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Institute of Economic Studies

How effective are subsidies for electric vehicles? An evaluation of Czech policy

Bachelor's thesis

Author: Jonáš Čekal
Study program: Economics and Finance
Supervisor: Petr Pleticha, M.Sc.
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Jonáš Čekal

Abstract

This thesis deals with the effectiveness of Czech electromobility support. First programs to incentivize electric vehicle purchases were introduced by two Czech ministries in 2016 with grants available until the end of 2021. To estimate the effect of Czech incentives on electric vehicle sales, generalized difference-in-differences design is used. The estimation employs two-way fixed effects model with annual and monthly data spanning over 2015-2021. Estonia, Latvia, Lithuania and Poland were chosen to serve as a control group with electric vehicle market share and electric vehicle registrations as the dependent variables. The results are ambiguous and do not suggest a clear link between the investigated variables and the subsidies. A more detailed dataset would be needed to conduct a definitive impact evaluation.

JEL Classification	O31, O38, R40, H25
Keywords	Electromobility, Incentives, Subsidies, Rebates, Policy evaluation
Title	How effective are subsidies for electric vehicles? An evaluation of Czech policy

Abstrakt

Tato bakalářská práce se zabývá efektivitou českých opatření pro rozvoj elektromobility. První programy na podporu nákupu elektromobilů byly spuštěny dvěma českými ministerstvy v roce 2016, přičemž dotace byly k dispozici až do konce roku 2021. K odhadu vlivu českých pobídek na prodeje elektromobilů byla použita zobecněná konstrukce metody rozdílů v rozdílech zkoumaná pomocí modelu fixních efektů jak časových, tak individuálních. Datové soubory s roční a měsíční frekvencí pozorování obsahovaly data z období mezi lety 2015 a 2021. Zahrnutí Estonska, Lotyšska, Litvy a Polska do analýzy pomohlo odlišit vliv zkoumaných opatření na české prodeje od ostatních vlivů. Jako závislé proměnné vystupovaly tržní podíl elektromobilů a počet nově registrovaných vozidel tohoto typu. Výsledky vlivu českých dotací na rozšiřování elektromobility jsou nejednoznačné a ke konečnému zhodnocení dopadu by byl zapotřebí podrobnější datový soubor.

Klasifikace JEL	O31, O38, R40, H25
Klíčová slova	Elektromobilita, Pobídky, Dotace, Slevy, Vyhodnocení opatření
Název práce	Jak efektivní jsou dotace na pořízení elektromobilu? Vyhodnocení opatření v ČR

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Acronyms

BEV Battery Electric Vehicle

EV Electric Vehicle

PHEV Plug-in Hybrid Electric Vehicle

Chapter 1

Introduction

The issue of environmental protection is burning like never before. The automotive belongs to the industries which are subject to the biggest change in their history in order to protect planet Earth from harmful substances. The latest Regulation (EU) 2019/631 sets annual emission targets for car manufacturers who are forced to decrease the average emissions of their produced vehicles. Every year onwards, these target levels will be stricter and will demand a higher share of low-emission vehicles in the producers' fleets (European Commission 2020). Given that the automotive industry plays an irreplaceable role in the Czech economy, the official governmental support for the outset of electromobility is likely to increase in the future.

Countries all over the world provide different types of incentives to promote Electric Vehicle (EV) sales. These may include vehicle purchase subsidies, license tax or fee reductions or parking free of charge. Many studies of the effect of incentives on sales of the electric vehicles have been conducted during the last decade (Hardman et al. 2017). In this thesis, we will follow them by evaluating the subsidy programs provided by the Czech government. Specifically, we want to test the hypothesis whether the Czech incentives led to increase in sales of battery and plug-in electric vehicles.

Methodologically, we will follow the example of studies using difference-in-differences approach, such as those of Liu et al. (2021) or Zheng et al. (2021). This approach is suitable in the case of evaluation of Czech EV promotion policy. From financial incentives, only one type has been significantly reducing EV purchase price in the Czech Republic from 2016, a specific form of rebate. We chose several similarly developed countries in Europe, where the least financial incentives were present from 2015, to serve as control group in our difference-in-differences model specifications. Furthermore, the time unit is reduced to months to explain possible relationships more precisely and to contribute to existing literature by rarely used procedure.

We obtain results which do not suggest a positive effect of EV subsidies on EV sales. Some models indicate this relationship when analysing EV registrations; however, others provide contradictory results.

In this thesis, we start with literature review summarizing existing research on this question from foreign countries. We proceed with description of Czech electric vehicle promotion with a special interest of policy programs of the Ministry of Industry and Trade and of the Ministry of the Environment. Then, description of the data is provided before moving on to methodological part of the thesis. Finally, the results of our models are presented, and limitations discussed.

Chapter 2

Literature Review

Studies examining the effect of different incentives to promote electric vehicles sales have begun to emerge shortly after the launch of the very first serial-produced electric cars in 2008 (Hardman et al. 2017). There are diverse ways of conducting such research from the point of methods. Hardman et al. (2017) provide a comprehensive overview of results of many studies which enables them to identify a likely effective policy leading to an increase in EV market share.

The incentives may be of different kinds. We distinguish one-time and recurring incentives, as well as incentives applicable either at the time of the vehicle purchase, or later. Apart from VAT or purchase tax exemption, the government might also provide a purchase grant which reduces the price directly when buying the EV. Through a rebate, part of the amount might be refunded only a certain time after the purchase. Similarly, the income tax credit provides a discount on the EV only retrospectively as the taxpayer is able to claim a reduction of the tax account in a reasonable amount reflecting the higher costs of EVs. According to Hardman et al. (2017), the most effective incentives are grant, VAT or purchase tax exemption, all of which are available to consumers prior to the vehicle purchase.

A very common way to evaluate the effectiveness of different incentives is to test whether they play a significant role in the properly built econometric model of EV sales. The exact methodology used in research varies a lot across studies (Hardman et al. 2017). We continue by introducing interesting research conducted by various authors, starting with those who found that incentives positively stimulated EV sales.

Gallagher & Muehlegger (2011) used fixed effects regression model to examine quarterly hybrid vehicle sales data in American states. They calculated the annual fuel savings from riding a hybrid car instead of the conventional one and they also included the value of state incentives and demographic data as independent variables. Among the demographic data, per-capita income, mean age, or variable reflecting education were used. After finding a positive and significant coefficient of the value of state tax incentives of all types as a whole, the authors proceeded by estimating the effect of distinct policy measures. They conclude that the sales tax waiver, although less generous at fair value, is much more efficient in increasing EV sales than the income tax credit due to the fact that it is immediately applicable at the time of purchase and no additional effort is required from consumers.

Using similar approach, Jenn et al. (2018) found that every $1000 offered as a monetary incentive increases the EV sales by 2.6%. This study was conducted in detail as monthly data for years 2010-2015 were used and all the American states included. In her masters' thesis, Tláskalová (2021) used annual data for 31 European countries between years 2010 and 2019 to compare effects of one-time and recurring incentives. While one-time incentives significantly increased battery EV market share, the effect of the recurring ones was found to be insignificant. On the other hand, plug-in hybrid vehicles sales were effectively promoted by both types of financial incentives.

Different methodology to assess Chinese EV promotion program was used by Zheng et al. (2021). They chose difference-in-differences approach to examine the effectiveness of purchase subsidies which were gradually introduced across all the 286 major Chinese cities included in the study. As the policy was launched at distinct times in different cities, the treatment and control group of cities could be divided through the examined period between years 2009 and 2018. The regression results show that the subsidy program accounted for approximately one third of EV sales increase over the period. Other control variables, such as number of charging stations or the gasoline price, were also found statistically significant.

In their study, Liu et al. (2021) separately regressed the electric buses and commercial vehicles sales between 2009 and 2012 on the dummy variables related to subsidy policy as well as on demographic and socioeconomic data to find out that in these sales categories, the effectiveness of subsidies was of high level. Furthermore, the problem of endogeneity in case of charging infrastructure is mentioned by Liu et al. (2021). Most of the studies of EV incentives ignore the fact that not necessarily the increase in the number of charging stations leads to EV registrations spread, but that the relationship might also be reversed.

Furthermore, Wee et al. (2018) aggregated EV policy instruments of 50 American states to attribute a 17.3% increase in EV registrations to average subsidy value of $2305. They used a within model difference-in-differences estimator with high-dimensional fixed effects.

Jin et al. (2014) analysed 2013 US vehicle sales data by calculating the total consumer benefit from state-level policies. They used stepwise linear regression process of adding and removing variables based on their significance in a gradually formed model. Results show that a 10% increase in the total benefit would increase the EV sales by approximately 1.8%.

Comparing conventional vehicles to the electric ones, Yan (2018) claimed that only strong tax incentives can outweigh the limited driving range of EV. Interpreting his benefit-cost analysis, he also pointed out that the largest difference in costs between the conventional and electric vehicles is in the segment of small cars.

Apart from EV market analysis, different studies used questionnaire surveys and interviews to evaluate incentives. As an example, Bjerkan et al. (2016) asked 3405 Norwegian EV owners to rate the importance of incentives. The exemption from purchase tax or VAT were critical for more than 80% of respondents which confirms the previous research results indicating that the incentives applicable at the time of purchase are the most attractive and efficient.

Several studies did not draw the conclusion of purchase incentives increasing the EV sales. For instance, that is the case of difference-in-differences research conducted by Liu et al. (2021) with a sample of 61 Chinese cities between 2009 and 2012. The treatment and control groups were distinguished, and insignificantly positive coefficient of the treatment term indicated no effect of the purchase subsidy on the sales of private EVs. The authors further examined the effect of all the incentives over a longer period until 2018. Purchase subsidy appeared to remain insignificant when affecting EV sales. However, the development of charging infrastructure was an effective measure.

Norwegian municipalities served as a sample for stepwise linear regression research of Mersky et al. (2016). Availability of charging infrastructure, median household income and location close to a major city were found to be important in increasing EV sales.

Finally, Jin et al. (2014) also conducted benefit-cost analysis to assess the effectiveness of policy measures. They measured the monetized benefit of each incentive and divided this figure by the costs related to providing the measure. As a result, the public charger seemed to be the most effective incentive to promote battery EV sales.

Chapter 3

Electromobility and its promotion in the Czech Republic

As our study intends to primarily evaluate effectiveness of Czech policy measures towards an electromobility spread, this chapter provides an overview of the key aspects of EV market and incentives provided during years in the Czech Republic. Firstly, a chronological description will be provided of how electric vehicles issues were evolving over time in Czechia. Then, the two evaluated major policy programs will be described in detail.

3.1 Evolution of electromobility in the Czech Republic

Program FutureMotion, presented in June 2009 by Czech semi state owned energy giant ČEZ Group, may be considered as the first harbinger of the onset of electromobility on the Czech market. Its first phase was focused on purchase of up to 100 battery electric vehicles until 2012 and testing the data from their operation. The then mayor of the capital city of Prague Pavel Bém was present to public disclosure of the program as active participation of the city was anticipated in form of public recharging stations construction. No local emissions from operation of BEV was mentioned as the core motive, adding that current ČEZ Group energy mix results in emitting 95 g/km of CO2 by using BEV in comparison to conventional vehicles average of 164 g/km of CO2 emitted (ČEZ Group 2009).

During 2009, discussions were held whether to introduce scrappage program for vehicles, as many other countries did so after the financial crisis. Electric vehicles were supposed to be promoted more generously. However, no such program was approved in the end (ČT24 2010).

The first public recharging stations officially registered by the Ministry of Industry and Trade of the Czech Republic were put into operation in early 2011 (EnviWeb.cz 2011; CDV 2021). ČEZ Group rivals Prague Energetics located it in two of Prague's shopping centres. A few other stations had already existed before, but 2011 marks the beginning of systematic and intensive development of recharging infrastructure. Later this year, also fast-chargers became available for Czech EV drivers, which was another step towards more comfortable use of this type of vehicles (Hybrid.cz 2011). Recharging stations operators demanded rather a symbolic fee for their use as it was still a pilot project and customers should have been rather incentivized than discouraged.

After first ever five registered battery electric vehicles in 2009 and other 6 in 2010, 56 of them were registered in 2011 and even 89 during 2012 resulting in 0.05% market share of total registered vehicles in that year (Czech Car Importers Association 2022b).

Already four Prague city districts officially promoted electromobility alongside couple of other Czech cities in early 2013. They rented BEV and used it for presentation purposes, but also for everyday use of the offices (ČEZ Group 2013). However, Czechia was still lacking official governmental support, which existed in many other European countries. Only some independent organizations supporting electromobility were founded which started to draw attention to the lack of governmental interest with slight exceptions of Prague municipality or the Ministry of the Environment (Hybrid.cz 2013).

Following the Directive 2014/94/EU of the European Parliament and of the Council, a national policy framework of the deployment of alternative fuels infrastructure was approved by the Czech Government in November 2015. The document prepared by the Czech Ministry of Industry and Trade was called National Action Plan for Clean Mobility. It predicted 2,2% market share of BEV on Czech market until 2020, whereas the real market share was around 1,5% that year. The Ministry considers public support of EV purchase logical as accelerating the entry of new technology into the market is often practiced in order to remove the initial obstacles (MPO 2015).

Three types of incentives are mentioned in the National Action Plan for Clean Mobility. Parking free of charge should account for EUR 200 annual benefit. Secondly, monetary subsidy aims to eliminate the gap in total cost of ownership between EV and conventional car. These costs include purchase price, maintenance costs and costs from operation of the vehicle. The ministry assumes that approximate rebate for one vehicle in the coming years might be EUR 8 000. Expected decrease in total cost of ownership difference in time should later result in lowering the subsidy. Finally, an incentive for building a public recharging station is mentioned as another type of EV spread support. This might be composed of direct monetary support and land offering in state property. Private financing of public recharging stations is very complicated because with the slow increase in registered electric vehicles, the investment in recharging equipment does not pay off. Owners of electric vehicles require a dense network of recharging points, but at the same time they are willing to pay only a very little for electricity to power their cars as nearly zero costs of operating an electric car are mentioned as one of the biggest advantages of using such a car. Furthermore, the problem of location arises from the fact that improving the electricity network in a remote locality is often necessary in order to safely and quickly recharge many vehicles at the same time. However, the costs of improvements are so high that many private property owners are rather not motived for construction of recharging station, given that only a few cars would use them for a low price. That is the reason why only energy giant companies are behind the proliferation of recharging points, using them as a secondary part of their business, which, although unprofitable, serves as an advertisement.

From the analysis of effectiveness of different scenarios of governmental electromobility support, the ministry deduces that parking and recharging infrastructure incentives are the best option from cost-benefit point of view. Nevertheless, rebates for municipalities and private firms are also recommended as a supplementary incentive. The state also needs to take into account future expenses related to electric network overload in case that many electric vehicles are being recharged at the same time.

The goals set by the National Action Plan for Clean Mobility for recharging infrastructure development until 2020 were nearly met. Over 700 slow-chargers and 400 fast-chargers were available at the end of 2020 as compared to the plan of having 800 of the former and 500 of latter type, respectively (European Commission 2022). A prospect until 2030 counts with 44 000 electric vehicles sold in that year. In 2021 this value reached 6 390 new cars.

In March 2016, the first public program incentivizing purchase of electric vehicles was launched by the Ministry of Industry and Trade of the Czech Republic (API 2016). Later that year, in November, also the Ministry of the

Environment started to offer a grant to reduce the extra cost of an EV. Both programs were different in terms of the accepted groups of applicants and the value of support (NPŽP 2016). More grant calls were to come in the following years, all of them described in the next subchapters.

Another milestone in the field of electric vehicle support was the introduction of special vehicle registration plate for vehicles emitting up to 50 g/km of CO2. Since April 2019, holders of such a plate are exempt from paying parking fees in the entire territory of Prague. Similar benefits were introduced also by other large Czech cities, such as Ostrava or Karlovy Vary. Last but not least, a free vignette to drive on Czech motorways was put into force in 2021 (Horčík 2019).

The spring of 2020 was marked by the update of the National Action Plan for Clean Mobility following the new international agreements, such as the Paris Agreement or the European Green Deal. Those set up very ambitious goals, which required systematic support from governments. The updated Czech plan expects up to 10% and 15% market share of battery electric vehicles in 2025 and 2030, respectively. While subsidy programs for public sector and firms are among intended policies, support for individuals is not mentioned in the document. Instead, the issue of fuel cell electric vehicles powered by hydrogen is elaborated to a larger extent (MPO 2020).

The launch of CitigoE iV and Superb iV by the Czech manufacturer Škoda in late 2019 significantly influenced the Czech market of BEV and PHEV. 50% share of the company on the total EV sales in 2020 speaks for itself. Furthermore, Enyaq iV joined the family of electric cars in 2021 (Czech Car Importers Association 2022b).

Finally, according to our data described in the next chapter, BEV together with PHEV reached nearly 4% market share of new vehicle registrations at the end of 2021. Around 1800 recharging points were available at that time with both figures indicating a rapid increase throughout the year 2021.

3.2 Program of the Ministry of Industry and Trade

The first ever Czech governmental program to incentivize EV sales was introduced in March 2016. Following the National Action Plan for Clean Mobility, the Ministry of Industry and Trade started to accept applications for grants a month later with the deadline in July 2016. 80 million CZK budget (over 3 million EUR) was financed by the European Regional Development Fund and all the projects accepted had to be finished by the end of 2018. Firms of all sizes were enabled to apply, but the granted cars were only allowed to be operated outside of the city of Prague. Competitiveness of businesses and sustainability of the Czech economy were among the main aims of the policy and that is the reason why Prague as the richest Czech region was excluded. The program did not support plug-in hybrid electric vehicles as a whole and from battery electric vehicles, only certain classes were subject to subsidy. Specifically, buyers of luxury cars did not get any grant. As for the value of rebate, the difference in purchase price between conventional and electric vehicle was used as a basis for its determining. Small, medium and large firms received 70%, 60% and 50% of the difference, respectively. Hence, the exact subsidy ranged from 70 000 CZK (2 800 EUR) to 217 000 CZK (8 700 EUR) for one car given its specification. Moreover, purchase and installation of private EV chargers within the business area were also incentivized from the overall budget (API 2016).

The second grant call was announced in January 2017 with applications submission from March to May 2017. This time, the budget was set more than two times larger. Altogether 150 million CZK (6 million EUR) were offered to support purchases of BEV until the end of 2019. The percentage discount from the purchase price difference was increased by 5% for all types of businesses, as compared to previous grant call. Moreover, flat 45% from the purchase price of all types of BEV was set as a basis for grant calculation (API 2017b).

Shortly after, the third program was introduced in June 2017. Firms were enabled to apply for the grant from July to September 2017 and realize their projects until 3 years from acceptance. From the budget of 60 million CZK (2.4 million EUR), also luxury BEV were subject to grant, but their purchase price above 1 million CZK (40 000 EUR) was not incentivized. Other terms were the same as in case of the second grant call (API 2017a). The fourth grant call came after a break in late 2018. Applications had to be reported between December 2018 and May 2019, while vehicles had to be purchased until November 2020. 200 million CZK (8 million EUR) were allocated for this call with same conditions as before (API 2018).

Finally, the last EV incentive program of the Ministry of Industry and Trade was presented in December 2019. Firms could apply for the grant in first seven months of 2020 and the budget was set to 150 million CZK (6 million EUR). Realisation of the project was due June 2021. This time, only 30%, 25% and 20% of the difference in purchase price between conventional and electric vehicle was granted for small, medium and large businesses, respectively (API 2019).

Due to covid crisis, no other incentive programs have been introduced since then.

3.3 Program of the Ministry of the Environment

The Ministry of the Environment of the Czech Republic followed with similar programs to those described in previous subchapter. However, these were intended for municipalities, regions, and other public entities, such as public universities. The first grant call was published in late 2016 with applications from November 2016 to March 2017. From the total budget of 80 million CZK (over 3 million EUR) every BEV was incentivized by 220 000 CZK (8 800 EUR) and every PHEV by 200 000 CZK (8 000 EUR). Projects had to be realized until the end of 2018 (NPŽP 2016).

The next round of applications was held from November 2017 to September 2018. The grant for BEV was increased to 250 000 CZK (10 000 EUR), while other terms remained the same. The deadline for purchases was set to the end of 2019 (NPŽP 2017). The third grant call was organised during first 9 months of 2019 with the budget increase to 90 million CZK (3.6 million EUR). Realization of projects was due December 2020 (NPŽP 2018). Finally, the last subsidy program enabled to apply for grant from February to October 2020. The budget was slightly increased again, and the subsidizing ended at the end of 2021 (NPŽP 2019).

Chapter 4

Data

The use of dependent and independent variables varies across the studied literature. Justification will be provided regarding the choice of variables which was adjusted for the purpose of our analysis. Furthermore, we will identify sources of data and issues that arose during the data collection. At last, summary statistics will be discussed, and the quality of the dataset checked.

4.1 Dependent variable

The data on both BEV and PHEV registrations figures are provided by European Alternative Fuels Observatory (EAFO). Established by the European Commission, since 2015 the EAFO collects information from all the EU member states regarding alternative fuels vehicles sales or infrastructure development required for their comfortable use. Coherent information, which can be found in one place, is a very useful tool at a time of major transport changes in connection with the Green Deal plan (European Commission 2022). The fact of availability of the registrations data on a monthly basis during the period between 2015 and 2021 encouraged us to conduct research with this granularity. Annual aggregation of monthly values was used to obtain annual data for the second part of research.

Although the sales of electric vehicles are often used in the literature rather than the registrations, due to the availability of the latter one figures only those were used. Moreover, incentive measures in the Czech Republic require vehicle registration in the Czech territory in order to apply for the rebate and a sale of vehicle reported does not imply its use at the same place, it may be transported to another country.

Existing studies differ in their approach to dependent variable representation in the regression model. While Gallagher & Muehlegger (2011) divide the EV sales by state population figure to obtain electric vehicle sales per thousand population, Sierzchula et al. (2014) use national market share of electric vehicles as a percentage of all car sales. Jin et al. (2014) even explained change in pure EV sales data as a unit variable in their study.

In our research we decided to use the latter two types of dependent variables to compare and possibly confirm the findings. Hence, monthly total vehicle registrations figures were obtained from the ACEA dataset (ACEA 2021a), and BEV + PHEV market share were subsequently calculated.

4.2 Independent variables

We needed to consider many variables that could possibly influence EV sales changes in time and in different countries. The most monitored explanatory variable was the incentive dummy variable for which we tried to estimate the significance of its effect on EV registrations to help us assess the effectiveness of this policy measure. Vehicle-related variables are directly linked to vehicle operation, and they include EV recharging points or fuel prices. Finally, socio-economic variables will be presented, such as household median net income or population share living in house.

4.2.1 Incentive dummy

Two Czech governmental subsidy programs to incentivize EV sales were in force during the observed period between 2015 and 2021. As described in the previous chapter, this policy in form of rebates was organised independently by the Ministry of Industry and Trade and also by the Ministry of the Environment of the Czech Republic. The programs had different terms and specifications and EV registrations could be affected in slightly different time periods. Hence, dummy variables were created separately for the program of the Ministry of Industry and Trade (API 2016; 2017a;b; 2018; 2019) and for the one organised by the Ministry of the Environment (NPŽP 2016; 2017; 2018; 2019) based on the dates by which the vehicle could be purchased according to the program specifications. Furthermore, separate dummy variable was created to cover both these programs, which can be interpreted as any Czech subsidy program in force.

Between 2015 and 2019, no other such program to incentivize EV sales was underway in the five monitored countries of the Czech Republic, Estonia, Latvia, Lithuania, and Poland. That is the reason why exactly the latter four countries were chosen to form a control group to enable measuring effect of treatment in the Czech Republic. Furthermore, all the five countries are quite similar in terms of standard of living and other conditions related to EV purchase or operation.

Unfortunately for our analysis, in 2020 and 2021, new EV subsidies were introduced in Estonia, Lithuania and also in Poland, with an average level of aid of EUR 5000. On the one hand, these were less supportive from point of the absolute percentage discount, on the other, also individual consumer could have applied for them. In any case, in order to try to account for these incentives in at least some of the model specifications, the fourth dummy variable indicating any EV subsidy program in any of the 5 countries was created.

In Estonia, applications for the first round of the aid began in half January 2020 and other rounds unregularly repeated until 2021 (KIK 2019; ERR 2021). Hence, both years were marked as incentive in force. Similar amount of rebate for EV purchase was offered by Lithuania and cars bought only after half March 2020 were eligible for the discount (APVA 2020). With another round this policy measure continued until the end of the period under review (APVA 2021). Therefore, the months from April 2020 till December 2021 are also considered treated. Finally, Polish citizens and firms started to register applications for the subsidy scheme from June 2020 (NFP 2020). In 2021, this program continued and so we marked the treatment since July 2020 until December 2021 for the dummy variable representing any incentive in the five countries in given time (Government of Poland 2021).

Apart from incentive schemes in form of rebates, some other nationwide measures were introduced during the monitored period between 2015 and 2021. A comprehensive overview of these is provided by regularly published pocket guide to the automotive industry. Besides EV incentives summary, information related to production, sales or employment are provided (ACEA 2015b; 2016b; 2017b; 2018b; 2019b; 2020b; 2021b). Nevertheless, the subsidy schemes described in previous paragraphs and indicated through dummy variables were not precisely covered by this guide. For instance, the Czech EV incentive program was mentioned only in 2020 publication, despite being active since 2016. Hence, a careful check on data provided and other sources usage was required.

An insight into what the exact benefit is and how it works gives another regularly produced document called ACEA Tax Guide. It provides a detailed list of taxes levied on vehicles in all the European countries (ACEA 2015a; 2016a; 2017a; 2018a; 2019a; 2020a; 2021a).

Throughout the observed period, electric vehicles registered in the Czech Republic were exempt from road tax. However, this tax is applied only on vehicles used for business purposes and is calculated according to engine size. Furthermore, the amount paid for common vehicle and therefore possible savings from EV operation are nearly negligible when compared to purchase prices of electric vehicles. We tried to calculate the amount of annual tax for very widespread car Škoda Octavia of engine size approximately 1500 cubic centimetres (cc) and assuming that the car is new, the operator of vehicle pays around EUR 50 (Penize.cz 2022). In the recent years, also exemption from registration charges and vignettes have come into force in the Czech Republic with a benefit of around same level as in the case of road tax.

In Latvia, a deduction of the amount of company car tax was provided as an incentive during the years subject to our study. A monthly fee for electric vehicles was EUR 10 as compared to the one for common vehicles of around EUR 30. The annual benefit therefore exceeds EUR 200. In 2015 and 2016, also a motor vehicle registration tax with exemption for electric vehicles was applicable in Latvia before its abolition in January 2017. In that time, our benchmark model Octavia was available with an default engine emitting 112 g/km of CO2 (Cars-data 2020). That placed it into the lowest band for tax calculation with only EUR 0.43 to be paid for every gram of CO2 emissions per kilometre resulting in less than EUR 50 annual tax in total. Since 2017, electric vehicles sales have been incentivized by exemption from road traffic tax. Annual benefit is also approximately EUR 50 when using Octavia for comparison. Lastly, from 2020 on the first registration of an electric car is free of charge. For other vehicles a fee of EUR 44 must be paid.

In Estonia, Lithuania and Poland no other significant incentives were in force during the observed period except for subsidy programs explained earlier in this subchapter.

For the purpose of our study, Czech and Latvian nationwide supplementary incentives will be neglected in our models' specifications as we consider them to hardly influence EV registrations. The monetary benefit they bring is negligible and they cannot compensate for a much higher purchase price of electric vehicle compared to a conventional vehicle of the same class. The inclusion of another dummy variable reflecting these measures could bring more damage than benefit to our models.

Finally, a plenty of local incentive programs to promote EV sales was in force between 2015 and 2021. For instance, municipalities often provide parking fee waivers for low emission vehicles, or they allow them to use bus lanes. As the nature of these measures is just local, they are not able to influence the demand for electric vehicles among citizens of the whole country. Mersky et al. (2016) used local incentive measures of Norwegian municipalities in their study to analyte regional EV sales data. However, in the existing literature the research is mostly conducted with state-level data. In these cases, the researchers often decide to omit variables reflecting local incentives or incentives with negligible effect on EV sales. Jenn et al. (2018) or Gallagher & Muehlegger (2011) did so, among others. We will follow their example in our study.

4.2.2 Vehicle-related variables

A spread of recharging points might be a factor influencing EV registrations in time to some extent. Ščasný et al. (2019) conducted a survey in 2017 on a representative sample of the population of the Czech Republic. 64% of people who planned to buy a new car in the next three years believed that the public recharging stations would be little available at the time of purchase in the Czech Republic. More than three fourths of these people claimed that sufficient network of public recharging points would make it easier for them to buy an electric car. That made it the most selected answer.

Many existing studies include charging infrastructure variable in their models. For instance, research of Sierzchula et al. (2014) or Mersky et al. (2016) found its positive impact on EV sales. However, the latter one admits possibility of endogeneity problem, since also spread of electric vehicles might cause charging infrastructure development and not the other way around. Münzel et al. (2019) adds that the number of charging stations varies significantly even among different regions of a country. Furthermore, people disposing of private home or work charging might be less incentivized by the public infrastructure than other possible EV users. It is therefore important to consider these possible shortcomings when interpreting the results of analysis.

The data on the number of Czech charging points were obtained from the database of the Czech Transport Research Centre (CDV 2021). For remaining 4 states, only data from EAFO were found and used (European Commission 2022). There are several types of chargers distinguished based on the charging speed, but we decided to account only on aggregated figures of all types of charges available in each country in given time. While the Czech data are on a monthly basis, unfortunately the rest are only annual data. For the purpose of monthly branch of research, the data for Estonia, Latvia, Lithuania and Poland were interpolated linearly between each two observations using Microsoft Excel trend function.

As there are huge differences in the sizes of studied countries, correction for population figure seemed reasonable. Population figures were obtained from each country's statistical office (Czech Statistical Office 2022; Official Statistics of Latvia 2022; Official Statistics Portal Lithuania 2022; Statistics Estonia 2022; Statistics Poland 2022). Monthly data were available except for Estonia for which monthly data were interpolated from annual as in the case of charging points. Lastly, the number of EV recharging points in each time was divided by the population figure in millions of inhabitants.

The petrol and diesel price are widely used control variable among existing research. Our monthly data were extracted from the dataset provided by the Department for Business, Energy and Industrial Strategy of the Government of the United Kingdom (Government of the United Kingdom 2022). The price figures include tax and are expressed in pence per litre. An additional variable overarching both the prices was created by taking the average in each observed time.

The decision regarding purchase of electric vehicle may be influenced also by electricity price. That is the case for customers living in houses and recharging from their own electricity. Semi-annual data of electricity price for household consumers were collected from Eurostat database and adjusted for the purposes of monthly data research (Eurostat 2022c). The figures are expressed in price per kWh with all taxes and levies included. Band of annual consumption between 2500 kWh and 5000 kWh was chosen for comparison between countries. Furthermore, instead of using exchange rates to convert to EURO, the purchasing power standard was used as currency. It enables to account for differences in price levels between countries and we can directly see where the good or service is relatively cheaper or more expensive (Eurostat 2014).

Tláskalová (2021) added an independent variable of renewable energy share to some of her model specifications. The significance of its effect on EV market share in her results inspired us to control for this variable in our research as well. We might expect that in countries with a higher share of energy from renewable sources its population will also be willing to drive environmentally friendly vehicles. On the opposite, coal-fired power plants as main electricity source might discourage people from buying and EV as they would only transfer emissions from the exhaust system to the chimney of the power plant. The latter may be the case of Czechia and Poland, where barely over 15% of electricity was generated with use of renewable sources in 2020. In contrast, in Latvia this value climbed to 42% in that year. The figures come from Eurostat database and are published on annual basis (Eurostat 2022f).

The total number of vehicles registered differs in each country due to differences in size of the market, but also due to different mentality or living conditions of the population. As this figure might affect the EV market share also from time perspective, the dataset for vehicles in use was obtained from ACEA (2022). Only annual data between 2015 and 2020 were available. Hence, 2021 and monthly figures were modelled in Microsoft Excel using the trend function as in previous cases. The Czech data including 2021 figure were available on the Czech Car Importers Association website and these were used as they might be more precise (Czech Car Importers Association 2022a). Every observation was divided by the population figure observed at the same point of time to get a figure of total vehicles in use per one thousand inhabitants. This action was considered necessary for the same reason as in the case of recharging points.

Liu et al. (2021) accounted for local EV manufacturer when examining EV incentives in Chinese cities. We decided to follow this example as in the Czech Republic the car market is significantly affected by the participation of domestic brand with a long tradition. Škoda Auto regularly reaches about 35% Czech car market share (ŠKODA AUTO 2022). The launch of its battery electric model CitigoE iV in November 2019 might have had a significant impact on BEV market share and nearly at the same time also a brand-new plug-in hybrid Škoda Superb iV recorded its first registrations. Finally, Škoda Enyaq iV started to influence BEV sales in 2021 (Czech Car Importers Association 2022b). There was no other country examined in our study with EV production during the observed period.

To capture how Škoda Auto influences BEV and PHEV sales, a dummy variable called local manufacturer was created marking November 2019 to December 2021 in the Czech Republic with 1.

4.2.3 Socio-economic variables

As electric vehicles remained expensive relative to conventional cars, controlling for population income seemed reasonable. Eurostat provides the annual data on household median equalised net income in purchasing power standard (Eurostat 2022d). An equivalised income enables a relative comparison of different households as various number of members and even their age are taken into account (Eurostat 2021a). The adjustment for monthly analysis purpose was made as in previous cases.

Many researchers include unemployment rate variable in their models. While Mersky et al. (2016) used it alongside household income in their models, Jenn et al. (2013) assumed that unemployment rate influences disposable income and therefore also EV sales. Availability of monthly data on unemployment encouraged us to use this variable as well (Eurostat 2022g). We chose seasonally adjusted data to eliminate influence of regular patterns on unemployment during year, such as harvest time or school graduation (U.S. Bureau of Labour Statistics 2001). A percentage of population in the labour force was used as a unit of measure of unemployment.

Another variable linked to population wealth is an income quintile share ratio. It rather measures inequality of income distribution as it divides the income of the top quintile of population by the income of the bottom quintile. The top and bottom quintile express the total income received by the 20% of the population with the highest and lowest income, respectively (Eurostat 2021b). The higher purchase price of electric vehicles might imply their larger market share in countries with large ratio. The annual data were obtained from Eurostat database and adjusted in Microsoft Excel as before (Eurostat 2022a).

An education of possible EV buyers might influence sales of these vehicles. To account for this, we found out and downloaded Eurostat annual database of share of 25-34 population with successfully completed tertiary education (Eurostat 2021c). The tertiary studies include university or higher technical education. Nevertheless, Sierzchula et al. (2014) did not prove any significant effect of education level on EV sales in different countries.

Some existing studies consider where do people live when examining EV sales. To run an electric vehicle in a city may be attractive as municipalities provide different benefits such as free parking. On the other hand, outside of a city there is a higher probability that a driver has its own house and recharging equipment.

To analyse possible relationship between a degree of urbanisation and EV sales, annual data were obtained from Eurostat (Eurostat 2022b). The database provided us with a share of people living in cities and separately with a share of people living in towns or suburbs. Each local administrative unit is assigned into a category of city, towns and suburbs or rural area based on the population density and geographical contiguity (Eurostat 2018).

Similar concept as with previous independent variable is applied in the case of a share of population living in a house. Such type of dwelling enables comfortable usage of an electric vehicle. Annual data were downloaded from Eurostat database (Eurostat 2022b). countries.

Finally, Gallagher & Muehlegger (2011) also controlled for age in different states. We used Eurostat annual dataset on median age (Eurostat 2022e).

4.3 Dataset description

It is important to explore possible correlation among independent variables. Strong negative correlation coefficient of -0.92 was detected for renewable energy share and population share living in house. Correlation coefficient for petrol and diesel price variables treated separately reached 0.93. As these variables measure similar factor influencing the decision regarding EV purchase, they were merged into one variable by computing the average of both values for each observation. To address the issue of possible multicollinearity, the variance inflation factor test will be performed and its implications discussed in the results section.

Finally, we provide summary statistics of monthly and annual data. The former one is presented in Table 4.1, the latter in Table A.1. Panel data are balanced in both cases, which was achieved by interpolation of missing values, especially in the case of monthly data. For that purpose, MS Excel function TREND was used, which returns values along a linear trend. The method of least squares is used to fit a straight line of known values.

While the dependent variable related to electric vehicle market is expressed directly as a rate of the EV sales to total sales, for other variables of share a percentage is the unit of measure. That is the case for renewable energy share, unemployment rate, share of population with higher degree education, and share of population living in specific places or type of dwelling. The incentive dummies are reported as binary variables, as well as the local manufacturer dummy. The recharging points are measured in units or in units per million inhabitants, the total number of registered vehicles was related to one thousand of inhabitants. The variable of electricity price measures the price per kWh using the purchasing power standard. Due to the availability of data, pence per litre express the average price of petrol and diesel. The purchasing power standard was further used to report median net income, while simple ratio measures the inequality. Finally, a year is a unit of measure for median age.

The summary statistics Table 4.1 created by stargazer package in R provides us with mean and median value, standard deviation and also with extreme values of minimum and maximum of each variable (Hlavac 2022). The highest BEV + PHEV market share of 11.4% was reported in Latvia in November 2021, although the overall mean and median figures are much lower. The main reason is a rapid growth in EV registrations especially in the last 2 years of the reference period. The independent variables offer significant variation among countries and time periods as well. For instance, in Estonia, there were nearly 328 recharging points per one million inhabitants in operation at the end 2020 as compared to only 3 units of them available in Lithuania at the beginning of 2015.

Table 4.1: Summary statistics for monthly data

Statistic	N	Mean	Median	St. Dev.	Min	Max
BEV + PHEV registrations	420	119.502	24	288.456	1	2,416
BEV + PHEV market share	420	0.011	0.004	0.015	0.0003	0.114
Czech incentive dummy	420	0.162	0	0.369	0	1
Foreign incentive dummy	420	0.150	0	0.357	0	1
Recharging points	420	424.474	301.4	480.574	10	2,811
Recharging points per 1.m	420	97.434	51.925	99.889	3.093	327.803
Petrol-Diesel avrg prc	420	97.374	98.338	12.790	66.830	124.735
Electricity price	420	0.215	0.220	0.033	0.152	0.306
Renewable energy	420	24.872	25.688	9.647	11.059	43.335
Cars per 1 k	420	494.722	515.956	99.506	304.454	679.277
Local manufacturer dummy	420	0.062	0	0.241	0	1
Household median net income	420	10,824.640	10,962.380	1,953.149	6,616.833	14,314.000
Unemployment rate	420	5.889	6.200	2.228	1.700	10.100
Inequality S80 S20 ratio	420	5.330	5.230	1.332	3.320	7.827
Higher degree	420	43.112	43.025	7.393	29.533	57.200
Population in cities	420	40.424	42.862	8.552	30.000	61.000
Population in towns/suburbs	420	18.309	19.113	10.516	0.800	34.600
Population in cities/towns/suburbs	420	58.733	59.200	7.152	43.900	69.700
Population in house	420	43.232	40.404	7.778	33.300	57.400
Female population	420	52.627	52.921	1.271	50.744	54.197
Median age	420	42.230	42.350	1.242	39.325	44.300

The second monthly dataset was created by deleting observations from years 2020 and 2021 for the purpose of our analysis. The statistics is provided in Table A.2.

Finally, we can compare the means and standard deviations from the summary statistics table. The standard deviation proved to be much greater than the mean in case of the dependent variables, which is caused by high skewness of the data.

Chapter 5

Methodology

Having panel data prepared, we can employ an appropriate regression method to estimate the effects of our independent variables on EV sales. As we intended to evaluate specific policy of one country in our research, difference-in-differences approach was chosen. It is widely used to compare the outcome of so-called treated group, where the examined policy was active at a specific period, to the outcome of control group, where no measures were taken at all.

Balanced panel data and multiple states and time periods are appropriate for using a generalized difference-in-differences design. Commonly in existing research, this design is analysed by using two-way fixed effects model (Wing et al. 2018). Hence, the difference-in-differences model in our specification represents a specific type of fixed effects estimation method. The two-way fixed effects regression consists in controlling for state- and time-specific trends. By inclusion of state-specific fixed effects, we ensure that we only analyse the impact of variables which vary across time periods. On the other hand, time-specific fixed effects remove the potential bias of other estimates resulting from common time trend across the states. Then, from general two-way fixed effects model, the difference-in-differences model is created by adding our incentive dummy variable, which marks by 1 a treatment active in a particular state at a particular time.

Assumptions for fixed effects include unobserved effects in model specification, random sample, no perfect linear relationship among the independent variables, strict exogeneity, homoskedasticity and no serial correlation. Hence, for each model, Breusch-Pagan test to detect possible heteroskedasticity and Breusch-Godfrey test to detect serial correlation will be conducted. Contemporaneous correlation or cross-sectional dependence will be checked with the

Breusch-Pagan LM test, while the augmented Dickey-Fuller test will verify the assumption of stationarity of the data. In case of non-stationarity, as this characteristic might distort the results of our regressions, robustness check using first differencing will be provided. First-difference model removes the unobserved, time-invariant variable. Furthermore, variance inflation factor test will be used to detect multicollinearity. For difference-in-differences design to work well, we need to add the common trends assumption, too. As we consider only state- and time-specific fixed effects, the time series of our outcome across states should only differ by a fixed amount in every period. However, in our models, we include additional independent variables to explain for variation, for which the treatment dummy fails to explain. That allows us to only plot the dependent variable across states in time and visually assure that the time series are approximately parallel lines (Wing et al. 2018).

We proceed with exact model specifications, which are used separately for monthly and for annual data. The first specification includes only the one independent variable of particular interest, the incentive dummy. The two-way fixed effects model is specified as follows.

$$BEV + PHEV\ market\ share_{it} = \beta_1 Czech\ incentive\ dummy_{it} + a_i + b_t + u_{it}$$

The dependent variable is the EV market share or the EV registrations. i represents the country, while t denotes the period of each observation. The $Czech\ incentive\ dummy$ is the only independent variable included. β_1 coefficient is of a particular interest to us because it indicates the effect of incentive on the market share or registrations. a_i denotes state-specific fixed effects, whereas b_t is included to cover time-specific fixed effects. Finally, u_{it} represents the error term.

After running these simple regressions, we extend the model by including all the other independent variables described in the previous chapter. No other changes are made with this two-way fixed effects model as compared to the basic one.

$$BEV + PHEV\ market\ share_{it} = \alpha Czech\ incentive\ dummy_{it} + \beta_k X_{it}^k + a_i + b_t + u_{it}$$

X_{it}^k stands for all the remaining independent variables described which are not already included in the model specification. β_k represents a set of coefficients describing the effect of each of these variables on the dependent variable.

This time, the coefficient α shows the estimated effect of the Czech subsidies. As with the basic models, different versions of specification varying in the dependent variable are provided.

Chapter 6

Results and discussion

In this chapter, we provide results of our regressions. We start with basic models exploring the direct relationship of incentives and EV market share or registrations. Only then the more complex regressions are discussed, which show the effect of other variables on EV spread.

6.1 Basic regressions results

As described in the methodological part of this thesis, we start our analysis by studying separately the effect of incentives on the EV sales. At first, results of assumptions testing are provided. We proceed by regressions results description afterwards. EV market share is explained before EV registrations.

Augmented Dickey-Fuller test for EV market share results in p-value above 0.01, indicating non-stationarity of the monthly data between 2015 and 2021. However, the monthly dataset restricted to period between 2015 and 2019 provides stationary time series for our basic model. This testing is not required for annual data as we only have 7 time periods. There is no need to run variance inflation factor test as we only include one independent variable in these models. The common trends assumption is checked by plotting the dependent variables. No serious violation is detected.

We fail to reject the null hypothesis of the studentized Breusch-Pagan test with sufficiently high p-value for complete monthly data and annual data. Hence, the homoskedasticity assumption is fulfilled except from the model of restricted monthly dataset. Breusch-Godfrey and Breusch-Pagan LM tests result in p-value below the threshold of 0.05 for both monthly datasets, indicating serial correlation and cross-sectional dependence, respectively. As for the annual data, only the contemporaneous correlation is detected. To correct for assumptions violation, heteroskedasticity and serial and contemporaneous correlation robust standard errors were used, reported in parentheses in the tables. Even though some assumptions are met, it is a common practice to report rather robust standard errors.

The results are presented in Table 6.1. The effect of Czech policy promoting EV purchases is not statistically significant in any of the three regressions. Hence, we did not find any evidence that the incentives lead to increase in market share of battery and plug-in hybrid electric vehicles. Our models are very underspecified, though, as also the goodness of fit measures indicate.

Table 6.1: Basic fixed effects models - results for EV market share

	Dependent variable:		
	BEV + PHEV market share		
	Monthly	Monthly 2015-2019	Annual
	(1)	(2)	(3)
Czech incentive dummy	-0.0002	-0.0005	0.0004
	(0.002)	(0.0005)	(0.001)
Observations	420	300	35
R^2	0.00004	0.002	0.001
Adjusted R^2	-0.266	-0.270	-0.477
F Statistic	0.012 (df = 1; 331)	0.416 (df = 1; 235)	0.015 (df = 1; 23)
Note:			*p<0.1; **p<0.05; ***p<0.01

The augmented Dickey-Fuller test for EV registrations dependent variable leads to the same conclusions as in the case of EV market share. Hence, complete monthly dataset requires robustness check. Moreover, visual check for common trends assumption is successful. The homoskedasticity assumption is fulfilled for all three regressions using different datasets, as Breusch-Pagan test shows. On the contrary, Breusch-Godfrey and Breusch-Pagan LM tests provide sufficient evidence to reject the null hypothesis of no serial correlation and no cross-sectional dependence, respectively. Heteroskedasticity and serial and contemporaneous correlation robust standard errors are reported as they provide a better picture of significance of the independent variable.

Our two-ways fixed effects models' results explaining EV registrations are listed in Table 6.2. This time, we can see an expected positive relationship between Czech incentive dummy variable and EV registrations in all three regressions. Specifically, when the Czech subsidy policy was in force, the monthly registrations of battery and plug-in hybrid electric vehicles increased by approximately 65 vehicles, as complete monthly data examination induces. The estimated effect is significant at 0.05 level. Annual data analysis corroborates this finding with estimate of 894 EV registrations annually attributed to the effect of the Czech incentive with significance at 0.1 level. Only restricted monthly dataset did not prove any significant relationship. Moreover, the effects are large, monthly sum of BEV and PHEV registrations in the Czech Republic ranged from 10 to 1521 vehicles with the upper bound being an outlier. Hence, the increase of 65 vehicles represents a significant effect. As for the annual data, total Czech BEV + PHEV registrations grew from 459 in 2015 to 6390 in 2021. However, the significance of our basic models is very limited due to absence of other independent variables.

Table 6.2: Basic fixed effects models - results for EV registrations

	Dependent variable:		
	BEV + PHEV registrations		
	Monthly	Monthly 2015-2019	Annual
	(1)	(2)	(3)
Czech incentive dummy	64.560**	8.584	894.125*
	(26.973)	(6.248)	(472.806)
Observations	420	300	35
R^2	0.003	0.002	0.006
Adjusted R^2	-0.263	-0.270	-0.470
F Statistic	0.852 (df = 1; 331)	0.452 (df = 1; 235)	0.137 (df = 1; 23)
Note:			*p<0.1; **p<0.05; ***p<0.01

Finally, a robustness check is performed with respect to violations of stationarity assumption in the case of complete monthly dataset. First-difference models with both possible dependent variables suffer from serial correlation, but they fulfil the assumption of homoskedasticity. Nevertheless, heteroskedasticity and serial and contemporaneous correlation robust standard errors are used.

In Table 6.3, the resulting estimates are listed for first-difference models exploring full monthly data. These results are not consistent with parallel fixed effects estimations. They show a significant negative effect of Czech EV purchase subsidies on EV market share and registrations. On the other hand, the estimated negative effects are of negligible magnitude. In the case of market share, a decrease of 0.1% is only minor as compared to more than 2% share of EV in some months of 2021. Reduction of 13 registered vehicles also represents a much smaller effect than the positive one from previous results table. In conclusion, the robustness check for previous results fails, if we assume non-stationarity of the data.

Table 6.3: Basic first-difference models - robustness check for complete monthly data

	Dependent variable:	
	BEV + PHEV market share	BEV + PHEV registrations
	(1)	(2)
Czech incentive dummy	-0.001**	-12.853***
	(0.0004)	(4.781)
Constant	0.001	7.853
	(0.0004)	(4.781)
Observations	415	415
R^2	0.00003	0.00002
Adjusted R^2	-0.002	-0.002
F Statistic (df = 1; 413)	0.011	0.010
Note:		*p<0.1; **p<0.05; ***p<0.01

6.2 Complete regressions results

In this subchapter, we proceed with results of regressions with full set of independent variables. As in the case of basic regressions, we first examine the EV market share. Afterwards, we work with EV registrations, only moving to robustness checks at the end.

Many time series in both monthly datasets are non-stationary, as the augmented Dickey-Fuller test revealed. As we intend to use many variables to explain EV sales changes, we also need to test for multicollinearity. The variance inflation factor test indicates some serious correlations when including all the described independent variables into the model specification. In order to keep the factor below 5 by all the variables, as many sources recommend, we had to exclude renewable energy share, household median net income, unemployment rate, higher degree, population share in house, female population and median age. Furthermore, the local manufacturer dummy variable was not examined in case of the restricted monthly dataset and annual data. Foreign incentive dummy was included in complete monthly and annual models. After reduction of variables, our Czech incentive dummy of special interested scored between 2 and 3.4 in different models. The common trends assumption was verified by plotting the data, as in previous cases. The non-stationarity and multicollinearity issues described apply for both sets of models differing in dependent variables.

The Breusch-Pagan test results in a value below 0.05 for both models of monthly datasets explaining EV market share, indicating heteroskedasticity. For the annual analysis, the homoskedasticity assumption is fulfilled. Finally, serial and contemporaneous correlation have to be dealt with in all cases as

Breusch-Godfrey and Breusch-Pagan LM tests provided enough evidence to reject the null hypothesis of assumptions fulfilment. Hence, heteroskedasticity and serial and contemporaneous correlation robust standard errors are reported in parenthesis.

Table 6.4 depicts the estimated effects of individual variables on EV market share. None of them is significant in case of Czech incentive dummy. These results confirm those of basic analysis of EV market share with goodness of fit measures better as more independent variables were included.

Table 6.4: Complete fixed effects models - results for EV market share

	Dependent variable:		
	BEV + PHEV market share		
	Monthly	Monthly 2015-2019	Annual
	(1)	(2)	(3)
Czech_incentive_dummy	−0.001	−0.001	−0.003
	(0.001)	(0.001)	(0.002)
Foreign_incentive_dummy	−0.005*		−0.006***
	(0.003)		(0.001)
Recharging_points	0.00000**	0.00001***	0.00000***
	(0.00000)	(0.00000)	(0.00000)
Petrol_Diesel_avrg_prc	0.0001	0.00003	−0.0002*
	(0.0001)	(0.0001)	(0.0001)
Electricity_price	0.019	0.025	0.007
	(0.035)	(0.018)	(0.029)
Cars_per_1_k	−0.00002	−0.00004***	−0.00001
	(0.00002)	(0.00001)	(0.00002)
Local_manufacturer_dummy	−0.004		
	(0.006)		
Inequality_S80_S20_ratio	0.003	0.003***	0.002
	(0.002)	(0.001)	(0.002)
Population_in_cities	0.0001	0.0002***	0.0002**
	(0.0002)	(0.0001)	(0.0001)
Observations	420	300	35
R^2	0.058	0.145	0.486
Adjusted R^2	−0.221	−0.117	−0.091
F Statistic	2.228** (df = 9; 323)	5.535*** (df = 7; 229)	1.894 (df = 8; 16)
Note:			*p<0.1; **p<0.05; ***p<0.01

We continue with estimating the effect of EV subsidies on EV registrations. Heteroskedasticity, serial and contemporaneous correlation are present in all our specifications, as the testing reveals. Hence, we use robust standard errors.

The results are provided in Table 6.5. As in the case of basic regression, the analysis of full monthly data shows a significant positive effect of Czech incentives on EV registrations. The magnitude is again large with 54 more vehicles registered per month throughout the period the policy was active. Restricted monthly dataset does not offer such relationship, which is in line with basic regressions results. However, these results are not confirmed by the model of annual data.

Table 6.5: Complete fixed effects models - results for EV registrations

	Dependent variable:		
	BEV + PHEV registrations		
	Monthly	Monthly 2015-2019	Annual
	(1)	(2)	(3)
Czech_incentive_dummy	54.472**	8.157	−570.824
	(27.129)	(13.566)	(380.745)
Foreign_incentive_dummy	98.764***		395.635
	(18.610)		(425.791)
Recharging_points	0.777***	0.291***	6.550***
	(0.053)	(0.053)	(0.201)
Petrol_Diesel_avrg_prc	−3.923*	−2.491***	−62.533*
	(2.025)	(0.684)	(37.015)
Electricity_price	830.514*	−232.428	13,776.360
	(432.712)	(420.973)	(9,560.092)
Cars_per_1_k	−1.647***	0.032	−11.576**
	(0.322)	(0.150)	(5.575)
Local_manufacturer_dummy	−147.181**		−1,162.209
	(62.190)		(1,110.708)
Inequality_S80_S20_ratio	−38.613	−12.266	−393.708
	(27.955)	(15.087)	(382.057)
Population_in_cities	7.391***	1.474**	78.937***
	(1.447)	(0.719)	(12.637)
Observations	420	300	35
R^2	0.829	0.450	0.957
Adjusted R^2	0.778	0.282	0.902
F Statistic	174.270*** (df = 9; 323)	26.791*** (df = 7; 229)	36.926*** (df = 9; 15)
Note:			*p<0.1; **p<0.05; ***p<0.01

We finish with the robustness checks using first-difference models for both monthly datasets due to suspicion of non-stationarity. Similar results are obtained as in the case of basic regressions. The effect of Czech policy in force is -0.1% and -0.03% in case of full monthly and restricted monthly dataset, respectively. 10 less vehicles were registered during the measure when analysing monthly data between 2015 and 2021. Excluding 2020 and 2021 reduces the negative effect to only 7 vehicles. The effects in all four models are weak, indicating only a limited influence. However, as before, we fail to confirm our findings of stimulating effect of Czech incentive programs on EV registrations.

Table 6.6: Complete first-difference models - robustness check for both monthly data

	Dependent variable:			
	BEV + PHEV share Monthly	BEV + PHEV reg. Monthly	BEV + PHEV share Monthly 2015-2019	BEV + PHEV reg. Monthly 2015-2019
	(1)	(2)	(3)	(4)
Czech_incentive_dummy	−0.001**	−10.464*	−0.0003**	−7.172***
	(0.0004)	(5.405)	(0.0001)	(2.495)
Foreign_incentive_dummy	−0.003	28.201		
	(0.004)	(25.888)		
Recharging_points	0.00001	0.510	0.00000	−0.138
	(0.00001)	(0.535)	(0.00001)	(0.157)
Petrol_Diesel_avrg_prc	0.0002	2.773	−0.0001	−0.497*
	(0.0001)	(1.961)	(0.00004)	(0.268)
Electricity_price	0.254	876.144	0.009	369.421
	(0.184)	(725.456)	(0.053)	(583.558)
Cars_per_1_k	−0.00004	1.864	−0.0001	0.453
	(0.0001)	(1.587)	(0.0001)	(0.466)
Local_manufacturer_dummy	0.001	23.944		
	(0.001)	(15.354)		
Inequality_S80_S20_ratio	−0.001	−118.059	0.009	35.414
	(0.011)	(98.037)	(0.006)	(51.056)
Population_in_cities	−0.0002	−4.094	0.001	−0.183
	(0.001)	(4.352)	(0.001)	(1.304)
Constant	0.0004	−4.024	0.0002	2.463
	(0.0003)	(3.756)	(0.0001)	(2.266)
Observations	415	415	295	295
R^2	0.015	0.016	0.011	0.007
Adjusted R^2	−0.007	−0.005	−0.013	−0.018
F Statistic	0.694 (df = 9; 405)	0.749 (df = 9; 405)	0.442 (df = 7; 287)	0.271 (df = 7; 287)
Note:				*p<0.1; **p<0.05; ***p<0.01

6.3 Limitations, findings, and hypothesis testing

We are aware of several issues, which burden our econometric analysis. For instance, the study of Mersky et al. (2016) suggest that the causal relationship between EV spread and recharging points figure might also be the other way around. That said, the increasing number of recharging stations would not necessarily lead to increase in EV sales, instead the changing EV demand in particular state might force government to improve the recharging points network so that it is even possible to comfortably use this kind of vehicle. In that case, our complete models' specifications would be problematic and yield biased results.

Additionally, more detailed data were required to obtain more accurate results. As we wanted to compare results of annual and monthly research, interpolation of some monthly time series was chosen to provide sufficient number of possible independent variables. Only those variables were adjusted that way, for which a fairly regular trend was visible. Variance inflation factor test excluded many of the interpolated series from our model specifications as these variables were often relative static and so correlated among each other. A typical example would be different shares of population, from which only population share living in cities was left in equation. Variables of recharging points in foreign countries, registered cars per thousand inhabitants or inequality ratio, which are included in complete regressions, were also interpolated to monthly data from only annual values available. In all cases, a clear trend was respected and this adjustment enabled us to analyse monthly data of EV spread, which were available at exact values.

Besides interpolation of different independent variables, we also marked the Czech incentive dummy of our special interest as active only approximately in time periods. It is very likely that in some periods in our monthly data, no EV was purchased with subsidy granted. However, detailed data about exact timing of subsidized purchases is missing, to the best of our knowledge. We marked rather wider time period with 1 as a policy in force, specifically, the whole period from the start of applications for grants until the realization deadline. Hence, it is possible that the effect was undervalued, because, for instance, in the first months there might have been no EV purchases with grants, although these months are already treated in the regression model.

The introduction of EV incentives in other countries also complicated the research. It was difficult to directly compare the programs across countries, and so other dummy variable had to be created. The inclusion of this variable naturally led to inaccuracies in results because the terms of such programs were different across countries. Furthermore, the spread of incentives in other countries took place at the same time as the rapid increase in EV registrations and market share in all the countries, that is during 2020 and 2021. This increase likely was not driven by the governmental policies and therefore their effect might have been overrated. The restricted monthly dataset was created to provide data unaffected of other policies.

Finally, local incentives might be relevant for potential EV buyers, but their inclusion to models is impossible. It would require even much more detailed data. Hence, the results of our regressions are inaccurate also because of omitting other important independent variables.

Many models with even different datasets were prepared to try to explain EV sales by incentive policy of the Czech government. Even second estimation method was used to ensure robustness of the results. From the results of fixed effects models listed in Table 6.2 and Table 6.5, we might deduce that some positive relationship between EV registrations and incentive policy of the Czech government really exists. And the effect is strong, as basic and complete regressions indicate for full monthly dataset in both tables. Furthermore, basic regression using annual datasets confirms this finding. However, the analysis of EV market share does not show any relationship with incentives at all. That applies for basic and advanced regressions of all datasets with results listed in Table 6.1 and Table 6.4. The robustness checks using first differencing lead to significant negative estimate of incentive dummy coefficient in all cases. That can be deduced from Table 6.3 and Table 6.6. These effects are of small magnitude and the correctness of use of this method is not certain as stationarity is violated only for several time series.

From other independent variables, increasing number of recharging points seems to be connected to EV spread, as a positive significant effect of a large magnitude was discovered in several models. However, the issue of causality would have to be resolved to draw conclusions. Higher share of people living in cities also appears to have a positive effect on increasing EV sales. Other estimates are either of unexpected sign, or insignificant.

Finally, as for our hypothesis testing, according to many models results, we fail to confirm that the Czech subsidy program led to increase in EV market share and registrations. To evaluate that policy more precisely, we would need more granular data to look into individual purchases.

Chapter 7

Conclusion

Electromobility is a clear trend and future of transportation. Countries all over the world incentivize the purchases of electric vehicles to reduce the difference in price as compared to conventional vehicle. The Czech Republic is no exception to this. The aim of this thesis was to present the Czech policy of electromobility promotion and evaluate its effectiveness. For that purpose, different panel datasets were created to estimate the effect of the policy using regression models. Monthly data were examined alongside annual data and additional restricted monthly dataset was presented to account for possible results distortions caused by incentives in foreign countries. We were inspired by similar studies from different countries and tried to replicate these analysis for Czech data as no such evaluation of the domestic policy had been performed before, to the best of our knowledge.

We chose a generalized difference-in-differences design to directly evaluate, whether the Czech governmental subsidies led to an increase in sales of electric vehicles. The market share and exact registrations were analysed separately to obtain robust results. Furthermore, the regressions were divided to basic and complete ones, which differed by inclusion of control additional independent variables. Two-ways fixed effects model was used for the purpose of our study.

Analysis of EV registrations showed strong, significant, and positive effect of Czech incentives in some of the model specifications. That would be what the government expected and aimed for. However, the robustness check using first-difference model showed significant negative effect, even though the magnitude was not so large.

When analysing market share, all the estimated effects of Czech incentives are statistically insignificant. Furthermore, first differencing indicates negative effect again, although the estimated coefficients are small and possibly enable us to conclude that there is no effect of Czech incentives on EV market share.

Given different and even contradictory results of specifications of our models, we are not able to confirm the hypothesis of Czech EV incentive programs increasing market share and registrations of such vehicles. Our analysis suffers from several limitations. First, more detailed data regarding the incentives itself would help to better track the exact effect. Additionally, causal relationship between EV sales and recharging points spread would need to be resolved. Interpolation and other issues also complicate applicability of the results.

To conclude, even though our study does not unreservedly state the exact effect of Czech incentive policy, the contribution of the thesis lies in proposing models to estimate the relationship and providing at least indicative results these regressions. Possible future extension of our work might focus on detailed data collection and possibly control group of countries adjustment. However, for our analysis, no others than the four chosen countries were able to serve as untreated. Hence, appropriate inclusion of foreign incentives seems to be inevitable.

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Appendix A

Summary statistics tables

Table A.1: Summary statistics for annual data

Statistic	N	Mean	Median	St. Dev.	Min	Max
BEV__PHEV__registrations	35	1,433.771	363	3,191.371	30	16,449
BEV__PHEV__market__share	35	0.010	0.005	0.012	0.001	0.041
Czech__incentive__dummy	35	0.143	0	0.355	0	1
Foreign__incentive__dummy	35	0.171	0	0.382	0	1
Recharging__points	35	494.000	324	583.368	18	2,811
Recharging.points.per.1.m	35	106.391	67.795	103.382	6.226	327.803
Petrol__Diesel__avrg__prc	35	98.886	98.125	14.085	70.770	122.460
Electricity__price	35	0.210	0.214	0.033	0.156	0.275
Renewable.energy	35	25.139	25.748	9.790	11.059	43.335
Cars__per__1__k	35	500.250	527.117	104.904	304.454	679.277
Local__manufacturer__dummy	35	0.057	0	0.236	0	1
Household.median.net.income	35	11,145.230	11,107	1,941.125	7,330	14,314
Unemployment.rate	35	5.666	6.000	2.226	2.000	10.000
Inequality__S80__S20__ratio	35	5.249	5.080	1.317	3.320	7.460
Higher__degree	35	43.311	43.1	7.444	31	57
Population__in__cities	35	40.626	42.800	8.991	30.000	61.000
Population.in.towns.suburbs	35	18.797	19.400	10.418	0.800	34.600
Population.in.cities.towns.suburbs	35	59.423	61.500	7.094	43.900	69.700
Population.in.house	35	43.211	40.500	7.947	33.300	57.400
Female.population	35	52.606	52.858	1.279	50.744	54.160
Median__age	35	42.357	42.483	1.241	39.600	44.300

Table A.2: Summary statistics for monthly data between 2015 and 2019

Statistic	N	Mean	Median	St. Dev.	Min	Max
BEV_PHEV_registrations	300	35.543	14	54.924	1	416
BEV_PHEV_market_share	300	0.004	0.003	0.003	0.0003	0.018
Czech_incentive_dummy	300	0.147	0	0.354	0	1
Foreign_incentive_dummy	300	0.000	0	0.000	0	0
Recharging_points	300	265.707	214	211.878	10	884
Recharging.points.per.1.m	300	76.127	34.265	92.956	3.093	294.231
Petrol_Diesel_avrg_prc	300	95.497	96.690	13.176	66.830	124.335
Electricity_price	300	0.209	0.217	0.029	0.155	0.257
Renewable.energy	300	24.222	25.515	9.626	11.059	40.929
Cars_per_1_k	300	480.147	506.849	91.204	304.454	634.660
Local_manufacturer_dummy	300	0.007	0	0.082	0	1
Household.median.net.income	300	10,124.960	9,954.500	1,711.572	6,616.833	13,374.000
Unemployment.rate	300	5.990	6.100	2.183	1.700	10.100
Inequality_S80_S20_ratio	300	5.477	5.484	1.373	3.320	7.827
Higher_degree	300	42.842	42.879	7.369	29.533	55.600
Population_in_cities	300	39.762	42.971	7.618	30.000	61.000
Population.in.towns.suburbs	300	17.697	19.262	11.060	0.800	34.600
Population.in.cities.towns.suburbs	300	57.459	58.887	7.362	43.900	69.700
Population.in.house	300	43.271	41.175	7.822	33.300	57.400
Female.population	300	52.673	53.054	1.290	50.786	54.197
Median_age	300	41.960	42.021	1.214	39.325	44.100