric engine.[7] As a result, the tax law change, on average, fiscally incentivizes eligible plug-in hybrids compared to non-eligible cars for employees.

Table 1: Tax Advantage after Policy Change

	Non-eligible	Eligible Plug-in Hybrid	Tax Advantage
Mean gross list price	42,449€	62,057€	
Old law			
** 1%*			
= monthly tax base	424€	621€	
** 12 months*			
= annual tax base	5,088€	7,452€	
** 42% income tax rate*			
= annual tax liability	2,137€	3,130€	
New law			
** 1% / **0.5%***			
= monthly tax base	424€	310€	
** 12 months*			
= annual tax base	5,088€	3,720€	
** 42% income tax rate*			
= annual tax liability	2,137€	1,562€	+**575€**

Own calculations on the tax liability for an average non-eligible car and an average eligible plug-in hybrid before the tax reform (old law) and after the tax reform (new law). Data from the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

While Table 1 shows the average fiscal advantage of the tax policy change, there are several reasons why the reform may not have increased new registrations of eco-friendly hybrid cars. (a) Employees might refuse to switch from an internal combustion car to an eligible hybrid car due to personal preferences. (b) The higher price for hybrid cars could prevent employees from being able to choose an eligible one as company car. And (c) employees might not appreciate the fiscal advantage since it comes to them indirectly via the income tax code. The outcome of the policy change is thus an open question for empirical analysis.

We start by investigating the effectiveness of this tax law change that fosters purchases of specific plug-in hybrids in Germany. Since applying the preferential tax treatment is based on the first registration of a new car after December 2018, we investigate the devel-

[7] Anecdotal evidence from talking to employers and employees suggests that employees can choose from a portfolio of company cars that may depend on the employee's budget. Some companies even increase the budget if an employee chooses a hybrid or electric car. Since hybrids are on average more expensive than traditional combustors, this may be an important incentive for employees to choose the more eco-friendly option, especially as prior literature does not find a willingness to lose wealth to invest in environmentally sustainable projects (see, e.g., Larcker and Watts, 2020).

opment of new registrations of eligible plug-in hybrids before and after the reform. Despite the possible objections to hybrid cars, we expect the number of newly registered eligible hybrid cars to increase after the reform due to the significant tax savings for employees. More specifically, we test the following hypothesis:

> H1: *The tax reform increased the number of newly registered eligible plug-in hybrids.*

While the policy may be effectively designed to incentivize the use of plug-in hybrid company cars, it also entails a major potential disadvantage. Whether a car replacement results in actual reductions in CO_2 emissions depends on whether employees predominantly use the hybrid car's electric or internal combustion engine. Since previous literature finds the electric driving share to be minor (Jöhrens et al., 2020, find an electric driving share of 15%), the resulting predominant use of a hybrid's internal combustion engine could result in a limited environmental effect of the policy. As a result, it is unclear whether the benefits of the reform outweighed the costs. Therefore, we conduct a cost-benefit analysis to investigate whether the tax reform efficiently reduced CO_2 emissions.

3 Empirical Strategy

3.1 Baseline Specification: German Car Market

To investigate whether the preferential tax treatment indeed resulted in an increase in new registrations of eligible plug-in hybrids (H1), we apply a difference-in-differences research design. Formally, we estimate the following regression model:

$$\begin{aligned} \text{CarRegistrations}_{i,t} = \beta_0 + \beta_1 \text{Eligible}_i + \beta_2 \text{Post}_t + \beta_3 (\text{Eligible}_i * \text{Post}_t) \\ + \gamma X_{i,t} + \zeta_{\text{t}} + \eta_{\text{brand}} + \epsilon_{i,t}. \end{aligned} \tag{1}$$

In our baseline setting, we examine the German car market and compare new registrations of eligible plug-in hybrids with new registrations of non-eligible cars, i.e., non-eligible plug-in hybrids and internal combustion cars.[8] Focusing on the German car market allows us to investigate the reform effects on the whole German car market. The dependent variable, *CarRegistrations*$_{i,t}$, depicts the number of new registrations of a specific car model i in month t. *Eligible*$_i$ is an indicator variable equal to one if the respective car model is an eligible plug-in hybrid, i.e., if the model is a plug-in hybrid that fulfills the requirements

[8] We exclude fully electric vehicles from our main analysis (see Section 4).

for the fiscal incentive. $Post_t$ equals one for observations after December 2018, when the regulation became effective. The explanatory variable of central interest is the interaction term $Eligible_i * Post_t$. If the tax reform increased the number of newly registered eligible hybrids, we expect a positive β_3.

$X_{i,t}$ comprises car model-specific control variables, the entry-level price and the mileage[9] of each specific car model. ζ_t represents time (month) fixed effects, which allow us to control for variables that are constant across car models but vary over time, like the fuel price or the number of available car models in the market. η_{brand} are brand fixed effects controlling for general time-invariant brand characteristics and preferences of the consumers toward specific brands. Finally, $\epsilon_{i,t}$ is the error term. We disregard observations from the six months between the announcement of the reform (June 2018) and the implementation of the reform (January 2019) to exclude anticipation effects.[10] In robustness checks (see Section 5.1.5), we address that our dependent variable, the number of newly registered cars per car model, is a count variable and estimate a Poisson model and a model with normalized values. Since treatment is assigned based on the individual technical characteristics of each car model, we use heteroskedasticity-robust standard errors clustered at the car model level in all regressions (see Abadie et al., 2022).[11]

3.2 Validation Specifications: German versus Austrian Car Markets

Focusing on the German car market comes with the advantage that we do not rely on the comparability of car markets across countries. However, evaluating the tax reform only within Germany comes with three potential challenges. First, the car models in the treatment and the control groups may, to some extent, be substitutes. For example, an employee choosing an eligible hybrid company car may otherwise have chosen a non-eligible internal combustion vehicle. Therefore, we may overestimate the effect of the tax reform. Second, our results may be partially driven by a general increase in the hybrid car market during our observation period. Third, eligible plug-in hybrids may be better cars; i.e., they may be superior to the non-eligible cars. Addressing these challenges makes it necessary to focus on the hybrid car market and, therefore, extend our analyses to a second country. We choose Austria since the German and Austrian car markets are highly comparable (see Section 4 for details). Austria, however, did not incentivize plug-in hybrid company cars

[9] We use the mileage as specified by the car producer.

[10] The preferential tax treatment also applies if an employer buys and registers a car before January 2019 but provides it to the employee for the first time after December 31, 2018. Therefore, the number of new registrations could increase already in the transition period before January 1, 2019. In Section 5.1.5, we include the transition period and find similar results.

[11] Following Cunningham (2021) and Bertrand et al. (2004), we use clustered standard errors at the group level to obtain correct confidence intervals in our difference-in-differences design. We cluster at the brand level in untabulated results and find similar standard errors.

during our observation period. More specifically, we compare new registrations of eligible plug-in hybrids in Germany with new registrations of the same car models in Austria (so-called pseudo-eligible hybrids) before and after the German reform. Formally, we estimate:

$$\begin{aligned} \text{HybridCarRegistrations}_{i,t} = \xi_0 + \xi_1 \text{German}_i + \xi_2 \text{Post}_t + \xi_3 (\text{German}_i * \text{Post}_t) \\ + \gamma X_{i,t} + \zeta_\text{t} + \eta_\text{brand} + \epsilon_{i,t}. \end{aligned} \tag{2}$$

The dependent variable, $\textit{HybridCarRegistrations}_{i,t}$, depicts the number of new registrations of a hybrid car model i that is eligible for preferential tax treatment in Germany and not eligible for preferential tax treatment in Austria in month t. $\textit{German}_i$ is an indicator variable equal to one for all German observations and zero for all Austrian observations. The remaining variables correspond to Equation (1). The explanatory variable of central interest is the interaction term between $\textit{German}_i$ and $\textit{Post}_t$. If the tax reform increased the number of newly registered eligible hybrids compared to the same car models on the Austrian car market, we expect ξ_3 to be positive.

To additionally control for time-variant differences between Germany and Austria, we combine Equations (1) and (2) and conduct a triple-difference-in-differences approach to compare the German and Austrian car markets as a whole. Specifically, we investigate the difference between eligible and non-eligible cars in Germany and the difference between pseudo-eligible and pseudo-non-eligible cars in Austria. Formally, we estimate:

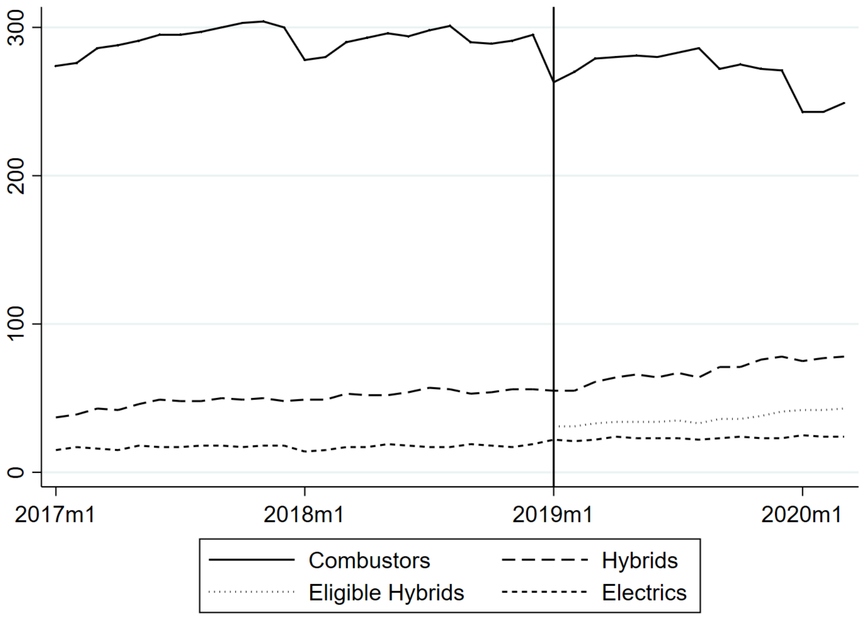
$$\begin{aligned} \text{CarRegistrations}_{i,j,t} = \rho_0 + \rho_1 \text{German}_j + \rho_2 \text{Post}_t + \rho_3 \text{Eligible}_i \\ + \rho_4 (\text{German}_j * \text{Post}_t) + \rho_5 (\text{German}_j * \text{Eligible}_i) + \rho_6 (\text{Post}_t * \text{Eligible}_i) \\ + \rho_7 (\text{German}_j * \text{Post}_t * \text{Eligible}_i) + \gamma X_{i,t} + \zeta_\text{t} + \eta_\text{brand} + \epsilon_{i,j,t}. \end{aligned} \tag{3}$$

The main explanatory variable in this setting is the triple interaction term between $\textit{German}_j$, $\textit{Post}_t$, and $\textit{Eligible}_i$. The coefficient estimate of this triple interaction term, ρ_7, is equal to the difference between eligible versus non-eligible cars in Germany, relative to the difference between pseudo-eligible hybrids versus pseudo-non-eligible cars in Austria. The remaining variables correspond to Equation (1). If the German tax reform increased the number of newly registered eligible hybrid cars in this bilateral comparison, we expect a positive and statistically significant estimate for the triple interaction term coefficient ρ_7.

4 Data and Descriptive Analysis

Our empirical analyses build on administrative data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich) that contain monthly new registrations for all existing vehicle models on the German and Austrian car markets from January 2017 until March 2020.[12] The data differentiates internal combustion, electric, and hybrid car models. Due to our focus on plug-in hybrids, we drop all purely electric models from our sample for our main specification.[13] Since business registrations in 2019 account for 63.5% of all new car registrations in Germany (see Sopp and Gast, 2020), we use overall car registrations as a proxy for newly registered company cars. Due to data limitations, we do not observe the number of newly registered company cars per car model and engine type. Therefore, we rely on total new car registrations in our baseline specifications.[14]

FIGURE 1: Car Models by Engine Type



Graph shows the number of available car models on the German car market by engine type over time. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt).

Figure 1 depicts the number of different car models by engine type in our sample

[12]We end our sample period in March 2020 due to the COVID-19 crisis. The extensive use of home office and the economic downturn may have affected car registrations.

[13]We include purely electric cars in our sample in a robustness check in Section 5.1.5 and find similar results.

[14]In Section 5.1.5, we conduct two robustness checks to more precisely depict company cars.

over time. The number of car models with internal combustion engines slightly decreased from 274 in January 2017 to 249 in March 2020. The number of hybrid models more than doubled over our sample period, from 37 in January 2017 to 78 in March 2020. When the preferential tax treatment became effective in January 2019, 31 hybrid models were eligible. This number increased to 43 eligible hybrid models in March 2020.

Figure 2a descriptively shows the number of new registrations by engine type across our observation period in Germany. While the number of new internal combustion cars fluctuates over time,[15] the number of new hybrid cars tends to increase over our observation period. Overall the number of newly registered internal combustion cars significantly exceeds that of newly registered hybrids over the whole observation period.

Additionally, we hand-collected technical information for each vehicle model from the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC) (see Allgemeiner Deutscher Automobil-Club, 2022). More specifically, we collected data on the CO_2 emission in grams for each driven kilometer and on the range with the exclusive use of the electric engine to identify the eligible plug-in hybrid models. We further collected mileage and the entry-level price for the basic configuration of each vehicle model.[16] Table 2 shows the descriptive statistics for our German and Austrian data.

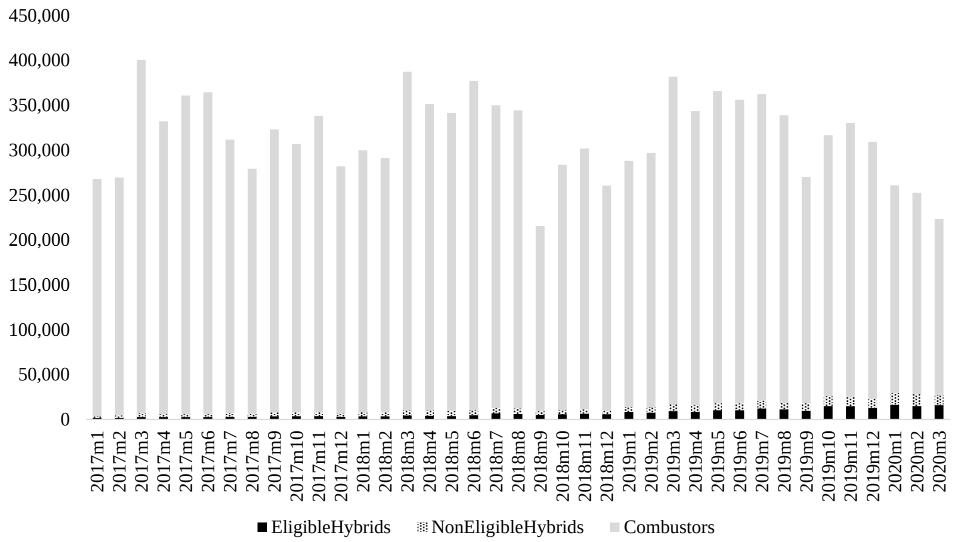
Overall our sample consists of 8,120 model-month observations for the German and Austrian car markets, respectively. The average number of newly registered cars per month per model in Germany is 875. Since the Austrian car market is significantly smaller, the respective average for the Austrian sample is lower (78 in the overall car market). To show that the German and the Austrian car markets are still comparable, Figure 2b shows the number of new registrations by engine type for Austria. As for Germany, we can see both the fluctuating trend in new internal combustion cars and the increasing number of newly registered hybrids. Figure A1 in the Appendix compares the brand shares in the German and Austrian car markets. Overall the brand shares are comparable across both markets. To further ensure comparability across the markets, Figure 3 depicts newly registered (both eligible and non-eligible) hybrids as a share of newly registered total cars for Germany and Austria. The first vertical line indicates the announcement of the preferential tax treatment in Germany (June 2018), while the second vertical line indicates that the reform came into force (January 2019). For our observation period, we see a highly comparable share and

[15]We can observe a striking decrease in new registrations in September 2018. The reason for this decrease is that, since September 2018, newly registered cars must meet the requirements of a new, stricter emission test. As a result, some car models were no longer allowed to be registered, which may result in a decrease in observed new registrations (see Kraftfahrt-Bundesamt, 2018). The new requirements also apply to Austria.

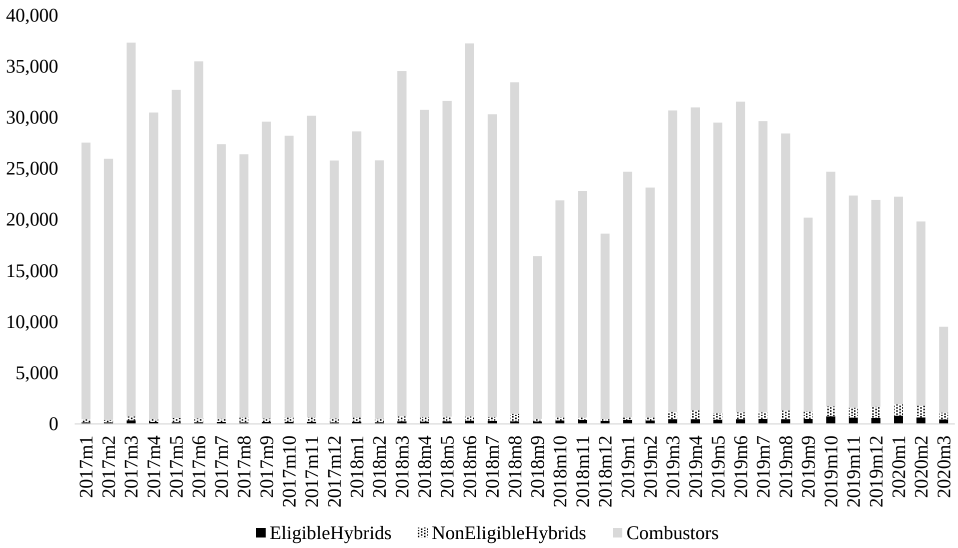
[16]We always use the mileage for the model with a gasoline engine for internal combustion cars.

trend of hybrid cars in Germany and Austria.[17]

FIGURE 2: New Car Registrations by Engine Type



(A) Germany



(B) Austria

Graphs show the number of newly registered cars on the German (Panel A) and the Austrian (Panel B) car market by engine type over time. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich).

[17]Austria also offers programs that incentivize e-mobility. Since 2016, purely electric vehicles have been exempt from a one-time tax for newly registered cars. Additionally, purely electric business vehicles have been eligible for input tax deductions since 2016. Since March 2017, Austria has applied an environmental bonus for new private and business electric cars. In a business context, a car does not have to fulfill specific technical criteria to be eligible for this bonus.

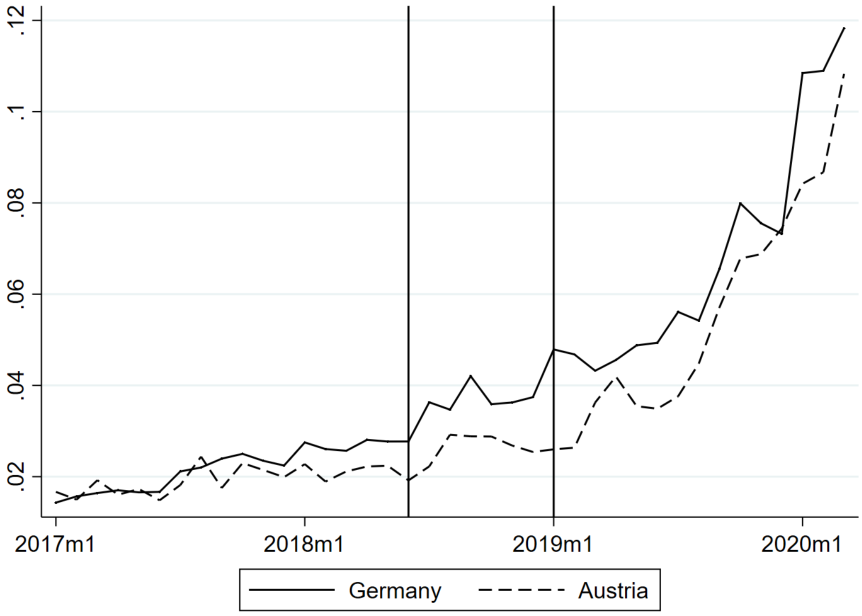
Table 2: Descriptive Statistics

Germany									
	Car Market (N=8,120)			Treatment Eligible Hybrids (N=752)			Control Non-eligible Cars (N=7,368)		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
CarRegistrations	874.9	277.5	1,603.6	197.8	85.0	322.6	944.0	328.0	1,664.8
EntryLevelPrice (€)	44,293	30,990	48,716	62,057	55,097	30,089	42,471	28,990	49,882
Mileage (l/km)	6.4	6.2	2.6	2.5	2.1	1.3	6.8	6.4	2.4

Austria									
	Car Market (N=8,120)			Treatment Pseudo-eligible Hybrids (N=752)			Control Pseudo-non-eligible Cars (N=7,368)		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
CarRegistrations	78.3	15.0	145.3	10.3	3.0	17.6	85.2	21.0	150.8
EntryLevelPrice (€)	41,140	29,980	38,122	62,057	30,089	55,097	42,453	28,990	49,769
Mileage (l/km)	6.3	6.0	2.5	2.5	2.1	1.3	6.9	6.4	2.3

The observational units are vehicle models. Monthly data from January 2017 to March 2020. Table A1 in the Appendix defines variables. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

FIGURE 3: Hybrid Share - German and Austrian Car Market



Graph shows the number of hybrid car registrations as a share of total car registrations for Germany and Austria over time. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich).

5 Empirical Results

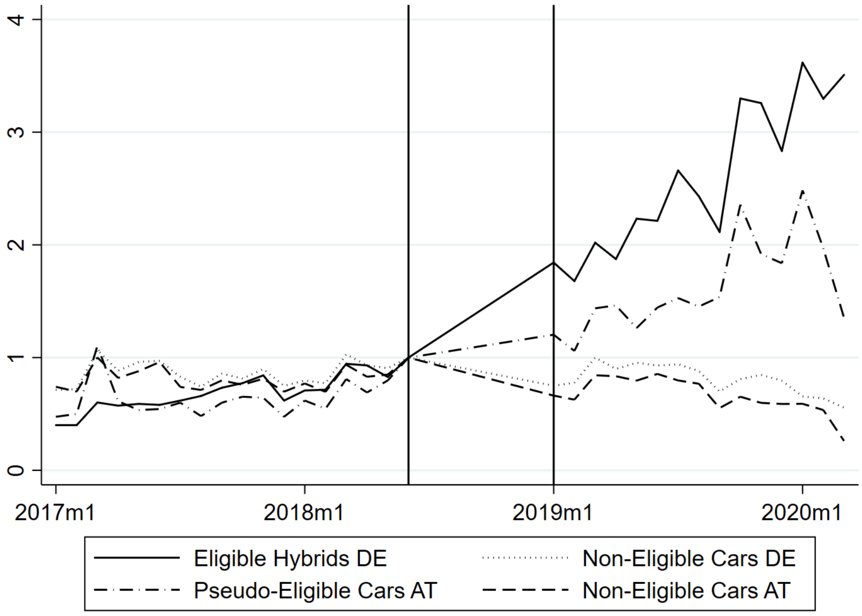
5.1 Effectiveness of the Policy Reform

5.1.1 Parallel Trends Assumption

Applying a difference-in-differences research design relies on the assumption that parallel trends in the treatment and control groups would have continued absent the reform. Since we cannot test this directly, we focus on investigating whether our treatment and control groups trended similarly prior to the implementation of the preferential tax treatment for plug-in hybrids.

For our baseline setting (Equation (1)), we assume parallel trends in the number of new registrations of eligible hybrids and non-eligible cars (i.e., non-eligible hybrids and internal combustion cars) in Germany. For our validation (Equations (2) and (3)), we assume parallel trends in newly registered eligible hybrids in Germany and pseudo-eligible hybrid cars in Austria prior to the implementation of the tax policy.[18]

FIGURE 4: Parallel Trends

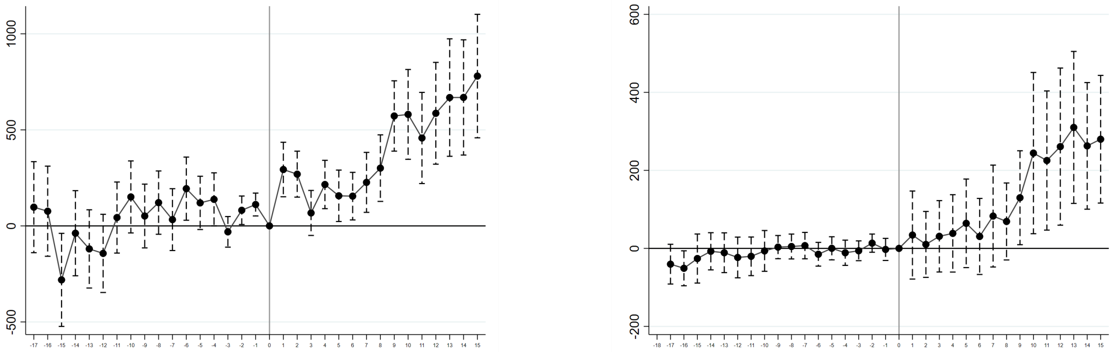


Graph shows the number of hybrid car registrations for the treatment group (eligible plug-in hybrids in Germany), our two control groups (non-eligible cars in Germany and pseudo-eligible cars in Austria), and the pseudo-non-eligible cars in Austria across our observation period. We normalize all values to one in June 2018. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich).

Figure 4 descriptively shows the number of newly registered cars for the treatment group (eligible plug-in hybrids in Germany), our baseline control group (non-eligible cars in Germany), and our validation control group (pseudo-eligible cars in Austria) across our observation period. To give a complete picture, we further plot the number of newly registered cars for the pseudo-non-eligible cars in Austria. Since the national car markets substantially differ in size, we normalize all values to one in June 2018. The first vertical line depicts the announcement of the policy reform (June 2018), the second vertical line depicts when the reform came into force (January 2019). Before the announcement of the reform, the treatment group (eligible hybrid cars in Germany) and the two control groups (non-eligible cars in Germany and pseudo-eligible cars in Austria) show very similar trends. After the implementation, however, we see a sharp increase in new registrations of eligible hybrids in Germany, compared to the control groups. The figure also shows a general

[18] Olden and Møen (2022) show that a triple-difference-in-differences estimator does not require two parallel trend assumptions for a causal interpretation as the difference between two biased difference-in-differences estimators will be unbiased as long as both estimators have the same bias. Therefore, our assumption is conservative with respect to the triple-difference-in-differences setting.

FIGURE 5: Event Studies



(A) German Car Market

(B) German & Austrian Hybrid Car Market

Graphs show coefficient estimates for two event studies. Panel (A) compares eligible and non-eligible car models for the German car market. Panel (B) compares German eligible models and Austrian pseudo-eligible models. Bars depict 90 percent confidence intervals. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

increase in the hybrid car market in Germany and Austria. We control for this trend in our validation test by comparing the German hybrid car market with its Austrian counterpart.

We further test our parallel trends assumption by conducting two event studies, first, for the German car market, where we compare eligible and non-eligible car models, and second, for the German and Austrian hybrid car market, where we compare German eligible models and Austrian pseudo-eligible models. We replace the post-indicator from Equations (1) and (2) with a series of month indicators. Figure 5 plots the estimated coefficients on the modified interaction terms. The bars depict 90 percent confidence intervals. We can interpret the estimated coefficients as the differential changes in newly registered eligible hybrids in Germany, relative to new registrations of non-eligible cars in Germany (5a) and new registrations of pseudo-eligible cars in Austria (5b).

Both Figures 5a and 5b show similar trends in new registrations for the treatment and the respective control group before the reform. The coefficient estimates are indistinguishable from zero for almost all months prior to the reform. In the German setting (5a), the coefficient estimates are positive and statistically different from zero after December 2018. This sharp increase indicates a difference in new registrations of eligible and non-eligible cars in Germany after the implementation of the preferential tax treatment. When we compare the eligible models in Germany with the pseudo-eligible models in Austria (5b), we observe an increase in the coefficient estimates after the implementation of the reform that became statistically significant after August 2019.

5.1.2 Baseline Results: German Car Market

In the baseline specification, we analyze the German car market to investigate whether the implementation of the preferential tax treatment for eligible plug-in hybrids resulted in an increase in new registrations of these models compared to non-eligible cars. More specifically, we compare new registrations of eligible plug-in hybrid models with new registrations of non-eligible car models. Table 3 reports the baseline estimation results for Equation (1). Following the difference-in-differences design presented in Section 3, column (1) regresses the number of new car registrations on the interaction term $Eligible_i * Post_t$ and its components. Column (2) additionally includes model-specific technical control variables (the entry-level price and the mileage) as well as time and brand fixed effects.

The coefficient estimates of the interaction terms are positive and statistically significant. The result from our main specification in column (2) shows a coefficient estimate for the interaction term of 391. Therefore, the reform resulted in an increase of 391 cars per eligible model. The average number of newly registered eligible cars per month per model in our sample in the pre-reform period is 108. Relating our coefficient estimate to this mean of eligible cars per model suggests a reform-induced increase of 362%.

We observe a much larger effect than the increase reported by Gallagher and Muehlegger (2011) for a US setting. For a one thousand dollar income tax credit, they find an increase in hybrid car sales of only 3%. Even though the tax advantage of our policy is smaller (575€ p.a. on average, see Section 2), our effect size is much larger. Gallagher and Muehlegger (2011) also investigate the effect of a sales tax rebate and find an increase in hybrid car sales of 45% for a rebate of one thousand dollars. Our estimated effect size of the income tax incentive is also substantially larger than this effect for a sales tax rebate. Since a sales tax rebate reduces upfront costs, this is a striking result, as reducing upfront costs is generally valued more than reducing running costs.

There may be two explanations for the high effect of reducing the running costs by granting an income tax incentive in our setting. First, we may pick up an increased environmental awareness. While Gallagher and Muehlegger (2011) use data from 2000 to 2006, our observation period ranges from 2017 to 2020. Second, the upfront costs of hybrid cars are negligible in our context, since employers and not employees bear these costs. For the employee who chooses the car, the running costs are, therefore, more important than the upfront costs, and an income tax incentive reduces these running costs. The same two arguments may explain why our results contradict previous findings by, for example, Diamond (2009). When studying US policies, he only attributes a small portion of hybrid car sales to income tax incentives.

Previous literature almost consistently found tax rebates affecting upfront costs (like registration or sales tax reductions) to be more effective than tax rebates affecting running costs (like annual vehicle taxes or income tax incentives). Our results show that this is only true if the beneficiary of a tax rebate bears both the upfront and the running costs. In the context of company cars, where the employer pays for the upfront costs, granting an income tax incentive and thereby reducing the running costs of a car may effectively incentivize employees to choose hybrid cars.

TABLE 3: German Car Market

CarRegistrations	(1)	(2)
Eligible*Post	297.04***	390.81***
	(3.26)	(4.06)
Eligible	-895.84***	-1351.62***
	(-4.25)	(-3.39)
Post	-128.60**	
	(-2.22)	
EntryLevelPrice		-0.01***
		(-5.05)
Mileage		-74.97*
		(-1.66)
Brand FE	No	Yes
Time FE	No	Yes
Observations	8,120	8,120
Adjusted R^2	0.02	0.10

The observational units are vehicle models. The dependent variable *CarRegistrations* is the number of new registrations per car model per month. *Eligible* is an indicator variable equal to one if a model is eligible for the preferential tax treatment and zero otherwise. *Post* is an indicator variable equal to one for all observation periods after December 2018, representing the implementation period of the preferential tax treatment for plug-in hybrids. Detailed variable definitions are provided in Table A1 in the Appendix. The baseline specification in column (2) includes time and brand fixed effects. Monthly data from January 2017 to March 2020. t-statistics are given in the parentheses, and standard errors are heteroskedasticity-robust and clustered at the car model level. ***, ** and * label statistical significance at 1%, 5% and 10% level, respectively. A constant is included but not reported. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

5.1.3 Validation Results: Germany versus Austria

Only investigating the German car market has major drawbacks. Our results could be driven by a general increase in the country's hybrid car market, by the fact that the eligible plug-in hybrids are superior to the non-eligible hybrid cars, and by a partial substitution between eligible and non-eligible cars. To address these concerns, we extend our analysis to a second car market and compare the German car market with the Austrian car market. In contrast to Germany, Austria did not implement a preferential tax treatment for hybrids during our observation period.[19]

[19] See Section 4 regarding the comparability of both markets and tax incentives for e-mobility in Austria.

TABLE 4: German versus Austrian Car Market

Sample	Eligible Hybrid Cars	All Cars
	(1)	(2)
German*Post	163.93***	-107.40**
	(2.80)	(-2.40)
German	100.79***	909.31***
	(4.56)	(8.71)
German*Eligible*Post		271.34***
		(3.17)
German*Eligible		-808.51***
		(-4.58)
Eligible*Post		76.44*
		(1.82)
Eligible		-326.04*
		(-1.76)
Controls	Yes	Yes
Time & Brand FE	Yes	Yes
Observations	1,504	16,240
Adjusted R^2	0.28	0.30

The observational units are vehicle models. The dependent variable is the number of new registrations per (eligible hybrid) model in Germany and per (pseudo-eligible hybrid) model in Austria per month. *German* is an indicator variable equal to one for all German observations and zero otherwise. *Post* is an indicator variable equal to one for all observation periods after December 2018, representing the implementation period of the preferential tax treatment for plug-in hybrids. *Eligible* is an indicator variable equal to one if a model is eligible for the preferential tax treatment and zero otherwise. The following control variables are included: *EntryLevelPrice* and *Mileage*. Detailed variable definitions are provided in Table A1 in the Appendix. All specifications include time and brand fixed effects. Monthly data from January 2017 to March 2020. t-statistics are given in the parentheses, and standard errors are heteroskedasticity-robust and clustered at the car model level. ***, ** and * label statistical significance at 1%, 5% and 10% level, respectively. A constant is included but not reported. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

We investigate the hybrid car market more closely by comparing new registrations of eligible plug-in hybrids in Germany to new registrations of pseudo-eligible hybrids in Austria before and after the reform. Column (1) in Table 4 reports the coefficient estimates for Equation (2). In contrast to Table 3, the sample now only consists of the (pseudo) eligible hybrid models. The resulting coefficient estimate of the interaction term is positive and statistically significant. After the reform, we observe an increase per eligible car model of 164 cars per month in Germany. For this sample's pre-reform period, the average number of new registrations per eligible hybrid model per month in Germany is 108. The results in column (1), therefore, indicate a 152% increase in newly registered eligible hybrids in Germany, compared to pseudo-eligible hybrids in Austria after the reform. The effect size is smaller than in our baseline specification but still considerably larger than the results reported by Gallagher and Muehlegger (2011).

Finally, to additionally control for time-variant differences between the German and Austrian car markets, we combine our first two analyses and apply a triple-difference-in-differences regression where we compare the difference in eligible versus non-eligible cars in Germany with the difference in pseudo-eligibles versus pseudo-non-eligibles in Austria. Column (2) in Table 4 reports the coefficient estimates for Equation (3). As for Equation (1), the dependent variable is the number of newly registered cars per car model per month. The estimated coefficient on the triple interaction term compares the difference in new registrations of eligible and non-eligible cars in Germany with the difference in new registrations of the pseudo-eligible and pseudo-non-eligible cars in Austria. The coefficient estimate of the triple interaction term is positive and statistically significant. Therefore the difference between eligible hybrids an non-eligible cars after the reform in Germany was higher (by 271 cars per car model) than the difference between pseudo-eligible hybrids and pseudo-non-eligible hybrids in Austria.

Overall our results support our hypothesis that the reform effectively fostered green driving in Germany.

5.1.4 Heterogeneity Analyses

We conduct two different heterogeneity analyses to learn more about which car models benefit from the reform. We report the results of the analyses for our baseline specification (Equation (1)). We conducted all analyses for Equations (2) and (3) and find similar (untabulated) results.

While the policy may effectively incentivize the purchase of plug-in hybrids as business cars, it also incorporates a major potential disadvantage. Business cars tend to be prestigious and expensive models with large engines and high CO_2 emissions. While creating an incentive to replace these cars with eco-friendlier ones seems reasonable, it is very unlikely that employees instead choose the most eco-friendly car. Instead they may most likely opt for again more prestigious eligible plug-in hybrids with large and heavy engines. We evaluate this concern in a first heterogeneity analysis. We split the sample based on the median entry-level price, a proxy for prestige, of all car models in June 2018 when the reform was announced. Columns (1) and (2) in Table 5 show the results for this sample split. We only find a statistically significant effect of the interaction term for cars with an above-median entry-level price. Since models with an above-median entry-level price emit more CO_2 (the mileage of the "high price" cars is 25% higher than the mileage of the "low price" cars), this calls into question the environmental effect of the incentive.

Another concern associated with the tax law change was that the government designed the reform in a way that German car manufacturers could benefit excessively (see, e.g., Heinrich Böll Stiftung, 2018). If German car manufacturers benefited more, this would indicate that this incentive was not only an environmental policy but also a subsidy for the

German car industry. Therefore, we evaluate whether the policy subsidized German car producers in a second heterogeneity analysis. We split the sample into models produced by German and non-German car manufacturers.[20] Columns (3) and (4) in Table 5 show the results for this sample split. We find a positive and statistically significant coefficient estimate for the interaction terms for both groups. Therefore, both German and non-German car producers seem to have benefitted from the reform. Comparing the coefficients with the respective subsample means before the reform, we find an increase in eligible plug-in hybrids, compared to non-eligible cars, for the car models produced by German car manufacturers of 468%. For the non-German models, we find an effect of 173%. Therefore, we find evidence of an excessive benefit for German car manufacturers.[21]

TABLE 5: Heterogeneity

CarRegistrations	**Entry-level Price**		**Car Producer**	
	Low Price	High Price	German	Non-German
	(1)	(2)	(3)	(4)
Eligible*Post	119.92	366.54***	481.57***	200.78**
	(0.67)	(3.95)	(2.82)	(2.51)
Eligible	-1022.22**	-869.85***	-2284.75**	-531.38***
	(-2.25)	(-3.30)	(-2.40)	(-3.31)
Controls	Yes	Yes	Yes	Yes
Time & Brand FE	Yes	Yes	Yes	Yes
Observations	3,880	3,750	2,667	5,453
Adjusted R^2	0.04	0.21	0.27	0.50

The observational units are vehicle models. This table presents a sample split at the median of the entry-level price of cars in our sample based on prices in June 2018 when the reform was announced in columns (1) and (2). Columns (3) and (4) present a sample split into models by German and non-German car producers. The dependent variable *CarRegistrations* is the number of new registrations per car model per month. *Eligible* is an indicator variable equal to one if a model is eligible for the preferential tax treatment and zero otherwise. *Post* is an indicator variable equal to one for all observation periods after December 2018, representing the implementation period of the preferential tax treatment for plug-in hybrids. The following control variables are included: *EntryLevelPrice* and *Mileage*. Detailed variable definitions are provided in Table A1 in the Appendix. All specifications include time and brand fixed effects. Monthly data from January 2017 to March 2020. t-statistics are given in the parentheses, and standard errors are heteroskedasticity-robust and clustered at the car model level. ***, ** and * label statistical significance at 1%, 5% and 10% level, respectively. A constant is included but not reported. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

5.1.5 Robustness

Our findings are robust to an extensive set of additional tests. We report all robustness checks for the baseline analysis within the German car market, Equation (1). In addition,

[20]The German manufacturers in our sample are Audi, BWM, Mercedes, Mini, Opel, Porsche, Smart, and VW.

[21]Conducting an F-Test confirms a statistically significant difference between the coefficient estimates for German and non-German car producers.

we conducted all robustness checks for Equations (2) and (3) and find similar (untabulated) results.

Dealing with count data Since our dependent variable (the number of new registrations for each model per month) is a count variable and is skewed[22], we perform a Poisson regression and normalize our dependent variable. Table 6, column (1), shows the results for a Poisson regression approach. In column (2), we normalize the dependent variable to one in the period in which the reform was announced (June 2018). This procedure comports with Figure 4 and depicts changes instead of levels. The coefficient estimates of the interaction terms are positive and statistically significant, confirm our baseline results, and translate into increases of eligible cars by 100%-220%, compared to non-eligible cars.[23] The effect sizes are, therefore, smaller than in our baseline specification.

Constant models over our observation periods During our observation period, the number of available hybrid car models increased. To ensure that an increased car model supply does not drive our results in the post-period, we restrict our sample to car models that were already available by the time of the policy announcement (June 2018). This restriction reduces our sample size to 7,442 observations. The results reported in Table 7 column (1) support our main findings. The coefficient estimate of the interaction term is positive and statistically significant. When we compare the magnitude of this coefficient estimate with our baseline results, the result translates into a comparable increase of 355%.

Restricted observation period - November 2019 As described in Section 2, in February 2020, the German government retroactively increased the environmental bonus as of November 2019 for private and company cars. Even though it is improbable that the increase could have been anticipated, we exclude observations after October 2019 to ensure that the additional incentive does not drive our results. Confirming our baseline findings in Table 3, the coefficient estimate for the interaction term in column (2) of Table 7 is still positive and statistically significant. The effect size, an increase of 235%, is at the lower bound of our findings, indicating a more pronounced increase in new registrations at the end of our sample period.

[22] Using both the Shapiro-Wilk and the Shapiro-Francia test, we find evidence that our dependent variable is skewed.

[23] Note that implementing a difference-in-differences research design requires strong functional form assumptions since the common trend assumption is not equivariant to nonlinear transformations (Melly and Santangelo, 2015). We still report Poisson regression results to account for our dependent variable being a count variable. However, these results should be interpreted with caution.

Full time period - Anticipation effects In the baseline regression, we exclude the months between the announcement of the reform in June 2018 and the entry into force in January 2019. The preferential tax treatment applies for new cars that are (1) newly registered after December 2018 or (2) provided to the employee by the employer for the first time after December 2018. Therefore, we expect anticipation effects within these six months. In this robustness check, we, however, include these months and investigate the whole period between January 2017 and March 2020. Column (3) in Table 7 reports the results. The coefficient estimate for the interaction term is positive and statistically significant and translates into an increase of 307%, which is lower than in our baseline specification. Therefore, there does not seem to be anticipation between the announcement and reform implementation.

Purely electric vehicles The policy also affected the taxation of non-cash benefits for purely electric company cars by reducing the monthly tax base to 0.25% of the domestic gross list price. Therefore, employees could choose a purely electric car, instead of an eligible hybrid model. To account for this, we also include purely electric models in our sample in this robustness check. Eligible models now include both eligible hybrids and eligible electrics. The coefficient estimate for the interaction term in column (4) of Table 7 is positive and statistically significant. The coefficient translates into an increase of 413%, which is 14% higher than our baseline specification. This result indicates that the beneficial tax treatment for electric vehicles also increased new registrations of eligible models. We may also conclude that our identified effect could be even higher if purely electric vehicles had not been treated.

Company cars The tax benefit is only applicable for eligible hybrid company cars. Due to data limitations, we cannot observe the number of newly registered company cars per car model and engine type. Therefore, we rely on total new car registrations in our baseline specification. Our data, however, contains the share of company cars per month and car model (i.e., we know the share of company cars for the Audi A3; we do not, however, know whether this share differs for Audi A3 internal combustion cars versus A3 hybrids). We perform two different robustness checks to proxy the number of newly registered company cars. We assume the share of company cars to apply for all engine types of a model (i.e., we assume the share of company cars for the Audi A3 to apply to both both kinds of A3s). In column (5), we multiply this share with the number of newly registered cars per car model per month and use this as a dependent variable. Our results show a positive and statistically significant coefficient estimate for the interaction term, translating into a 229% increase in eligible hybrids, compared to non-eligible cars. In columns (6) and (7), we split our sample based on whether the share of company cars of a specific car model exceeds (column (6)) or undercuts (column (7)) the average share of company cars in our sample. In other words, we define a car model as a "company car" model if the business share of this model exceeds the average business share. In contrast, we define a car model as a "private car" model if the business share of the model undercuts the average business share. We expect a higher effect for "company cars" than for "private cars". Our results confirm this expectation. While we observe a positive and statistically significant coefficient estimate for the interaction term when we investigate "company cars" that translates into an increase of 700%, we do not find a statistically significant coefficient estimate for the "private cars". Therefore, we may underestimate the effect of the reform when we investigate the whole car market in our main specification.

TABLE 6: Count Data - German Car Market

CarRegistrations	Poisson	Normalized
	(1)	(2)
Eligible*Post	1.03***	3.17***
	(4.47)	(4.01)
Eligible	-2.20***	-0.05
	(-5.48)	(-0.07)
Controls	Yes	Yes
Time & Brand FE	Yes	Yes
Observations	8,120	7,442
Adjusted R^2		0.06
Pseudo R^2	0.67	

The observational units are vehicle models. The dependent variable *CarRegistrations* is the number of new registrations per car model per month. *Eligible* is an indicator variable equal to one if a model is eligible for the preferential tax treatment and zero otherwise. *Post* is an indicator variable equal to one for all observation periods after December 2018, representing the implementation period of the preferential tax treatment for plug-in hybrids. The following control variables are included: *EntryLevelPrice* and *Mileage*. Detailed variable definitions are provided in Table A1 in the Appendix. All specifications include time and brand fixed effects. Column (1) shows a Poisson model, and column (2) normalizes *CarRegistrations* to June 2018. Monthly data from January 2017 to March 2020. t-statistics are given in the parentheses, and standard errors are heteroskedasticity-robust and clustered at the car model level. ***, ** and * label statistical significance at 1%, 5% and 10% level, respectively. A constant is included but not reported. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

TABLE 7: Robustness Analyses - German Car Market

Sample	Constant Models	Shorter Period	Full Period	Electric Cars	Approx. Company Cars	Company Cars	Private Cars
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Eligible*Post	382.98***	254.33***	332.16***	371.56***	246.51***	621.50***	52.47
	(4.01)	(3.09)	(4.07)	(4.08)	(3.69)	(4.12)	(0.41)
Eligible	-1,465.90***	-1,332.90***	-1,305.81***	-1,194.42***	-898.78***	-2,000.31***	-482.20*
	(-3.25)	(-3.20)	(-3.34)	(-4.46)	(-3.07)	(-2.71)	(-1.83)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time & Brand FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,442	6,792	9,573	8,430	7,797	4,382	3,738
Adjusted R^2	0.37	0.36	0.36	0.11	0.08	0.11	0.09

The observational units are vehicle models. The dependent variable *CarRegistrations* is the number of new registrations per car model per month. *Eligible* is an indicator variable equal to one if a model is eligible for the preferential tax treatment and zero otherwise. *Post* is an indicator variable equal to one for all observation periods after December 2018, representing the implementation period of the preferential tax treatment for plug-in hybrids. The following control variables are included: *EntryLevelPrice* and *Mileage*. Detailed variable definitions are provided in Table A1 in the Appendix. Column (1) only investigates models that were available on the market before the implementation of the tax reform. Column (2) excludes observation periods after October 2019. Column (3) investigates the whole observation period from January 2017 until March 2020 without the cutout period. In column (4) we include eligible purely electric models in our sample. In this case, *Eligible* equals one for all eligible hybrid cars and for purely electric cars. In column (5), we approximate company cars and multiply *CarRegistrations* with the share of company cars on a car model level. Columns (6) and (7) present a sample split based on whether a car model is assumed to be mainly used as a company car (column (6)) or as a private car (column (7)). All specifications include time and brand fixed effects. t-statistics are given in the parentheses, and standard errors are heteroskedasticity-robust and clustered at the car model level. ***, ** and * label statistical significance at 1%, 5% and 10% level, respectively. A constant is included but not reported. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

5.2 Efficiency of the Reform

While our results so far indicate that the reform effectively increased new registrations of eligible hybrid models in Germany, we analyze the efficiency of the reform and conduct a cost-benefit analysis in this section. To make a statement on the efficiency of the policy, we estimate both the costs and the benefits of the reform. The reform costs are equal to the lost income tax revenues.[24] From a policymaker perspective, a desired benefit of the reform is a potential reduction of CO_2 emissions in the transportation sector. In the following, we will estimate both the costs of the reform and the resulting savings of CO_2 emissions in a back-of-the-envelope calculation.[25] This analysis aims to derive costs for each reform-induced saved ton of CO_2.

5.2.1 Assumptions

In the following, we will justify the assumptions underlying the cost-benefit analysis. We make baseline assumptions for our main results as well as assumptions resulting in a lower and upper bound of estimated costs per saved ton of CO_2. Table 8 displays the assumptions.

TABLE 8: Cost-benefit Analysis: Assumptions

	Baseline Assumption	**Lower Bound**	**Upper Bound**
Assumptions affecting the costs			
Usage of company car	4.4 years	4.4 years	4.4 years
Income tax rate	42%	42%	42%
Assumptions affecting the benefits			
Working life of a car	129,200 km	200,000 km for combustors 160,000 km for hybrids	129,200 km
Electric driving share of hybrids	15%	75%	0%
Assumption affecting costs & benefits			
Ownership situation	31 % scenario 1 69 % scenario 2	0% scenario 1 100% scenario 2	0% scenario 1 100% scenario 2

Overview of assumptions underlying the cost-benefit analysis for the baseline setting, the lower bound, and the upper bound. Scenario 1 refers to a situation where an employee who drove a hybrid car that would not have been eligible for preferential tax treatment chooses an eligible hybrid after the reform. Scenario 2 refers to a situation where an employee who drove an internal combustion car drives an eligible hybrid car after the reform .

[24]Note that the aim of this section is to roughly estimate costs and benefits. We, therefore, abstract from a potential increase in value added tax revenues and a potential decrease in fuel duty.

[25]For detailed calculations, see Appendix 1.B.

Costs - Reduced Tax Revenues

The tax reform costs are lower income tax revenues due to the preferential tax treatment and lower tax base. Instead of gaining income tax on 1% of the gross list price of a company car per month, the government only obtains income tax on 0.5% of the gross domestic price. Since the preferential tax treatment only applies to company cars, the German government has a reform-induced tax revenue loss as long as a car is used as a company car, which is on average 4.4 years (Statista, 2021). If a company car enters into private use afterward, the private owner does not benefit from the preferential tax treatment, and there are no additional costs for the government. To calculate the lost tax revenue, we assume an individual income tax rate of the employee of 42%.[26]

Benefits - Reduction in CO_2 Emissions

While the costs of the reform only arise as long as a car is used as a company car, the reduction in CO_2 emissions persists over the working life of a car. Therefore, the average CO_2 reductions depend on that life. On average, a car is used for 9.5 years and driven 13,600 kilometers yearly.[27] Over the working life of a car, this results in 129,200 kilometers. The CO_2 emissions of hybrid cars heavily depend on whether the car is used as an electric car or an internal combustion one. While manufacturer information on the mileage assumes an electric driving share of 75%, the actual electric driving share is much lower. Conducting a study on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Jöhrens et al. (2020) find, on average, an electric driving share for plug-in hybrids in Germany of 15%. In our baseline analysis, we, therefore, assume an electric driving share of hybrid cars of 15%.

Costs &Benefits - Car Ownership Situation

Finally, the estimation of the costs and benefits depends on employees' previous car ownership situation. Four different car ownership shifting scenarios could have occurred after the policy reform. First, an employee who drove a hybrid car that would not have been eligible for preferential tax treatment can choose an eligible hybrid after the reform (scenario 1). Second, an employee who drove an internal combustion car can drive an eligible hybrid after the reform (scenario 2). Third, an employee who drove an eco-friendly

[26] Company cars are most likely provided to employees with an above-average taxable income. Since the average income in Germany for 2018 (2019) is 55,980 (57,810), these employees at least pay a marginal tax rate of 42%. Some may even experience the top income tax rate of 45%, resulting in even higher net tax losses.

[27] See Kraftfahrt-Bundesamt (2022a,b). We use the value for 2019 since this is the first year of the preferential tax treatment.

hybrid may choose a new and now eligible eco-friendly one after the reform (scenario 3). Fourth, an employee who did not have a company car before the reform may drive an eligible hybrid company car after the implementation of the preferential tax treatment (scenario 4).

As our data does not allow us to investigate employees in scenarios 3 and 4, we focus on scenarios 1 and 2 to devise estimates for the costs and benefits of the preferential tax treatment. However, we assume the share of employees in scenarios 3 and 4 to be relatively small: Given the paucity of eligible hybrids prior to the reform, the share of employees having an eligible hybrid and choosing an eligible hybrid afterward may be quite low (scenario 3). Since we see an overall decrease in new car registrations in our observation period (see Figure 2), we also expect scenario 4 to occur rarely. Still, we acknowledge that our estimates are a lower bound for the costs of saved CO_2.

To infer the share of employees in scenarios 1 and 2, we employ a regression analysis that builds on Equation (1). We replace the indicator for eligible hybrid models with a categorical variable ($EngineType$), taking the value of 1 for eligible hybrid cars, 2 for non-eligible hybrids, and 3 for internal combustion cars. The eligible hybrids represent the baseline category in this analysis. Therefore, the (expected) negative coefficients of the interaction terms ($EngineType * Post$) represent reduced registrations in both non-eligible hybrids and internal combustion cars in the post-policy period, compared to eligible hybrids.

We can draw two conclusions from the results in Table A3 in the Appendix. First, the coefficient estimate of the internal combustion car interaction is larger than the coefficient estimate of the non-eligible hybrid interaction, indicating that more owners of the former cars than of the latter cars switched to eligible hybrids after the reform. Second, we only find a significant coefficient estimate for the internal combustion car interaction, indicating that this switching behavior (scenario 2) is more prevalent than scenario 1. We use the coefficient estimates of the two interaction terms to approximate the shares of both switching groups: on average, 31% switch from a non-eligible hybrid to an eligible hybrid and 69% switch from an internal combustion car to an eligible hybrid.

Upper and Lower Bounds

To derive our lower bound, we use a less conservative estimation regarding the working life of a car and vary the electric driving share. We use an average working life of 200,000 kilometers[28] for internal combustion cars and 160,000 kilometers for hybrids.[29] The higher

[28]See Chip (2018).

[29]This refers to the warranty granted on the battery by most producers (see Carwow, 2022).

the electric driving share, the lower the emissions and, therefore, the higher the benefits of the reform. To get the lower bound of costs per saved ton of CO_2, we use emissions as specified by the manufacturer, assuming an electric driving share of 75%. To derive the upper bound, we use emissions for the exclusive use of the internal combustion engine.

Additionally, our assumption on the ownership switching behavior of employees affects both the costs and the benefits of our estimate. In our baseline estimation, we use a regression approach to estimate the share of scenario 1 to 31% and the share of scenario 2 to 69%. To derive the lower and the upper bounds of costs per saved ton of CO_2, we apply a share of 100% to scenario 2. For the lower bound, switching from an internal combustion car to an eligible hybrid results in substantial CO_2 reductions when we use emissions as reported by car manufacturers. The substantial benefits–in contrast to scenario 1 in this setting–outweigh the slightly higher costs of scenario 2. For the upper bound, switching from an internal combustion car to an eligible hybrid no longer reduces but increases CO_2 since CO_2 emissions of eligible hybrid cars when used predominantly with the internal combustion engine exceed CO_2 emissions of internal combustion cars. Therefore, we also assume scenario 2 to be 100% for deriving the upper bound.

5.2.2 Baseline Results

To derive our results, we always compare the average eligible hybrid with the average non-eligible hybrid or internal combustion car within a car classification.[30] Table B1 in the Appendix calculates the average costs of the reform per eligible hybrid car for scenarios 1 and 2. We derive costs amounting to 4,698€ per car if an employee switches from a non-eligible hybrid to an eligible hybrid (scenario 1) and 5,147€ if an employee switches from an internal combustion car to an eligible hybrid (scenario 2). Table B2 in the Appendix calculates the average CO_2 reduction of the reform per eligible hybrid car for both scenarios. Our results show an overall average reduction in CO_2 emissions of 18.67 tons per eligible car in scenario 1 and 2.26 tons in scenario 2. Using the estimated shares for scenarios 1 and 2, we derive average costs and average CO_2 savings per car in Table 9. We get reform-induced average costs per car of 5,008€ and average CO_2 savings per car of 7.35 tons. This results in estimated costs per saved ton CO_2 of 682€.

[30] We differentiate between minicars, small cars, lower mid-size, mid-size, upper mid-size, and large cars. Since there are no eligible hybrid car models in our observation period that are minicars and small cars, we neglect the lower two car classifications.

TABLE 9: Cost-benefit Analysis

	Switching to an eligible hybrid from a	
	Non-eligible Hybrid **Scenario 1**	Combustor **Scenario 2**
Estimated switching share	31%	69%
Average costs per car	4,698€	5,147€
Average CO_2 reduction per car	18.67 tons	2.26 tons
Weighted average costs per car	5,008€	
Weighted average CO_2 reduction per car	7.35 tons	
Costs per saved ton of CO_2	**682€**	

Own calculations on the reform-induced average costs per saved ton of CO_2. Data from the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

5.2.3 Cost Efficiency - Upper and Lower Bounds

Applying our lower bound assumptions, we calculate costs of 195€ per saved ton of CO_2 via the reform. This lower result is mainly driven by the assumed higher kilometers over the working life of a car and the higher electric driving share. Applying the higher bound assumptions no longer results in reduced CO_2 emissions but increased emissions. Deriving the upper and lower bounds results in a wide range of costs per saved ton of CO_2 via the reform. The assumptions and driveability, therefore, strongly drive the results on a very individual level.

5.2.4 Policy Evaluation

To evaluate the policy reform, we start by comparing our estimated total costs to the costs predicted by the German government. Combining the number of newly registered eligible hybrids between January 2019 and March 2020 (196,251) and the average estimated costs per registered eligible car (5,008€), we derive total estimated costs of 980 million€. This amount is significantly higher than the estimated costs by the German government, amounting to 420 million €.[31] To evaluate the efficiency of the policy, we compare the costs of a saved ton of CO_2 across different policies. An obvious comparison is the CO_2 credits

[31]The procedure of our cost-benefit analysis can explain this difference. We always compare eligible hybrids with non-eligible cars within a car classification. In our view, this is the most realistic method since employees most likely do not choose between cars in different car classes. However, when we compare eligible with non-eligible cars across all car classes, we estimate total costs of 407 million €, which is highly comparable to the estimate by the German government.

trading price on the European Climate Exchange, derived from CO_2 emission futures. The average price for such future contracts over the whole sample period (the treatment period) is 12.87 (21.51)€. Our estimates, therefore, exceed the costs of CO_2 credits trading by a factor of 50 (30).

Several studies have evaluated the effect of subsidies and tax incentives on purchasing or registering ecologically friendly cars. Most studies report lower costs per saved ton of CO_2. For a US setting, Beresteanu and Li (2011) estimate the cost of federal tax credit for hybrids of up to \$177 (approximately 158€[32]) per saved ton of CO_2. Chandra et al. (2010) evaluate the use of a sales tax reduction on hybrid cars and estimate costs of \$195 (174€) per saved ton of CO_2. The closest policy regarding costs per saved ton of CO_2 is the "Cash for Clunkers" program. This US policy was designed to encourage owners of older cars to purchase more fuel-efficient ones. Li et al. (2013) estimate the costs of this program with up to \$288 (257€) per reduced ton of CO_2, while Knittel (2009) estimates potential costs of \$200 up to \$450 (179 to 402€). One can also compare other transportation-related policies to our results. For example, Metcalf (2008) investigates an ethanol tax credit to enhance the use of ethanol in passenger vehicle gasoline. The lower bound of this estimated cost per ton saved CO_2 for this policy is \$450 (402€).

The results of this cost-benefit analysis suggest that, compared to other potential emission-reducing policies, especially those targeting the transportation sector, the investigated policy is quite expensive. Several aspects accentuate this result. Our heterogeneity analysis in Section 5.1.4 shows that the reform particularly increases the number of newly registered large and expensive company cars. This result contradicts a claim proposed by Damert and Rudolph (2018) that tax policy should aim at reducing the vehicle size for company cars. What's more, hybrid cars can be used as both electric cars and internal combustion ones. Used with the internal combustion engine, the hybrids in our sample emit, on average, more CO_2 than internal combustion cars. The German government does not monitor the driving of employees taking advantage of the preferential tax treatment. Therefore, the reform may cause free riding. However, the German policy reform fosters eco-friendly driving for company cars. In contrast, in most OECD countries, tax policy favors traditional cars (see Berggren and Kågeson, 2017; Mandell, 2009; Pricewaterhouse-Coopers, 2007; Wesseling et al., 2015).

While the pure focus on CO_2 prices may be too narrow to evaluate the policy, we also follow Dechezleprêtre et al. (2022) to evaluate the policy. They argue that the support and success of climate policies depend on three key perceptions: (1) the effectiveness of the policy in reducing CO_2 emissions, (2) distributional impacts on lower-income households, and (3) the impact on the beneficiary's household. Applied to the German policy reform

[32]We apply the average Euro to US dollar exchange rate in 2019 of 1.12 (Statista, 2022).

for hybrid company cars, the first part of this paper finds the policy to be effective. We observe an increase in newly registered eco-friendly hybrids. However, the effectiveness in reducing CO_2 emissions mainly depends on the employees' driving behavior. Regarding inequality aspects, the German reform tends to perform rather badly: the government favors employees driving a company car who are generally wealthier. Evaluating the impact on the employee's household, we see a clear financial benefit in taking advantage of the reform and choosing a hybrid company car.

6 Conclusion

This paper analyzes the effectiveness of a preferential tax treatment for hybrid company cars in Germany. As the aim of the policy was to reduce greenhouse gas emissions in the transportation sector, this study relates to Goal 13 on "Climate Action" of the United Nation's agenda for Sustainable Development. We conduct a difference-in-differences analysis to investigate the effectiveness of a 50% reduction in the tax base for non-cash benefits for specific hybrid company cars. We find that this benefit is associated with an increase in the number of eligible hybrid car registrations by 362%, compared to non-eligible cars, in the German car market. To validate our findings, we employ a pseudo-treatment affecting pseudo-eligible hybrids in Austria. We compare eligible hybrids in Germany with pseudo-eligibles in Austria and use a triple-difference-in-differences design to find that the policy is also effective in these settings. Our findings are robust to an extensive number of robustness checks.

Our results indicate that the introduced tax policy effectively enhanced the use of eligible hybrid cars. Prior literature finds a low impact of income tax credits on the number of hybrid cars in the market. Additionally, it almost consistently finds the reduction of upfront costs to be more effective than the reduction of running costs. Since we find a strong effect of an income tax credit, our study contradicts prior research. Some exceptional attributes of the analyzed income tax policy may explain our results. As the reform only affects company cars, the employee does not bear any costs when choosing the more expensive hybrid car but only receives the benefits. Instead, the employer pays the higher price of the hybrid. This separation of receiving the benefit and paying the higher price can explain our findings and shows that income tax benefits can be an effective policy tool.

In addition, we use a back-of-the-envelope cost-benefit analysis to estimate the costs of the policy. Using information on the average working life of a car and the estimated car-shifting behavior of employees, we calculate a price of 682€ per saved ton of CO_2. Comparing our findings to prior studies, we conclude that the policy was rather expensive. The design of the policy measure explains this inefficiency. The reform specifically benefits hybrid cars, which can be used either with an internal combustion or electric engine. However, the German government does not require a predominant electric driving behavior to grant preferential tax treatment. Our data show that, when predominantly used as internal combustion cars, eligible hybrids emit more CO_2 than traditional ones. Since the electric driving share of hybrids in Germany is only 15% (Jöhrens et al., 2020), the reform-induced savings in CO_2 emissions are minor.

As climate change is the predominant issue of the 21st century, effectiveness may be more important than cost efficiency. Therefore, the policy measure may still help in urging a change in the transportation sector. With adjustments in design, an income tax benefit for hybrid company cars has the potential to be both effective and efficient.

Appendix

A Tables and Figures

Table A1: Variable Definitions

Variable	Description	Source
$CarRegistrations_{i,t}$	Number of new registrations of a specific car model i in month t	Kraftfahrt-Bundesamt & Bundesanstalt Statistik Österreich
$HybridCarRegistrations_{i,t}$	Number of new registrations of a specific eligible hybrid car model i in month t	Kraftfahrt-Bundesamt & Bundesanstalt Statistik Österreich
$Eligible_i$	Indicator variable equal to one if the respective car model i is an eligible plug-in hybrid, zero otherwise	Own calculations
$Post_t$	Indicator variable equal to one for observations after December 2018 (implementation of tax reform), zero otherwise	Own calculations
$German_j$	Indicator variable equal to one for German observations, zero otherwise	Own calculations
$EntryLevelPrice_{i,t}$	Entry-level price for the basic configuration of a specific car model i in month t	ADAC
$Mileage_{i,t}$	Mileage of a specific car model i in month t	ADAC
$EngineType_i$	Indicator variable equal to 1 if the engine type of a model i is an eligible hybrid, 2 if the engine type of a model is a non-eligible hybrid, and 3 if the engine type of a model is a combustor	Own calculations

Overview of variables and data sources we use in this paper.

Table A2: Tax Advantage after Policy Change for a Mercedes S-Class

	Hybrid	Combustor Plug-in Hybrid	Tax Advantage
Mean gross list price	110,254€	93,385€	
Old law			
** 1%*			
= monthly tax base	1,103€	934€	
** 12 months*			
= annual tax base	13,236€	11,208€	
** 42% income tax rate*			
= annual tax liability	5,559€	4,707€	
New law			
** 1% / **0.5%***			
= monthly tax base	551€	934€	
** 12 months*			
= annual tax base	6,612€	11,208€	
** 42% income tax rate*			
= annual tax liability	2,777€	4,707€	**+1,930€**

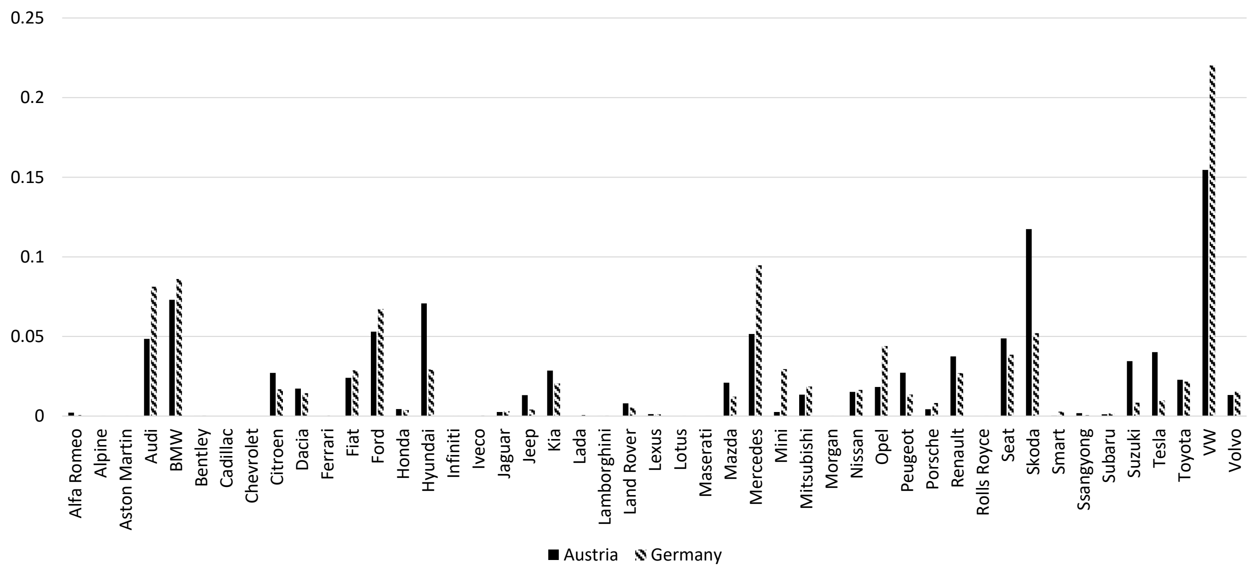
Own calculations on the tax liability for an eligible hybrid Mercedes S-Class and a non-eligible combustor Mercedes S-Class. Data from the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

Table A3: Within Car Market Shift

CarRegistrations	
EngineType=NonEligibileHybrid	810.98**
	(2.16)
EngineType=Combustor	1670.52***
	(3.77)
EngineType=NonEligibleHybrid*Post	-168.52
	(-1.28)
EngineType=Combustor*Post	-382.25***
	(-3.83)
Controls	Yes
Time & Brand FE	Yes
Observations	8,120
Adjusted R^2	0.37

The observational units are vehicle models. The dependent variable *CarRegistrations* is the number of new registrations per car model per month. *Post* is an indicator variable equal to one for all observation periods after December 2018, representing the implementation period of the preferential tax treatment for plug-in hybrids. *EngineType* is an indicator variable that equals 1 if the engine type of a model is an eligible hybrid, 2 if the engine type of a model is a non-eligible hybrid, and 3 if the engine type of a model is an internal combustion car. The following control variables are included: *EntryLevelPrice* and *Mileage*. Detailed variable definitions are provided in Table A1 in the Appendix. All specifications include time and brand fixed effects. Monthly data from January 2017 to March 2020. t-statistics are given in the parentheses, and standard errors are heteroskedasticity-robust and clustered at the car model level. ***, ** and * label statistical significance at 1%, 5% and 10% level, respectively. A constant is included but not reported. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt), the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich), and the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC).

Figure A1: Brand Shares in Germany and Austria



Graph shows the brand shares in Germany and Austria in our sample. Data from the German Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and the Austrian Federal Office of Statistics (Bundesanstalt Statistik Österreich).

B Details on Calculating Costs and Benefits of the Reform

Costs - Reduced Tax Revenues

Table B1 calculates the average costs of the reform per eligible hybrid car for scenarios 1 and 2. We compare car models within a car class. The lower income tax revenues for the German government depend on whether an employee drove a non-eligible hybrid or internal combustion car before choosing the eligible hybrid. Since the tax base for the income tax refers to the gross list price of the respective company car, we start our calculations with the average gross list prices for the different car types. For the non-eligible hybrids and the internal combustion cars, the monthly tax base of the non-cash benefit is 1% of the gross list price.

In contrast, the monthly tax base for eligible hybrids is only 0.5% of the gross list price. We assume an individual income tax rate of 42% to receive annual tax payments. Comparing the average tax payments for the non-eligible hybrid (scenario 1) or the internal combustion car (scenario 2) with the average tax payments for the eligible hybrid results in the annual lost tax revenue for the government. Multiplying the lower annual tax revenue by the average lifetime of a company car results in average tax revenues lost for each eligible hybrid. Finally, to derive an average tax loss per eligible car, we weight the annual lost tax revenues with the occurrence of the different car classes and get average lost tax revenues per car of 4,698€ in scenario 1 and 5,147€ in scenario 2.

Benefits - Reduction in CO_2 Emissions

Table B2 calculates the average CO_2 reduction of the reform per eligible hybrid car for scenarios 1 and 2. Here, we compare the average emissions of CO_2 per driven kilometer of non-eligible hybrids and internal combustion cars with the emissions of eligible hybrids. We assume an electric driving share of 15% for the hybrid models. We can derive the CO_2 emissions per driven kilometer from the mileage.[33] We multiply the average reduction per kilometer by the average working life of a car (129,200 km) and get a reduction of CO_2 emissions per car. Finally, we derive an average reduction of emissions per car by weighting according to car classes. Our estimate is a reduction of CO_2 emissions of 18.67 tons per car for scenario 1 and 2.26 for scenario 2.

[33] One liter corresponds to 2.370 grams of CO_2 (Handlesblatt, 2022). We derive the mileage for hybrid cars with the exclusive combustion engine use with the following formula: $((Electricrange + 25) * Mileage)/25$ (Zeit, 2014).

Upper and Lower Bounds

There are two assumptions that affect the benefits, i.e., the reduced CO_2 emissions in our calculation. First, the working life of a car, i.e., the total driven kilometers, affects the amount of saved CO_2. Increasing this parameter increases the benefits of the reform. To derive our lower bound, we use a less conservative estimation regarding the working life of a car. We use an average working life of 200,000 kilometers[34] for internal combustion cars and of 160,000 kilometers for hybrids.[35] Second, the actual usage of the eligible hybrid car, i.e., whether a hybrid is used with both the electric and the internal combustion engine or solely with the internal combustion engine affects the amount of CO_2 saved. In the baseline setting, we use emissions resulting from an electric driving share of 15%. The more employees use the internal combustion engine of their eligible hybrid, the higher the emissions and therefore the lower the benefits of the reform. To get the lower bound of costs per saved ton of CO_2, we use emissions as specified by the manufacturer assuming an electric driving share of 75%. To derive the upper bound, we use the emissions for the exclusive use of the internal combustion engine. Additionally, we vary the shares of the ownership switching scenarios to 100% of scenario 2 both for the lower and the upper bound.

[34] See Chip (2018).

[35] This refers to the warranty grant on the battery by most producers (See Carwow (2022)).

Table B1: Costs - Reduced Tax Revenues

	Scenario 1							
	Lower Mid-size Cars		Mid-size Cars		Upper Mid-size Cars		Large Cars	
	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid
∅ Gross list price	25,742€	32,258€	44,590€	47,531€	61,248€	69,953€	100,093€	112,145€
Monthly tax base	1%	0.5%	1%	0.5%	1%	0.5%	1%	0.5%
	257€	161€	446€	238€	612€	350€	1,001€	561€
Annual tax base	3,089€	1,935€	5,351€	2,852€	7,350€	4,197€	12,011€	6,729€
Annual tax payment (42%)	1,297€	813€	2,247€	1,198€	3,087€	1,763€	5,045€	2,826€
Annual lost tax revenues	484€		1,050€		1,342€		2,219€	
∅ Working life of a company car	4.4 years		4.4 years		4.4 years		4.4 years	
∅ Lost tax revenues per car	**2,132€**		**4,618€**		**5,826€**		**9,762 €**	
Share of car classification	33.88%		32.46%		20.55%		13.11%	
Weighted ∅				**4,698€**				

	Scenario 2							
	Lower Mid-size Cars		Mid-size Cars		Upper Mid-size Cars		Large Cars	
	Combustor	El. Hybrid	Combustor	El. Hybrid	Combustor	El. Hybrid	Combustor	El. Hybrid
∅ Gross list price	22,420€	32,258€	36,224€	47,531€	54,512€	69,953€	155,368€	112,145€
Monthly tax base	1%	0.5%	1%	0.5%	1%	0.5%	1%	0.5%
	224€	161€	362€	238€	545€	350€	1,554€	561€
Annual tax base	2,690€	1,935€	4,347€	2,852€	6,541€	4,197€	18,644€	6,729€
Annual tax payment (42%)	1,130€	813€	1,826€	1,198€	2,747€	1,763€	7,831€	2,826€
Annual lost tax revenues	317€		628€		985€		5,004€	
∅ Working life of a company car	4.4 years		4.4 years		4.4 years		4.4 years	
∅ Lost tax revenues per car	**1,395€**		**2,763€**		**4,332€**		**22,020 €**	
Share of car classification	33.88%		32.46%		20.55%		13.11%	
Weighted ∅				**5,147€**				

Own calculations on the average reduced tax revenues of the reform per car if an employee switches from a non-eligible hybrid car to an eligible hybrid car (scenario 1) and if an employee switches from an internal combustion car to an eligible hybrid car (scenario 2). Data from the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC) and Statista (2021).

Table B2: Benefits - Reduction in CO_2 Emissions

	Lower Mid-size Cars		Mid-size Cars		Upper Mid-size Cars		Large Cars	
Scenario 1								
	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid
∅ CO_2 emission per km	336 g	172 g	266 g	137 g	273 g	193 g	382 g	148 g
∅ CO_2 reduction per km	164 g		129 g		79 g		234 g	
∅ Driven km	129,200 km		129,200 km		129,200 km		129,200 km	
∅ CO_2 reduction per car	**21.22 tons**		**16.68 tons**		**10.27 tons**		**30.22 tons**	
Share of car classification	33.88%		32.46%		20.55%		13.11%	
Weighted ∅				**18.67**				
Scenario 2								
	Lower Mid-size Cars		Mid-size Cars		Upper Mid-size Cars		Large Cars	
	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid	Non-el. Hybrid	El. Hybrid
∅ CO_2 emission per km	145 g	172 g	166 g	137 g	194 g	193 g	278 g	148 g
∅ CO_2 reduction per km	-27 g		29 g		1 g		130 g	
∅ Driven km	129,200 km		129,200 km		129,200 km		129,200 km	
∅ CO_2 reduction per car	**-3.51 tons**		**3.76 tons**		**0.1 tons**		**16.81 tons**	
Share of car classification	33.88%		32.46%		20.55%		13.11%	
Weighted ∅				**2.26**				

Own calculations on the average CO_2 reduction of the reform per car if an employee switches from a non-eligible hybrid car to an eligible hybrid (scenario 1) and if an employee switches from an internal combustion car to an eligible hybrid (scenario 2). Data from the German Automobile Club (Allgemeiner Deutscher Automobil-Club – ADAC), Kraftfahrt-Bundesamt (2022a), and Kraftfahrt-Bundesamt (2022b).

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