Tampere University

Emmi Hynninen

EFFECT OF THE SUBSIDY GIVEN FOR THE PURCHASE OF ELECTRIC VEHICLES IN FINLAND BETWEEN 2018 AND 2022 TO THE DEMAND OF ELECTRIC VEHICLES

Faculty of Social Sciences
Master’s thesis
May 2024

ABSTRACT

Emmi Hynninen: Effect of the subsidy given for the purchase of electric vehicles in Finland between 2018 and 2022 to the demand of electric vehicles
Master's thesis
Tampere University
Degree Programme in Social Sciences Research, Public Policy Analysis
May 2024

There are several policies set globally and locally in the efforts of trying to slow down global warming and its inevitable effects by reducing CO2 emissions. One big contributor of CO2 emissions is road traffic, and due to this, the European Union has implemented several policies and plans in this sector. One of the goals set by the European Union is to increase the percentage of electric vehicles in road traffic, which would reduce the CO2 emissions caused by road traffic. To achieve this goal, many policies and schemes have been implemented in all the member countries.

This thesis focuses on the Pigouvian subsidy given in Finland for the purchase of electric vehicles between 2018 and 2022. The aim is to study the impact of the subsidy to the number and the percentage of new electric vehicles registered, as previous studies have not been made on the subject in Finland.

The impact of the subsidy is analyzed with a difference-in-differences analysis, using hybrid petrol/electric vehicles registered in Finland as a control group. Although previous studies and the theoretical framework suggest that implementation of a subsidy should have had an impact in the growth of the percentage of electric vehicles registered, the analysis shows no indication of this. The reasons why the analysis showed this result, are discussed in the conclusions part of the thesis.

Keywords: Pigou, subsidy, electric vehicles, difference-in-differences, externalities

Acknowledgements

Being able to successfully complete my master's studies and this thesis was never something I took for granted. It took a lot of work, which I can only partly credit myself, as I received constant help and support from various fronts.

First, I'd like to sincerely thank Katri Sieberg for the time, support, and effort she took to make sure I get over the finish line. Thank you for gently pushing me forward, giving continuous feedback and suggestions, and offering help with everything, especially when I was discouraged by my ability to do the math and theoretical framework required.

Another invaluable help was Manela Karunadasa, who helped me with the empirical part of the thesis, and suggested ways to complete my analysis, when I encountered problems. Thank you for making the time to help me, even throughout weekends, and providing suggestions and ideas to go forward.

I'd also like to thank my awesome classmates, Hira, Ajim, Tana and Marian. The support I got from all of you throughout our studies was priceless, and especially in our thesis seminars. Besides the useful advice, the mental support and group spirit is something I hold dear at heart.

Lastly, I'd like to thank my family for supporting me throughout my studies and the thesis process. My husband Atte, who believed in me and my skills, and my daughter Mila and Alma who are my biggest cheerleaders.

This thesis is dedicated to my daughters, to help them remember that the right path is not always straightforward, and that with hard work, dedication, and effort, you can achieve anything you want.

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1 Introduction

The need to reduce the CO_2 emissions is recognized globally, and several measures have been done and goals for reductions have been made in order to reduce the emissions, and to slow down global warming as much as possible. Based on the goals set in the Paris Agreement, the European Union has set its own goals and timelines in achieving reductions in CO_2 emissions, and member states have in return made their own plans on how to achieve these goals.

This thesis focuses on measures done in Finland to reduce the CO_2 emissions caused by road traffic. One policy in particular is under investigation, the subsidy given for the purchase of electric vehicles between 2018 and 2022. The goal is to measure the impact of the subsidy on the increase of the number and percentage of the registration of new electric vehicles. This will be done with a difference-in-differences analysis.

The thesis starts off with a literature review that takes an overview of policies and measures done in the European Union and Finland to reduce the CO_2 emissions, especially the ones caused by road traffic. The literature review also explains the reasoning for government intervention, and the ways governments can intervene and impact on consumers decisions, especially when dealing with externalities. In addition, the literature review presents previous studies made on the effect of subsidies given for the purchase of electric vehicles in other countries, as well as difference-in-differences analysis made on the topic.

After the literature review, the theoretical framework is presented. In this part of the thesis, the basic function of supply and demand is explained, and how Pigouvian tax and subsidy can affect the demand and supply when dealing with externalities. The concept of perfect and imperfect subsidies is introduced, and it is shown how the cross-demand of elasticity determines how close substitutes are to one another. The game theoretical part of the theoretical framework shows how the decision between purchasing an electric vehicle instead of a combustion engine vehicle can be seen as a

Collective action problem, and it is explained by using the global warming example by Schecter and Gintis (2016) as a base for the model. The theoretical model focuses on the effect of taxes and subsidies to the demand of goods.

Based on previous studies and the theoretical framework, two hypotheses are made:

- *Hypothesis 1. After the subsidy was introduced in Finland, the demand for electric vehicles increased.*
- *Hypothesis 2. When the subsidy for electric vehicles was introduces, the demand of alternative options, in this case petrol and diesel vehicles, decreased.*

These hypotheses are examined with data collected from Statistics Finland and are tested with a difference-in-differences analysis.

The difference-in-differences analysis shows the causal effect of the subsidy to the increased demand of electric vehicles in Finland. The analysis is conducted with R Studio. To complement the difference-in-differences analysis and to test its validity, the parallel trends assumption is tested both with a Mann-Whitley U-test and visual observation of data. For these analyses, data from Statistics Finland is used to compare the percentage of electric vehicles registered to the percentage of hybrid petrol/electric vehicles registered. The percentage of new electric vehicles registered is considered the treatment group, and the percentage of new hybrid petrol/electric vehicles are considered the control group, in order to conduct the difference-in-differences analysis.

After the analysis, the results are studied and further discussed in the concluding chapter, and some suggestions for future analysis is made.

2 Literature review

The literature review goes through efforts done globally, in the European Union and in national level in Finland to help reduce the number of CO2 emissions, to slow down global warming. Focus on these are on the road transportation sector. Means of how governments can intervene on consumer behaviour are introduced, focusing on Pigouvian tax and subsidy. Previous studies made on the subject are discussed, and the purpose of this thesis is presented.

2.1 Efforts done globally and in the European Union to slow down global warming.

There are several policies set both globally and locally in the efforts of trying to slow down global warming and its inevitable effects. United Nations has set the 2030 Agenda for Sustainable Development, which provides a “blueprint for peace and prosperity for people and the planet, now and into the future.” (United Nations, 2024). At the core of the agenda are the 17 Sustainable Development Goals, which are a call for action for a global partnership for all the UN member countries. In these 17 goals it is recognized, that “ending poverty and deprivation must go together with the strategies that improve health and education, reduce inequality and spur economic growth while simultaneously tackling climate change and to preserve the oceans and forests” (United Nations, 2024).

Number 13 of the Sustainable Development Goals is climate action. Within this goal, measures are focused on keeping the global warming as low as possible, to keep ecological catastrophes in minimum. It is recognized that a deep, rapid and sustained greenhouse gas emission reductions are required. The goal set by the United Nations is to reduce the emissions by 43% by 2023, and to net zero by 2025 (United Nations, 2024). This goal is adopted by the member states, including the countries in the European Union, in the Paris Agreement. The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change

Conference (COP21) in Paris, France, on 12 December 2015. (United Nations Climate Change, 2024).

The European Union climate policy guides the policy measures to mitigate climate change and adapt to it, both within the EU as a whole and individually in all the Member States. The EU climate policy is based on the United Nations Framework Convention on Climate Change, the Kyoto Protocol to the Convention, and Paris Agreement on Climate Change (Ministry of the Environment, 2024).

The European Union is committed to reduce the net greenhouse gas emissions it causes by at least 55 per cent by 2030, compared to emissions of 1990. This is also the commitment the EU has declared to the Secretariat of the UN Framework Convention on Climate Change for the purposes of the Paris Agreement. In addition, the European Union aims to achieve climate neutrality by 2050, which would mean a balance of emissions and removals regulated by the EU legislation. These climate targets to 2030 and 2050 are included in the Regulation on the European Climate Law adopted in 2021 (Ministry of the Environment, 2024).

2.2 Electrification of the car fleet in Europe

One big sector to consider when aiming to climate neutrality, is traffic. According to the European Environment Agency (EEA) that works under the European Union, the transport sector is one of the largest greenhouse gas emissions contributors in the EU (EEA, 2024). They also state, that demand for transport keeps growing in volumes, so more sustainable means of transport are required. Good news is, that Europe is currently the global frontrunner in the adoption of electric vehicles, and in 2022 13,4% of all new registered vehicles within the EU were fully electronic (EEA, 2024). However, the goal is to increase the percentage more. In October 2022 the European Parliament and Council reached an agreement that ensures that all new vehicles and vans registered in Europe will be zero-emission by 2035 (European Council, 2022). Another important policy on the EU level that are focused on the electrification of road transport are the European Green Deal and the Sustainable and Smart Mobility strategy.

The European Green Deal includes the zero-emission goal by 2030, and additionally ensures that the infrastructure and public charging capacity will be in place for the increasing need in the future (European Council, 2024). Additionally, the road transport in EU will be covered by emissions trading by 2027. This means, that there will be a price on pollution, which is hoped to increase the use of cleaner fuel options (European Council, 2024).

The Sustainable and Smart Mobility strategy gives a more detailed roadmap onto how the goals of the European Green Deal will be met, by setting a total of 82 initiatives in 10 key areas with concrete measures. With these measures, the goal set for 2030 is to have at least 30 million zero-emission vehicles operating in Europe, and by 2025 nearly all vehicles should be zero-emission (Sustainable and Smart Mobile Strategy, 2021). As the name of the strategy suggests, the European Council aims to have a Sustainable, Smart and Resilient traffic in the future. The strategy for sustainability contains the aim to boost the uptake of zero-emission vehicles, by for example providing funding for subsidies, and by installing up to 3 million public charging stations by 2030 (Sustainable and Smart Mobile Strategy, 2021).

2.3 Goals and actions towards electrifying the car fleet **in** Finland

The Finnish government has set out several environmental goals, and one is to reduce the overall CO2 emissions in Finland. One big sector where the government has set goals on, is reducing the emissions caused by road traffic. According to the Ministry of Transport and Communications, approximately fifth of all emissions in Finland are caused by traffic, and in 2019 approximately 94% of all traffic emissions were from road traffic (Ministry of Transport and Communications, 2021).

The goals to reducing the CO_2 emissions caused by traffic are set in the "Roadmap for Fossil-Free Transport" published on 6 May 2021. The main goals set on the roadmap are to reduce the emissions by half by 2030, and to reach carbon neutral road traffic by 2045 (Ministry of Transport and Communications, 2021). The roadmap also lists supports and incentives that are done to help meet these goals for 2030 and 2045. The three main supports and incentives in the Roadmap for Fossil-Free Transport are the replacement of fossil fuels, renewal of the car stock, and improving the efficiency of the transport system. The predicted reductions for these actions are 0.62 Mt CO_2, which would be a significant change for the better (Ministry of Transport and Communications, 2021). The renewal of car stock includes plans to support the purchase of electric vehicles.

Some measures to support the acquisition from fossil to electric have been done already before the publishing of the roadmap in 2021. In 2017 the Finnish government made a new law, (19.12.2017/971) which stated that it is possible to get a subsidy of 2000 euros when purchasing an electronic vehicle with maximum worth of 50,000 euros. The subsidy was available first from 2018-2021, and it was then prolonged also for the year 2022 with law 1289/2021 (Finlex.fi). In addition to the subsidy, starting from October 2021, the car tax for electric vehicles has been waived, which has given an additional incentive to purchase an electronic vehicle instead of combustion-engine vehicle. All the funds, 30 million euros (6 million per year) allocated for the subsidy for purchasing an electronic vehicle were used in 2018-2022. This would indicate that the subsidy was successful in the sense that people purchased more electric vehicles between 2018-2022 than in the previous years. On this thesis, a difference-in-differences analysis will be conducted, to see the possible causal effects of the subsidy given in 2018-2022 in the electrification of the car fleet in Finland.

2.4 Means of government intervention

When investments in sustainable energy and consumption don't meet the projected future energy needs and environmental goals of a society, it is often deemed a market failure, and governments are incentivized to intervene (Greene, German and Deluchi 2009). It is clear, that to meet the carbon neutrality goals set by the United Nations, European Union and the Finnish Government, ways to move from combustion-engine to electric in road transport are required, and the change should be done as soon as possible. As cars are mostly owned by private companies and individuals, the governments around the world need to find ways to incentivise private companies and individuals to change their purchasing habits. For this purpose, governments can set economic policies such as taxes or subsidies, as tools to affect consumers purchasing habits (Varian, 2010, p. 26).

It is important to remember that governments are not able to, nor should intervene all consumer behaviour. However, a motivation for a government to intervene in the economy, is the existence of a market failure. Market failure is “a problem that causes the market economy to deliver an outcome that does not maximize efficiency” (Gruber, 2019, p.46). According to Gruber (2019), a classic example of a market failure are externalities. Externalities occur when actions of one party makes another or other parties worse or better off, without the first party receiving any cost nor benefits of doing so (Gruber, 2019, p. 214). There are positive and negative externalities. An example of a positive externality are vaccines; by being vaccinated, people also protect those who are not vaccinated from diseases spreading. A good example of a negative externality are CO2 emissions caused when driving a normal combustion-engine vehicle. The owner of the vehicle is not required to compensate for the CO2 emissions for the others who are affected of it, for example in the form of global warming. For this purpose, the government can intervene, and place a tax for vehicles that pollute, or a subsidy for purchasing a vehicle that pollutes less or none, for example an electric vehicle.

2.4.1 Pigouvian tax and subsidy

When externalities are taxed or subsidized, a model often used to determine the level of tax or subsidy is Pigou tax or Pigou subsidy, often also called Pigouvian tax and subsidy. The Pigou tax and subsidy fall under the Pigou theory, which indicates that when prices decrease, the purchasing power of money increases (Friedman & Schwartz, 1993). The name comes from the English economist Arthur Pigou (1877-1959) who contributed heavily to the externality theory (Investopedia, 20.2.2024).

A Pigouvian tax is towards on actions that have negative effects on other people, who are not directly involved. As the tax focuses on the actions of consumers, essentially Pigouvian tax is a tax on behaviour. The tax increases the cost of the action, to make consumers less likely to act in that certain way. The harmful effects of the actions are called negative externalities. The harm the externalities impose to others are called external costs, which the Pigouvian tax helps to offset (Goolsbee, 2013).

A Pigouvian subsidy is counterpart to the Pigouvian tax. As Pigou suggested that negative externalities are offset by taxes, he also suggested that positive externalities would be offset by a Pigouvian subsidy. Positive externalities are caused by behaviour or actions that benefit other people, or the society. Essentially, a Pigouvian subsidy is used to encourage this kind of behaviour (Goolsbee, 2013).

There has been criticism on the Pigouvian theory, most notably by the Nobel prize winner Ronald Coase (1960), who suggested that no tax or subsidies would be required, if the ones creating externalities, positive or negative, could negotiate with the people affected by them. He claimed, that while Pigou focused on the externality theory, the critical element in these situations was transaction cost theory, which focuses on how much effort, resources, or cost is necessary for two parties to complete an exchange (Williamson, 1981). Coase (1960) also claimed that externalities did not necessarily lead to an inefficient result, and even if they did, the Pigouvian taxes did not necessarily lead to an efficient result. However, Olson (1965), and several others after him argued that also the Coase Theorem had serious flaws. Olson claimed that when there are more that two parties involved in the bargaining of an externality or public good, there will always be the problem of free riding. Dixit and Olsen (2000) also tested the bargaining theory that Coase suggested with a simple public goods model, and presented serious doubts that it would not work in group settings.

Another criticism on the Pigouvian theory by from example William Baumol (1972) and Martin Weitzman (1974), is to the difficulty to correctly calculate the proper amount of Pigouvian tax or subsidy. To calculate the amount of Pigouvian tax for example, the government would need to know in advance what the most desirable outcome would be. In addition, the government would need to know the exact externality cost and the exact price and output for any given market. These critics claim, that if the external costs are overestimated, Pigouvian taxes could cause more harm than good.

Another problem with both Pigouvian tax and subsidy is that they are not permanent solutions. By nature of the model, as the tax or subsidy is set and has been implemented for a certain time, and consumer behaviour has been modified to consume more or less of the taxed of subsidized goods, the amount of tax or subsidy should be modified to meet the new demand. However, this does not take away from the effect of these models, it just means that they need to be re-evaluated and adjusted as time goes by.

Regardless of criticism, Pigouvian taxes and subsidies have been and still are broadly used. The most common example of a Pigouvian tax is carbon tax, which is placed on fossil fuels, and is used in many places around the world. The aim of the carbon tax is to include the externality cost into the price of the fuel, and the higher the price goes due to the tax, to change the consumer behaviour towards greener options. Previous studies have shown that the carbon tax has reduced the CO_2 emissions, for example in Sweden the emissions from transport reduced by 11% after issuing a carbon tax (Andersson, 2019), and in British Columbia by 5-15% (Murray and Rivers, 2015).

Pigouvian subsidies are less common than Pigouvian taxes, but they are also in use. An example of a Pigouvian subsidy would be a subsidy given for a purchase of an electric vehicle. The subsidy encourages consumers to choose the less polluting option, and the positive externality is therefore rewarded with a price decrease. This thesis aims to study the effect of such subsidy given in Finland between 2018-2022.

2.5 Previous studies on electrification of the car fleet

There are several studies that asses the market attractiveness and environmental impact of electric vehicles. What the earlier studies, such as Delucchi and Lipman (2001) focusing on the factors of car fleet electrification in the United States, and Carlsson and Johannsson (2003) focusing on the adaption of electric and hybrid vehicles in Sweden have commonly found, is that although there are concerns for example on the range between loadings and the loading infrastructure, the biggest obstacle in the process of transforming the car fleet electric is the high price of manufacturing an electric vehicle. The high manufacturing cost is forwarded to the consumers as the higher price of electric vehicles compared to a combustion-engine or hybrid vehicle. During the pandemic, manufacturing costs of electric vehicles increased as the raw materials were harder to obtain (Jones, Nguyen-Tien & Elliot, 2023). However, in the near future the manufacturing cost of electric vehicles are predicted to decrease, leading to a possible price decrease as well. For example, market research company Gartner released a statement in March 2024, in which they predicted that the manufacturing costs of electric vehicles could decrease by 40% by 2027 (Gartner, 2024).

Other studies have focused on how the high price can be offset with government intervention, thus decreasing the obstacle of higher price for consumers. Empirical research finds that subsidies can be effective at stimulating demand for electric vehicles. In their study, Gallagher and Muehlegger (2011) studied the effects of tax waivers in the United States and found that they substantially increased the demand of alternatives for combustion-engine vehicles. Beresteanu and Li (2011) came to the same conclusion in their study, when they studied the effect of rising gasoline prices and tax waivers for hybrid vehicles. They found that tax waivers had a significant effect in the increase of sales for hybrid vehicles. Muehlegger continued to study the topic of tax waivers with Rapson (2018) and found that in the United States the tax reductions were especially effective in low- and middle-income populations. However, Rapson and Muehlegger (2018) also noted that in order for the public to fully be able to change from combustion-engine to electric vehicles, the gasoline prices in the US should increase, for example with targeted taxation, to make electric vehicles always the cheaper option per mileage. Ystmark Bjerkan et al (2016) focused on the buyers of electric vehicles in Norway, and on which incentives or subsidies were the most crucial in their decision to purchase an electric vehicle instead of a combustion-engine vehicle. They also found that the reduced purchase cost was overall the strongest incentive amongst electric vehicle owners to purchase the electric vehicle over a combustion-engine vehicle.

Although tax reductions are an effective tool, direct subsidies for the purchase of electric vehicles may also be required in order to electrify the car fleet. Allcott et al. (2014) argue that other subsidies, such as a subsidy given for purchase, could be more effective. They claim that it may not be feasible to set Pigouvian taxes on petrol, or give tax reductions to electric vehicles, as consumers may miscalculate or undervalue the future savings on energy costs, which then makes consumers under-adopt electric vehicles relative to the social optimum that the Pigouvian tax would be based on. The same argument is made by Krause et al. (2013), as they state that consumers tend to underestimate the benefits of electric vehicles in the longer term. It is likely easier for consumers to see and correctly value the benefits, in this case subsidies, if they are given right away at purchase, compared to the tax benefits received over a longer period of time.

Dong (2020) focused in his study on the factors that effected the willingness to accept subsidies for purchase of electric vehicles in China. He discovered, that unsurprisingly, environmentally conscious people were the most likely group to accept the subsidies. Other factors were also age and sex, as his analysis showed that younger people and women were more likely to accept subsidies for electric vehicles. Caulfield et al (2022) found on their study, that focused on subsidies given for electric vehicles and home charging stations in Ireland, that the subsidies seemed to benefit people with higher income level, while those with lower income levels and especially ones living in rural areas, were less likely benefit from the subsidies. Criticism that the subsidies only benefit those with higher income levels has been presented in Finland as well. For example, in

Helsingin Sanomat in 2022, a criticism was raised, that the subsidies were used only by those who could afford to purchase a new car regardless of subsidies given (HS, 20.8.2022). An idea, that the subsidy could be extended in the future also for the purchase of used electric vehicles was also raised in Helsingin Sanomat. This would be a great idea for the possible future subsidies considered in Finland, as subsidies are taxpayer funded and should therefore be used to benefit all income levels.

Olsen (2015) uses a variety of scenarios to calculate the costs and benefits of the Norwegian subsidies for electric vehicles. In his study, Olsen compares the emissions caused by an electric vehicle compared to a similar combustion-engine vehicle and figures out the average costs lost in taxes that would have been gained without the subsidies. He claims that the subsidy costs in Norway for the purchase of electric vehicles are higher than the environmental benefits. However, he does recognize, that the subsidies have been effective in Norway in the sense that more and more people choose electric vehicles over a combustion-engine version. Regardless of the criticism, Norway has continued their ambitious subsidies and at the moment is the leading country in the adoption of electric vehicles. It is likely that Norway will achieve the goal set by the Norwegian Parliament, that all new vehicles sold by 2025 should be zero-emission (EV Norway, 2024). It is hard to measure whether the cost of the subsidy is covered by the environmental impacts of subsidies given to electric vehicles. Holland et al. (2016) found that the environmental benefits vary greatly depending on whether the benefits are measured locally or globally, and that there are great differences between the local environmental benefits of subsidies given in the US. Chen et al. (2021) also found that the cost of the subsidy programme did not cover the environmental benefits achieved. They claim that the marginal cost of the subsidy program exceeded the marginal environmental benefits by nearly 300 percent. However, both Holland et al. (2016) and Chen et al. (2021) recognize that regardless of the cost, the subsidies have increased the number of electric and other fuel-efficient vehicles in the areas.

Zheng et al. (2022) studied the impact of subsidies on the number of electric vehicles sold in China. They did a Difference-in-Differences analysis in addition to Propensity Score Matching and found that subsidies in China played a significant role in the adoption of electric vehicles. They estimate that approximately a quarter of the annual increase of the sales of electric and hybrid vehicles in China is due to the subsidies given in 2009-2018. Another Difference-in-Differences analysis was made in California by Clinton and Steinberg (2022), where they found, that for every thousand dollars of incentive offered, the number of new registrations of electric vehicles increased by approximately 8 percent. Haan et al. (2022) focused on the subsidies given for purchase of electric vehicles in Germany between 2017-2021. In Germany, the subsidy amount increased during the set time period, starting from 2000€, the same amount as the subsidy given in Finland between 2018-2022, into 9000€ by 2021. However, the study did not focus on the effect of the increase, only in the overall effect of the subsidy on the number of electric vehicles purchased. What Haan et al. (2022) found, although only in this preliminary version of their full Difference-in-Differences analysis, was that the subsidy significantly increased the number of electric vehicles purchased, and decreased the number of combustion-engine vehicles purchased.

2.6 Purpose of this thesis

Based on the literature reviewed, it can be gathered that government intervention in the form of subsidies has sped up the market acceptance and increased the number of electric vehicles sold in the countries in question. Some studies also show that while the number of electric vehicles sold increases, the number of combustion-engine vehicles sold decreases. In this thesis the effect of subsidies for electric vehicles granted in Finland between 2018-2022 will be studied. So far there has been no studies on whether the subsidies had direct effect on the increased number of electric vehicles sold during the time period of 2018-2021 in Finland. The literature and analysis made in other countries indicate that subsidies do increase the number of electric vehicles sold, so the first hypothesis of this thesis is, that the subsidies have significantly increased the number of electric vehicles purchased in Finland on the given time. The second hypothesis is, that while the number of electric vehicles sold increased, the number of combustion-engine vehicles sold decreased.

As electric vehicles have become more popular, it is hard to distinguish whether the increase of new electric vehicles purchased is caused by the subsidy, or the general interest increase towards electric vehicles. To try to analyse the effects, a Difference-in-Differences analysis will be conducted, comparing the number of electric vehicles sold in Finland and the number of hybrid (petrol/electric) vehicles sold in Finland at the same time period. For the hybrid vehicles no subsidies have been granted. This way the effect of the subsidy can be separated from the overall increase of the number of electric vehicles sold.

Although the effects of subsidies have been analysed with Difference-in-Differences analysis in other countries (Zheng et al. 2022, Clinton and Steinberg, 2022, Haan et al. 2022) none have been done in Finland, or for the subsidies given for the purchase of electric vehicles in Finland 2018-2022. Other studies have also focused on data only from one country, where subsidies were only available in certain states or areas, or they have compared the electric vehicles eligible for subsidies to electric vehicles in higher price points, which were not eligible for the subsidies. However, no previous studies were found, that would have compared the impact of the subsidies given to electric vehicles to hybrid vehicles.

As both electric and hybrid vehicles can be considered as the more environmentally friendly option, comparing the two can be justified. Although the two vehicles types are different, they are similar enough for consumers to consider one over the other, given that a subsidy is provided for the purchase.

As the subsidy in Finland has been discontinued, it is beneficial to analyse the effects of the subsidy, in order to make recommendations on whether or not there should be continuation for the subsidy. If a positive effect of the subsidy for the purchase of electric vehicles can be proven in analysis, it could be beneficial to re-consider implementing the subsidy, in order to meet the goals of the electrification of the car fleet set by the Finnish government. If it is proven that the subsidy has no positive effect to to the demand of electric vehicles, the discontinuation of the subsidy can be justified.

3 Theoretical framework

The theoretical framework covers the basic supply and demand model, and how it can be affected with different types of government interaction. The concept of externalities is covered, and how externalities can be taken into consideration in economic models with Pigouvian tac and subsidy. The game theoretical model of N-player prisoners dilemma is compared to the collective action problem, and the way to connect these together is shown in the theoretical model. At the end, hypotheses of the thesis are presented.

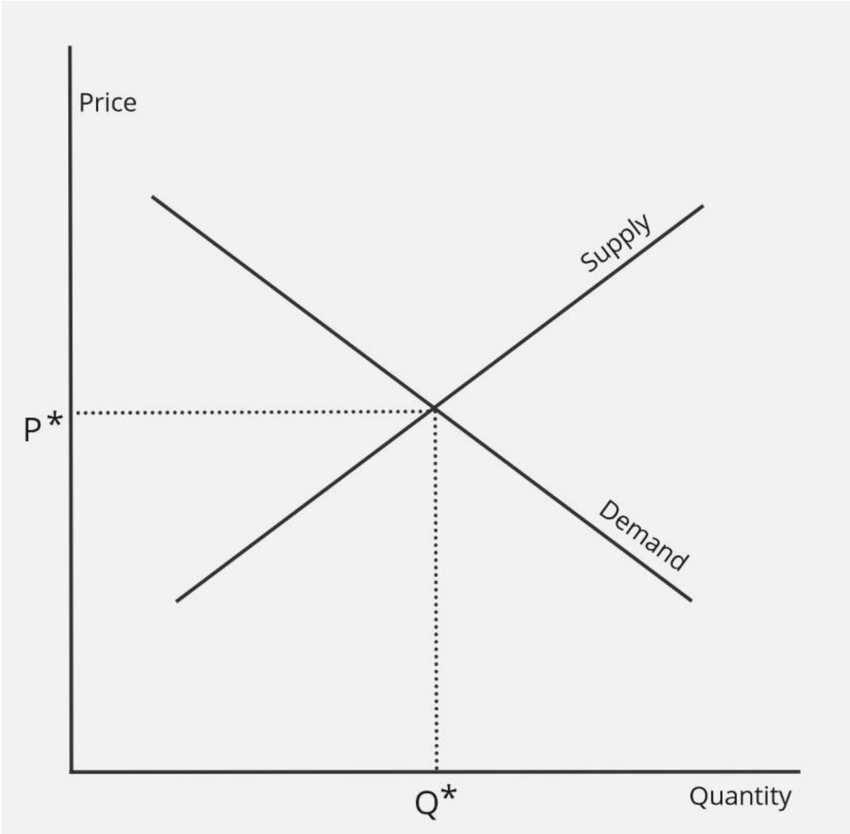
3.1 Supply and Demand

The typical rationale behind the assumption of a competitive market is that each individual consumer or producer has a minimal impact on the overall market price due to their small share of the market. For instance, a milk supplier perceives the market price as largely unaffected by their decisions regarding milk production and supply. While the actions of any single agent may not significantly influence the market price, it is the collective actions of all agents that determine the price (Varian, 2010).

The equilibrium price, where supply equals demand, is found where the demand and supply curves intersect. As Varian (2010) explains, an economic equilibrium is a situation where all the agents choose the best possible action for themselves, and each agents behaviour is consistent with the behaviour of others. At any other price other than the equilibrium price, some agents would be better off choosing a different price. This means, that any other price but the equilibrium price cannot be expected to persist, since at least some agents would be incentivized to change their behaviour. If we let D(p) be the market demand curve and S(p) the market supply curve, the equilibrium price is the price $p*$ that solves the equation:

$$D(p*) = S(p*)$$

The solution to this equation, p∗, is the price where market demand is equal to market supply. The same is also shown in Graph 1.



Graph 1: The equilibrium price.

The demand and supply curves represent the optimal choices of the agents involved. The fact that the demand and supply meet at some price point, p∗, indicates that the consumers (demand) and suppliers (supply) behave in a compatible way. At any other price point the conditions of the equilibrium price will not be met.

For example, consider that at some price point p' < p* where the demand is greater than the supply. In this scenario, some suppliers realize that they can increase their prices from the price point p' as there are more demanders than supply. As more suppliers realize the same, the market price will rise to the point where the demand and supply are equal again. Similarly, if demand is less than supply, p'>p*, some suppliers will not be able to sell the expected amount and will have to decrease their price. And as they decrease their price, others will need to match their price point, where the demand matches the supply. Only when the amount that the consumers want to buy at a given price point equals the amount that people want to sell at that price point, will the market be in equilibrium (Varian, 2010).

If we suppose that both the demand and the supply curves are linear:

$$D(p) = a - bp$$

$$S(p) = c + dp.$$

The coefficients (a, b, c, d) are parameters that determine the intercepts and slopes of the linear curves. By solving the following equation, the equilibrium price can be found:

$$D(p) = a - bp = c + dp = S(p).$$

The answer then is:

$$p* = \frac{a - c}{d + b}$$

The equilibrium quantity demanded (and supplied) is

$$D(p*) = a - bp*$$

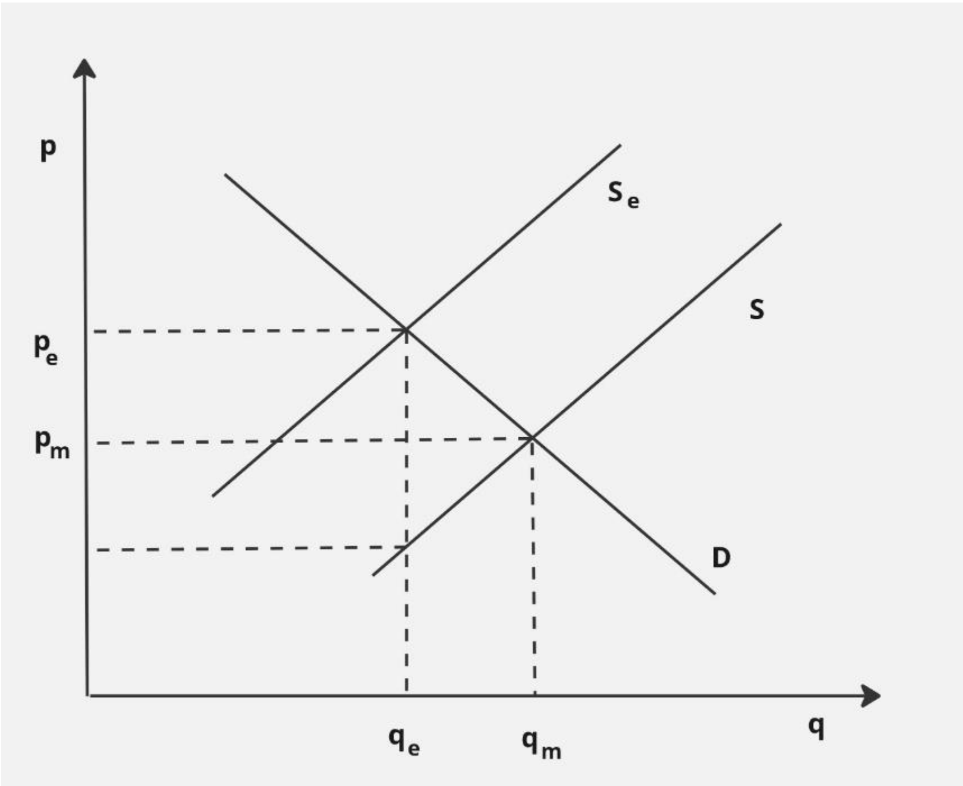
$$= a - b\,\frac{a - c}{b + d}$$

$$= \frac{ad + bc}{b + d}$$

After figuring out how to find the equilibrium with the demand equals supply condition, it can be seen how the equilibrium will change as the demand and supply curves change. For example, if the demand curve shifts to the right, meaning that the demand increases, the equilibrium price and quantity must also both rise. On the other hand, if the supply curve shifts to the right, meaning that the supply increases, the equilibrium quantity rises, but the equilibrium price must fall (Varian, 2010).

3.2 Negative and positive externalities

As mentioned in the literary review, there are both negative and positive externalities. As externalities are not normally considered in market prices, they cause economic inefficiencies (Tuomala, 2009). Let's consider that there is a paper factory that pollutes a nearby river, which cleanliness is essential for other livelihoods. With a graph it is possible to analyse externalities caused in this scenario, shown in Graph 2.

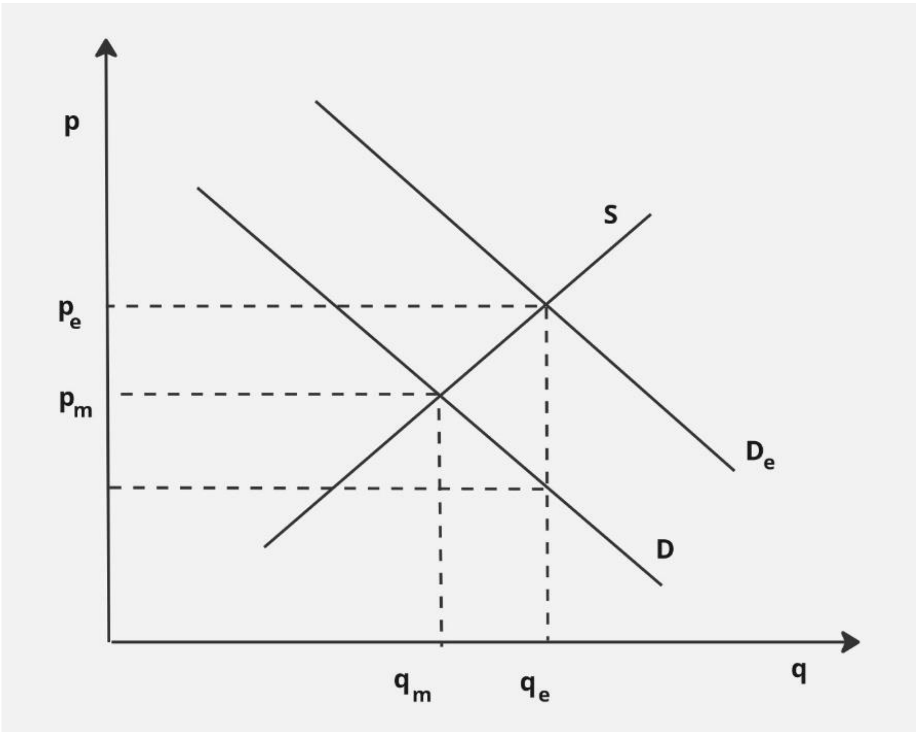


Graph 2: Negative externalities.

The market price for the paper produced by the factory is *Pm*, which is the market equilibrium price, meaning the price point where the supply and demand intersect. The factory will maximize their profits by supplying the amount where the marginal cost is equal to the price. When the factory changes their supply, the costs for other users of the river also change. This cost can be called the marginal cost of externalities. When the externality in question is pollution, often the marginal cost of externalities increases while the supply increases.

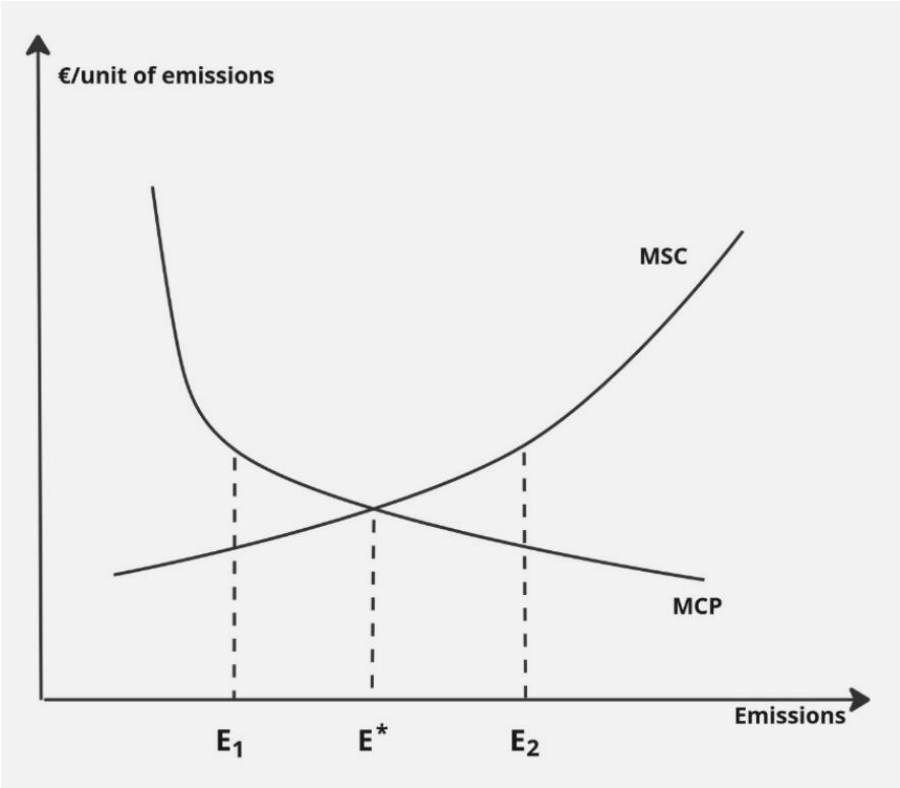
From the social perspective the negative externalities mean that the social marginal costs are beyond the private costs. From the graph above it is shown, that the efficient supply, *Se*, is met in a situation where the supply is equal to the social marginal cost. As the demand reflects the added value for the consumers, the most efficient output, *Qe*, is where the demand and the marginal social cost intersect. However, the market equilibrium is at *Qm*, where the demand and the marginal private cost intersect. As the graph shows, there is too much output in the market to meet the social optimum.

A similar graph can be used to show the situation with positive externalities. If the same factory would somehow make the river cleaner while producing paper, making the other livelihoods using the river better off, it would be socially beneficial to help the factory supply even more paper than the market equilibrium amount (Tuomala, 2009). This is illustrated in Graph 3.



Graph 3: Positive externalities.

These situations where the market equilibrium is not meeting the social optimum are called market failures. Governments have means to intervene to correct the market failures. In the factory example used, it was established that the only way to reduce pollution is to decrease the supply. The way the government can intervene here is to add a tax or a subsidy for the product, depending on whether the externality is positive or negative. Often companies can however try to change their technology, and that way reduce the amount they pollute, without decreasing the supply. Changing the technology is also a cost to the company, so how to determine what is the right option for the company in each case?



Graph 4: Emissions of a company.

Graph 4 shows the number of emissions made by a company. The company can reduce the emissions, which will cost them. There are two curves in the graph, one of them showing the marginal social cost (MSC), which shows the costs increased by the amount of emissions. This shows, that as the supply increases, the costs also increase. The other curve shows the marginal cost of reducing the emissions (MCP). This curve is downwards sloping, showing that marginal cost of reducing the emissions is smaller when the reduction is small, but when the amount reduced is increasing, so is the price of reducing the emissions. This shows, that often to cut the emissions, the technology in the company must be replaced, making the cost high for the company. In the intersect of the two curves, E*, the MCP and MSC is minimal. If the emissions are smaller than in E*, for example in E1, the marginal cost of reducing the emissions are higher than the marginal social cost. This means, that the emissions are too minimal. In E2 the emissions are too high. To achieve the situation in E*, government can intervene with different ways, for example with taxes (Tuomala, 2009).

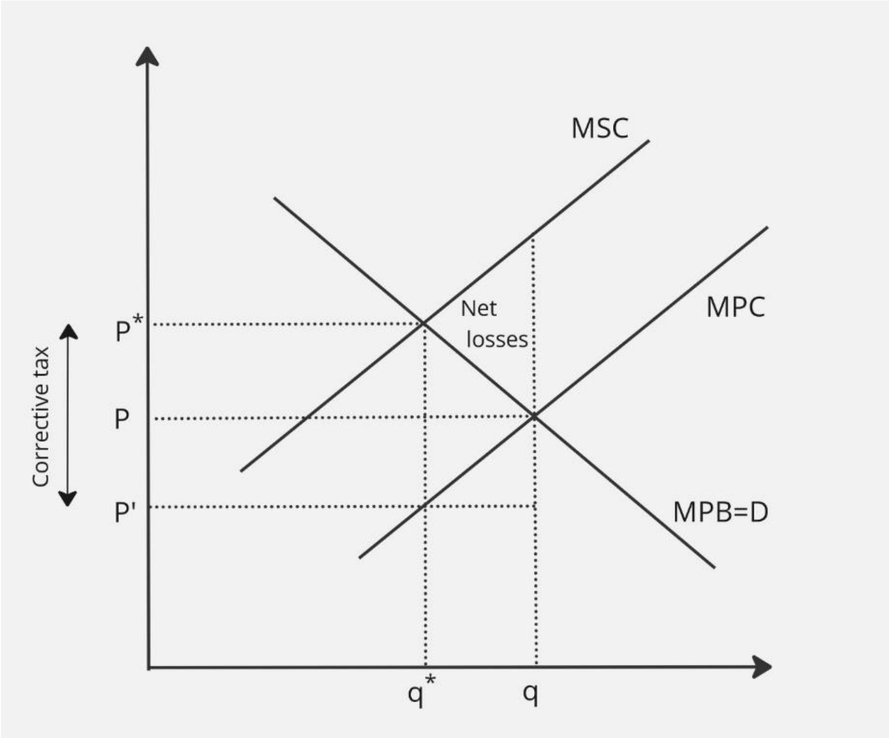
3.2.1 Pigouvian tax

Pigouvian taxes are often used to correct the market to meet the socially optimal situation. The Pigouvian tax is set so that the emissions are equal to E* shown in Graph 5. When the Pigouvian tax is set correctly, the tax is equal to the marginal cost of reducing the emissions (MCP).

The most common Pigouvian tax is the carbon tax, which is directed to the combustion-engine vehicles. The way the Pigouvian taxes work is that an additional cost, a tax, is added to the price of the item, in this case a combustion engine vehicle, to compensate for the marginal social cost caused. When the tax is added, the price to the consumers will increase, leading to a decrease in demand. The implementation of the carbon tax will raise the price and reduce the demand, in effect both reducing the pollution caused and generating tax revenue for the government, to invest in new technologies and energy alternatives, or to fund the subsidies for zero-emission options.

Graph 5 shows how the Pigouvian tax works. Without any taxes, a market will produce and consume at the intersection of its supply and demand curves, as it is the market equilibrium. These curves are represented by the marginal private cost (MPC) curve and the marginal private benefit (MPB) curve. The free market will produce output of q, at a price of p, if there is no government intervention. However, this is not the most efficient social outcome.

The marginal social cost (MSC) curve reflects the private and external costs to society. The triangle named “net losses” on the graph represents the economic losses to society when the true cost curve is ignored. The most efficient social equilibrium point is actually at the intersection of the MPB and



Graph 5: Pigouvian tax.

MSC curves, with an output of q* and a price of p*. To make the shift from the market equilibrium p=q to p*=q*, a Pigouvian tax is implemented.

Assuming, that the government can estimate the MPB and MPC curves accurately, it will know that at an output level of q* consumers are willing to pay a price of p*. Additionally, the government then knows that producers are happy to produce q* for a lower price of p'. Therefore, the optimal corrective tax should be set equal to p* - p'. When this happens, an inflow of revenue for the government will be created, which is equal to the dotted area between p’, p* and q*, and can be written as a formula where the inflow to the government is

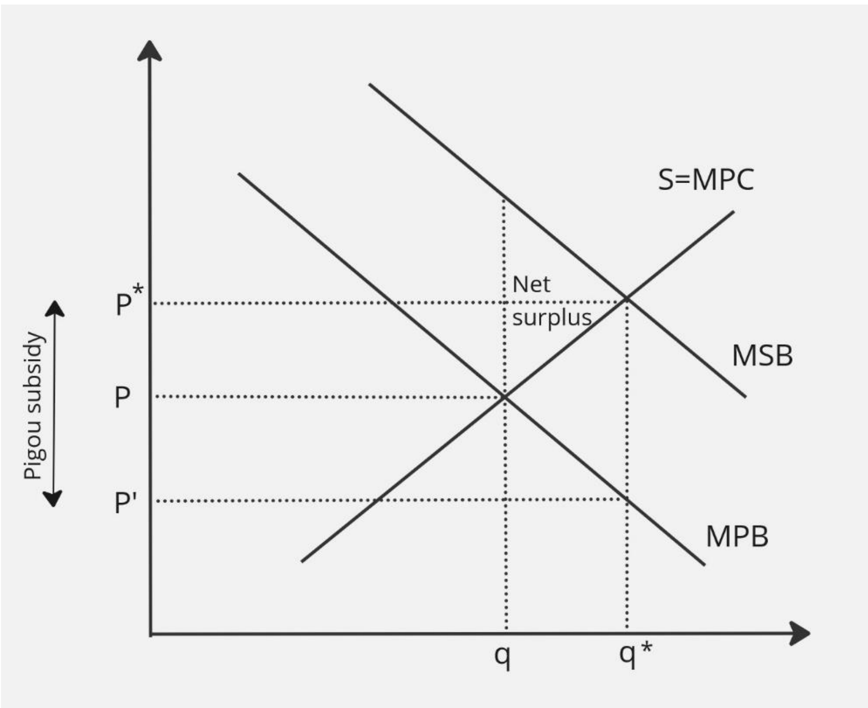
$$q * (p * - p').$$

This revenue could ideally be used to fund a subsidy programme for zero-emission options, that would in addition decrease the emissions caused by traffic.

3.2.2 Pigouvian subsidy

Pigouvian subsidies can be applied to any market that has a positive externality attached to them. The idea of a Pigouvian subsidy is to encourage an increase in production and consumption in order to reach a more efficient outcome, that fully takes advantage of the potential gains that the free market will not reach without government intervention. Pigouvian or any other subsidy is often the most efficient means of reaching the desired equilibrium point on the free market. This can be illustrated with a graph to show how it works.

Similarly, as in the Graph 5 explaining the Pigouvian tax, on Graph 6 the market equilibrium without any intervention from the government is where the marginal private cost (MPC) and the marginal private benefit (MPB) curves intersect, with an output of q in the price of p. However, the marginal private benefit curve does not show the full benefits to the society. The full benefits are represented by the marginal social benefit (MSB) curve, and the efficient equilibrium point in the market occurs at its intersection with the supply curve S=MPC, where the marginal social benefit equals the marginal social cost.



Graph 6: Pigouvian subsidy.

As can be seen in Graph 6, this results in an efficient equilibrium price of p* at an efficient output level of q*, and the net gains to society from this are illustrated by the triangle titled "Net surplus" located between the S=MPC and the MSB curve.

As at an output rate of q*, the marginal private benefit (MPB) curve shows that private individuals will only pay a price of p', a Pigouvian subsidy is needed to fill up the shortfall, and it should be equal to p* - p'. The overall cost of the subsidy can be written as:

$$Cost \ = \ q*(p* \ -p')$$

Both producers and consumers will benefit in this situation. The extra consumer surplus is equal to the top part of the net surplus area, and extra producer surplus is equal to the bottom part of the net surplus area. This means, that the consumers pay a lower price, and the producers sell more products and gain more revenue. Only the government loses out, as the subsidy is government funded. This often means that the costs are bore by the taxpayers, as some taxes will need to rise in order to cover for the cost of the subsidy.

Ideally, a government can use Pigouvian taxes and subsidies simultaneously. This could be the case with the electrification of the road traffic. As Pigouvian tax can be placed on the CO2 emissions caused by consumption engine cars, and zero-emission alternatives such as electric cars can be subsidized, theoretically the tax revenue can be used to fund the subsidies. However, it is important to remember that although all are subject to the taxes, not all benefit from the subsidies, as was studied by Caulfield et al (2022). Often these types of subsidies that are given at purchase are used more by people with relatively higher income levels. Other policies that help to improve this imbalance would therefore also be required.

3.3 Perfect and Imperfect substitutes

In economics a substitute refers to a product or service that consumers see as more or less the same or similar-enough to another product. In simple terms, a substitute is a good or service that can be used instead of another (Krugman and Wells, 2005).

Substitutes provide alternatives for the consumers. As consumers have more choice, suppliers need to compete in the marketplace, often resulting with lower prices. However, there are different levels to which goods or services can be defined as substitutes. Substitutes can be defined perfect or imperfect, depending on whether the substitute satisfies the consumer's needs completely or only partially.

A perfect substitute, as the name suggest, is more or less identical to another product or service. For example, an A4 paper sheet is a perfect substitute to another A4 paper sheet, as it can be used in an exact same way as the other. Another example would be a carton of regular milk from two different producers, which can also be considered perfect substitutes. Although the producers may differ, the purpose and usage of the product are the same.

Imperfect substitutes are goods that are similar enough to be used in the same purpose, but which are still not the same. For example, a cup of coffee and a can of energy drink can both give you energy but are often very different taste. It is important to remember that whether substitutes are perfect or imperfect isn't always straightforward, but sometimes the definition depends on consumer preferences. For example, Coke and Pepsi can be considered perfect substitutes by many, but some have very strong preferences on one over the other, making them imperfect substitutes for those consumers (Investopedia, 03.05.2022).

Substitutes, both perfect and imperfect have a positive cross-demand elasticity. Cross-demand elasticity measures the responsiveness of demand for one good to changes in the price of another (Doyle, 2016). This means, that when the price of Y increases, the demand for X is likely to increases. The formula for cross elasticity of demand (E_{xy}) measures the change in percentages in the quantity demanded of one good, in response to a one percent change in the price of another good. The cross-elasticity if demand is calculated with the following formula:

$$E_{xy} = \frac{\%\ Change\ in\ Quantity\ Demanded\ of\ Good\ X}{\%\ Change\ in\ Price\ of\ Good\ Y}$$

The result of the cross elasticity of demand will indicate whether the goods are substitutes (positive value), complements (negative value), or unrelated (zero value). If two goods are close substitutes, the cross-elasticity of demand will be high, and if the goods are weak substitutes, the cross elasticity of demand will be low (Investopedia, 29.2.2024). Elasticities that are 1.0 or more are often considered strong, indicating that changes in price of Y have significant effect to the demand of X.

When comparing electric and combustion-engine vehicles, depending on the price range of the vehicles the two car types can be considered nearly perfect substitutes or imperfect substitutes with higher or lower cross elasticity of demand. The amount of elasticity depends on whether we compare luxury electric vehicles, like higher price point Teslas to luxury vehicles like BMWs, or if we compare them to mid-range Toyotas. We can also compare the e-Toyotas to the combustion engine comparisons. The cross-elasticity of demand will change depending on the items in comparison.

For example, if the price of a Tesla is reduced by 10%, the demand for BMWs may decrease by 20%, but the demand for Toyotas increase only by 2%. By calculating the cross elasticity of demand for Tesla and BMW,

$$E_{xy} = \frac{\%\ Change\ in\ Quantity\ Demanded\ of\ BMW = 20}{\%\ Change\ in\ Price\ of\ Tesla = 10} = 2.0$$

and for Tesla and Toyota

$$E_{xy} = \frac{\%\ Change\ in\ Quantity\ Demanded\ of\ Toyota = 2}{\%\ Change\ in\ Price\ of\ Tesla = 10} = 0.2$$

we can see that the cross elasticity between Tesla and BMW is significant in 2.0, but the elasticity between a Tesla and a Toyota is low in 0.2. This would indicate that Tesla and BMW are close substitutes, and a Tesla and a Toyota are weak substitutes to one another.

3.4 Collective action problem vs. N-player prisoners dilemma

When discussing and deciding measures on how to handle or share public goods, a collective action problem is often met. Public goods are any goods that, if supplied to anybody, are simultaneously supplied to everybody, and from whose benefits it is impossible or impracticable to exclude anybody. In addition, each individual's consumption of the good leads to no subtraction from any other individual's consumption of that good. Examples of public goods are for example national parks or clean air (Brown et al. 2018).

Collective action problem occurs in situations in which the actions of each player may not result in the best outcome they can achieve. The main problem in these situations is, that it would be best if everybody participated in providing a good, but every individual is usually better when they try to free-ride and let the other players provide the good. However, if all or most of the people free-ride the good is not provided.

In game theory, these types of situations are called social dilemmas, and are often studied with public goods games. Game theory is a branch of mathematics that studies strategic decision-making in situations where the outcome of one players action depends critically on the actions taken by others (Brown et al. 2018).

In a public goods game, when a player cooperates, they add more to the total payoffs for all players than what is their own cost of cooperating. However, the cost of cooperating is greater than the players individual share of the payoffs. Per the economic model, although the group would be best off if every player would contribute, each individual player would be better off by not contributing, if all other players were to contribute (Schecter and Gintis, 2016).

A good example of a publics good game is the "Global Warming game" by Schecter and Gintis (2016), in which 10 countries are considering fighting global warming. The Global Warming game is an example of a N-player prisoners dilemma, a common game studied in game theory.

In the game, each country must choose to contribute an amount of x_i to reduce their carbon emissions, where $0 \leq x_i \leq 1$. The total benefits gained are twice the total expenditures: $2(x_1 + \cdots + x_{10})$. Each country receives $\frac{1}{10}$ of the benefits. Set of strategies available for country *i* is just the closed interval $0 \leq x_i \leq 1$. A strategy profile is then $(x_1, \dots x_{10})$ where $0 \leq x_i \leq 1$ foreach *i*. The *i*th country's payoff function is its benefits minus the expenditures:

$$\pi(x_1, \dots, x_{10}) = \frac{1}{10}2(x_1, \dots, x_{10})\text{-}x_i = \frac{1}{5}(x_1, \dots, x_{10})\text{-}x_i$$

For each country, strategy $x_i = 0$ is the dominant strategy, meaning that there will be no contributions to fight global warming. This can be shown by just showing the strategy for one country, as all 10 countries have the same dominant strategy.

Consider $x_i > 0$ and consider any strategies for the other countries. Now we want to see if the country would be better off from choosing 0 than by choosing some positive amount x_1. If the country would be better off, the difference between them would be greater than 0.

When this is calculated the result is always greater than 0:

$$\pi 1(0, \dots, x_{10})\text{-}\pi 1(x_1, \dots, x_{10})$$

$$= (\frac{1}{5}(0 + x_2 + \cdots + x_{10})\text{-}0)\text{-}(\frac{1}{5}(x_1 + \cdots + x_{10})\text{-}x_i) = \text{-}\frac{1}{5}x_1 + x_1 = \frac{4}{5}x_1 > 0$$

This applies no matter what the contributions of other countries are.

If all countries could agree to contribute 1 each to fight global warming, each country would be better off. In that case the payoff for each country would be

$$\frac{1}{5}(1+1+1+\cdots+1)-1=2-1=1$$

and each country would receive benefits of 2 for an expenditure of 1. The problem of this scenario is that each country would still be tempted to free ride, as a reduction of country i's expenditures by y_i euros reduce the total benefits of all countries by $2y_i$ but only reduces the benefits of country i by $\frac{1}{5}y_i$ euros (Schecter and Gintis, 2016).

However, the dominant strategy can be affected. Rewards and punishments can be implemented, or global agreements can be drafted with requirements for minimum contributions. There is also another way to look at the problem, if we consider that the players have personal preferences, or differing utilities. The Global Warming game can then be changed from a public goods game to a collective action problem.

In a collective action problem, all players may not have the same dominant strategy. Some players may have a preference to contribute, even if other players wouldn't, as the utility they perceive from the contribution is higher than others.

For example, if we consider reducing the number of emissions in the atmosphere, which is the best option for the group which in this case is the whole population, by purchasing an electric vehicle instead of a combustion-engine vehicle. The purchasing cost of the electric vehicle is higher than the alternative, so without any subsidies for most players the dominant strategy is to not purchase an electric vehicle but the alternative. However, for some players the utility of the electric car is more than just the price. They may see value in the status it provides, for example a status impact of new Tesla, or the environmental benefits gained, and choose to contribute by purchasing a electric vehicle. Then again, if a subsidy for the purchase of an electric vehicle is introduced, the dominant strategy for most players can shift, and they choose to purchase electric vehicles in their own self-interest, thus reducing the common action problem.

This can be shown with using the equations of the global warming example by Schecter and Gintis (2016), but instead of a clear dominant strategy for all players, K players out of N have higher utility, leading to no absolute dominant strategy.

If there are ten players in total, and one out of ten players have a higher utility. As they consider the status and ecological impact of electric vehicles highly valuable, their payoff of each 1-euro contribution is 2 euros, plus 1 euro, meaning their gain is always more if they contribute than if they would not. Each player must still choose to contribute an amount of x_i to reduce their carbon emissions with a purchase of electric vehicle, where $0 \leq x_i \leq 1$. The total benefits gained are twice the total expenditures plus their initial contribution: $2(x_1 + \cdots + x_{10})$ for all of the other players, and $2(x_1 + \cdots + x_{10})$+1 for the one player. Each player receives $\frac{1}{10}$ of the benefits. The players payoff function is its benefits minus the expenditures, and +1 for one of the players, so either:

$$\pi(x_1, \ldots, x_{10}) = \frac{1}{10}2(x_1, \ldots, x_{10})\text{-}x_i = \frac{1}{5}(x_1, \ldots, x_{10})\text{-}x_i$$

or

$$\pi(x_1, \ldots, x_{10}) = \frac{1}{10}2(x_1, \ldots, x_{10})\text{-}x_i = \frac{1}{5}(x_1, \ldots, x_{10})\text{-}x_i\text{+}1$$

For most players the dominant strategy would still be to contribute 0, but as one of the players the initial contribution is reimbursed not reduced from the total gain, and they gain $\frac{1}{5}$ of all contributions, the dominant strategy is always to contribute. Payoff for the one player would be higher when they contribute even if no other player would contribute:

$$\frac{1}{5}(0 + 0 + 0 + \cdots + 1) = 0.2\text{+}1\text{=}1.2$$

This means, that they will always contribute, as it makes their utility higher even when they are the only one contributing, thus benefiting all other players in the process.

Let's consider that the value players or consumers put on the environmental impact, e, and status, z, of the vehicle can vary from 0 to any positive amount. 0 meaning they see no additional value in the status or environmental value, and an amount >0 states the value they see in these things. If the combined value they see in e and $z \geq 1$, it means they get the same value back from the contribution as what they make. This makes the total utility gained high enough for some people to always contribute, and others not to.

To help those whose overall utility is closer to 1 than 0 reach the utility that changes the dominant strategy from not to contribute to always contribute, subsidies can be included. If a subsidy, s, would give 0.3 euros back for every euro contributed, those whose personal utility gained from e and z would be 0.6 or higher would then always contribute, as their benefit would always be higher than with not contributing.

Building again on the Schecter and Gintis (2016) model, the equation would be

$$\pi(x_1, \ldots, x_{10}) = \frac{1}{10}2(x_1, \ldots, x_{10})\text{-}x_i = \frac{1}{5}(x_1, \ldots, x_{10})\text{-}x_i + s + e + z$$

This means, that even if the player would be the only player contributing, the payoff would be

$$\frac{1}{5}(0 + 0 + 0 + \cdots + 1) = 0.2\text{-}1\text{+}0.3\text{+}e\text{+}z$$

If the personal utility value would be higher than 0.6, for example e=0.2 and z= 0.4, the dominant strategy would be to contribute, as

$$(0.2\text{-}1\text{+}0.3\text{+}0.2\text{+}0.4)>1$$

With varying values for the subsidy, environmental impact, and status, we can see differing dominant strategies for each player. This shows, that based on players personal utility value on status and environmental impact, implementing subsidies can make contributing the dominant strategy. For some players, the environmental impact or status alone could increase the personal utility value enough for contributing to become the dominant strategy even without the subsidy, but for many the subsidy could be a crucial part of the shift of the dominant strategy.

3.4.1 Comparative static analysis

To see how high the subsidy, environmental impact or the status value should be for the dominant strategy to change from not contributing to contributing, we can do comparative static analysis. In comparative static analysis, we see how the result of the formula changes if there is a change in one of the variables $x_i, s, e\ or\ z$ while other are constant. We can take the following equation:

$$\pi_i = \frac{1}{5}(x_1, \ldots., x_{10}) - x_i + s(x_{i)} + e(x_{i)} + z(x_i)$$

and derive:

$$\frac{\partial \pi_i}{\partial x_i} = \frac{1}{5} - 1 + s' + e' + z'$$

$$\frac{\partial \pi_i}{\partial \mathrm{x}_i} = \frac{-4}{5} + \mathrm{s}' + e' + z'$$

This shows that a change in x_i is equal to $\frac{-4}{5} + \mathrm{s}' + e' + z'$. Meaning, that increase in x_i leads to $\frac{-4}{5} + \mathrm{s}' + e' + z'$ increase of the individual payoff, π_i.

For the individual payoff to increase enough to change the dominant strategy with an increase in x_i , it must be the case that $\mathrm{s}' + e' + z' > \frac{4}{5}$. For instance, if the amount of the subsidy, *s*, were to increase with an increase in government spending on electrification of the car fleet, and that amount would be sufficient to compensate for the disutility caused by unilateral contribution, then the individual would purchase an electric vehicle.

The effect of changes in other variables are the same to one another, meaning a change in s, e or z, when all other variables are held constant, have the same impact to the payoff, π_i.

Change in s	$$\pi_i = \frac{1}{5}(x_1, \dots, x_{10}) - x_i + s(x_i) + e(x_i) + z(x_i)$$ The derivative of constant terms with respect to *s* is zero. The derivative of $s(x_i)$ with respect to *s* involves the chain rule: $$\frac{d}{ds}(s(x_i)) = s'$$ Therefore: $$\frac{\partial \pi_i}{\partial s} = s'$$ Meaning, that if $s > 0$, the individual payoff, π_i, will increase when there is an increase in *s,* and x_i is positive. If x_i is negative, increase in *s* will decrease the π_i.
Change in e	$$\frac{d}{de}(e(x_i)) = e'$$ Therefore: $$\frac{\partial \pi_i}{\partial e} = e'$$ Meaning, that if $e > 0$,the individual payoff, π_i, will increase when there is an increase in *e*, and x_i is positive. If x_i is negative, increase in *e* will decrease the π_i.
Change in z	$$\frac{d}{dz}(z(x_i)) = z'$$ Therefore: $$\frac{\partial \pi_i}{\partial z} = z'$$

	Meaning, that if $z > 0$,, the individual payoff, π_i, will increase when there is an increase in z, and x_i is positive. If x_i is negative, increase in z will decrease the π_i.

3.5 The theoretical model

As established, the equilibrium price in a linear supply and demand model can be found by solving the following equation (Varian, 2010):

$$D(p) = a - bp = c + dp = S(p).$$

When taxes or subsidies are implemented, the price paid by the consumers either reduces or increases. When a Pigouvian or any other type of tax, t, is implemented, the new equilibrium is determined by:

$$a - bpD = c + dpS$$

and

$$pD = pS + t.$$

Substituting from the second equation into the first, we have

$$a - b(pS + t) = c + dpS\,.$$

Solving for the new equilibrium supply price, $p * S$, gives

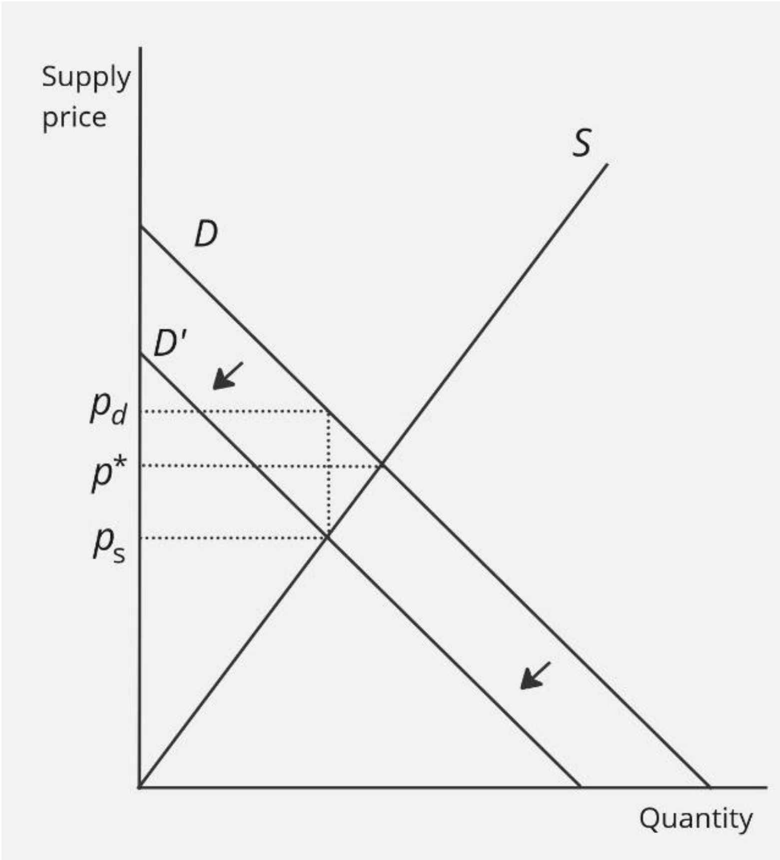
$$p * S = \frac{a - c - bt}{d + b}$$

The equilibrium demand price, $p * D$, is then given by $pS + t$.

$$p * D = \frac{a - c - bt}{d + b} + t$$

$$= \frac{a - c + dt}{d + b}$$

This is visualized in Graph 7, and as can be seen, the demand decreases when a tax is imposed. The higher the tax, the more the demand decreases.



Graph 7: The effect of a tax to the demand.

Based on the same model, if a Pigouvian substitute is implemented, the effective price paid by consumers is reduced by the amount of the subsidy, *s,* and the demand in increased.

3.5.1 Comparative static analysis

As established, the new equilibrium of demand price, pD when a tax is introduced can be determined by

$$pD = \frac{a - c + dt}{d + b}$$

Comparative static analysis shows, how changes in one variable affect the outcome of a model, when the other variables are constant. In this case, how an increase or decrease in *a, b, c, d* or *t* affects the outcome of the model.

Change in *a*	$$\frac{\partial pD}{\partial a} = \frac{d+b}{(d+b)^2} = \frac{1}{d+b}$$ ↑ in a leads pD to ↑ by $\frac{1}{d+b}$, and ↓ in a leads pD to ↓ by $\frac{1}{d+b}$
Change in *b*	$$\frac{\partial pD}{\partial b} = -\frac{a-c+dt}{(d+b)^2}$$ If $a+dt > c$, ↑in *b* leads pD to ↓ by $\frac{a-c+dt}{(d+b)^2}$, and if $a+dt < c$, ↑ in *b* leads pD to ↑ by $\frac{a-c+dt}{(d+b)^2}$.
Change in *c*	$$\frac{\partial pD}{\partial c} = -\frac{1}{d+b}$$ ↑ in *c* leads pD to ↓ by $\frac{1}{d+b}$, and ↓ in *c* leads pD to ↑ by $\frac{1}{d+b}$
Change in *d*	$$\frac{\partial pD}{\partial d} = -\frac{-a-c+bt}{(d+b)^2}$$ If $c+bt > a$, ↑in *d* leads pD to ↑, otherwise ↑in *d* leads pD to ↓ by $\frac{a-c+dt}{(d+b)^2}$, and ↓ in *d* leads pD to ↑ by $\frac{a-c+dt}{(d+b)^2}$
Change in *t*	$$\frac{\partial pD}{\partial t} = -\frac{d}{d+b}$$ ↑ in *t* leads pD to ↑ by $\frac{d}{d+b}$, and ↓ in *t* leads pD to ↓ by $\frac{d}{d+b}$

In the formula, *a, b, c, d* and *t,* all indicate some specific part of the supply and demand curve. Variable *a* represents the intercept of the demand curve. Any change in *a* represent an increase or decrease to the intercept of the demand curve, meaning the up or down movement of the curve. *a* can increase for example if the government implements a new subsidy for purchasing.

Variable *b* represents the elasticity of supply with respect to price, meaning how sensitive the supply is for changes in price. If *b* increases, the supply becomes more sensitive to price changes, and if *b* decreases, supply becomes less sensitive to price changes.

Variable *c* represents the intercept of the supply curve. Any change in *a* represent an increase or decrease to the intercept of the supply curve, meaning the up or down movement of the curve. *c* can increase for example if there are new competitors entering the market.

Variable *d* represents the elasticity of demand with respect to price, meaning how sensitive the demand is for changes in price. If *d* increases, the demand becomes is very sensitive to price changes, and if *d* decreases, demand becomes less sensitive to price changes.

Variable *t* represents the tax imposed. If there is an increase in *t,* for example in a situation where the government decides to tax more heavily on certain goods, the price also increases.

3.5.2 Hypotheses

In the market of road vehicles there are imperfect substitutes for electric vehicles, which in this this case are combustion-engine vehicles, some with high and some with low cross-elasticity of demand between the substitute and the subsidized electric vehicles. As the demand for the substitute increases, the demand for these alternative options should decrease, relevant to their cross-elasticity of demand. When all electric vehicles from basic to high-end models are subsidized, it is justified to assume that combustion-engine alternatives at all price points are somewhat considered as substitutes, and that there are both high and low cross-elasticity of demand in the mix.

As the electrification of the car fleet is seen as a big factor in the reduction of emissions caused by road traffic, it can be pointed out that the choice between the purchase of an electric vehicle over a combustion-engine vehicle is a collective action problem; all would be better off if all contributed, as the emissions caused by traffic would be lower. However, as electric vehicles tend to have a premium cost, the dominant strategy for most people is to not contribute, as their private cost is lower with no contribution. With a subsidy or a tax, it is possible to reduce the cost a purchase of an electric vehicle, which in some cases can make the purchase of an electric vehicle instead of a combustion-engine vehicle the dominant strategy.

Based on previous literature and the theoretical framework presented in this thesis, the following hypotheses are made for the effect of the subsidies given to the purchase of electric vehicles in Finland between 2018-2022:

- *Hypothesis 1. After the subsidy was introduced in Finland, the demand for electric vehicles increased.*
- *Hypothesis 2. When the subsidy for electric vehicles was introduces, the demand of alternative options, in this case petrol and diesel vehicles, decreased.*

These hypotheses are examined with the data collected and tested with a difference-in-differences analysis.

4 Empirical study

The empirical part of the thesis explains the data that was used, and how it was analysed. The focus is on the difference-in-differences analysis and the parallel trends assumption that states the validity of the difference-in-differences analysis. The empirical framework is also presented.

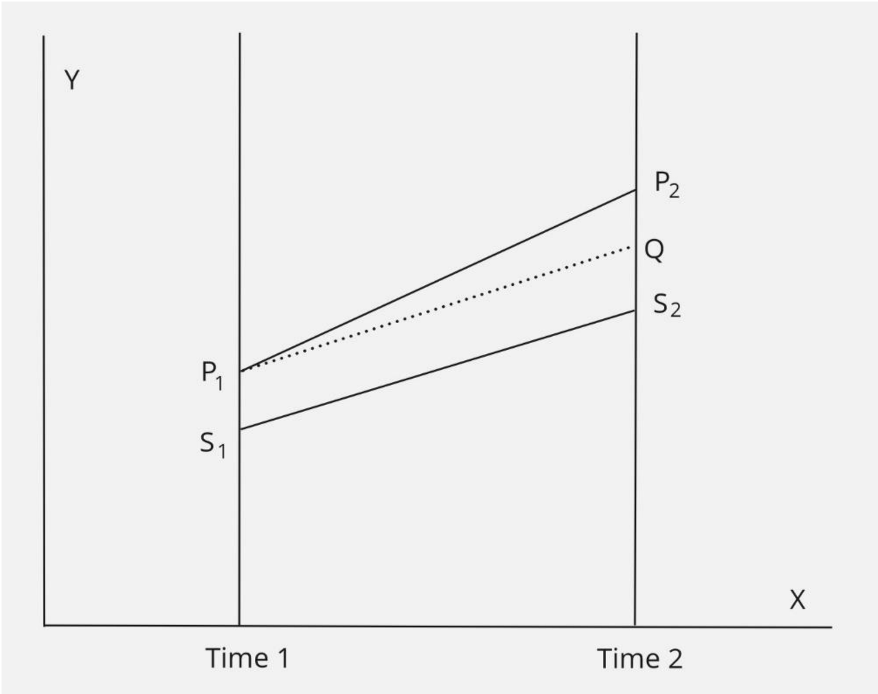
4.1 Difference-in-differences method

Difference-in-differences analysis is an often-used method in impact evaluation studies. The method is often used if normal randomized testing is hard or difficult. The difference-in-differences method is based on a combination of a comparison of before and after situation, and treatment and control group. The method is widely used in public policy, economics, management, health research and many other fields (Fredriksson and Magalhães de Oliveira, 2019). The most famous difference-in-differences analysis was made by Card & Krueger (1994), studying the impact of the raise of the minimum wage to employment in New Jersey.

Difference-in-differences analysis relies on the comparison of the change of outcomes over time between two groups. One group is the treatment group, which experiences some kind of treatment, for example a country that decides to submit subsidies for the purchase of electric vehicles. Other group is a control group, which experiences no such treatment. The analysis required observations or data from both, the treatment, and the control group, over at least two distinct time periods, which are before and after the treatment has taken place.

The key idea is then to compare the difference in the outcome variable between the treatment and control groups before the treatment with the difference in the outcome variable between the groups after the treatment. The difference of these differences is the difference-in-differences analysed.

In Graph 8 an example of difference-in-differences is shown.



Graph 8: Difference-in-differences.

Line *P* shows the outcomes in the treatment group and line *S* shows the outcomes in the control group. The outcome is measured at two time periods: Time 1, which is before the treatment has been implemented, is represented by the points P_1 and S_1. The treatment group is then exposed to the treatment and the outcome of both groups are measured again at Time 2. The total difference between the treatment and control groups at time 2 (the difference between P_2 and S_2) does not indicate the difference-in-differences effect, as the treatment group and control group started at different outcomes at Time 1. The difference-in-differences calculates the difference in the outcome variable between the two groups that would have occurred without the treatment, represented by the dotted line *Q,* with the expectation that the trends in both groups would have been parallel without the treatment. The treatment effect is then calculated as the difference between the observed outcome (P_2) and the outcome that would have occurred without the treatment, *Q*.

This can be also shown as an equation:

$$DiD = (P_2 - P_1) - (S_2 - S_1)$$

4.1.1 Empirical framework

For this thesis, the impact of the subsidy given to the purchase of electric vehicles in Finland is examined by comparing the percentage of electric vehicles registered in Finland out of all registered vehicles to the percentage of hybrid petrol/electric vehicles registered in Finland at the given time periods. There are two groups, electric vehicles being the treatment group and hybrid petrol/electric vehicles being the control group. These two groups are viewed at two time periods, one pre-treatment and one post-treatment. The pre-treatment time period includes monthly data on new registered vehicles from 2016 and 2017, and the post-treatment group includes monthly data on new registered vehicles from 2021 and 2022. The regression analysis for difference-in-differences, to estimate the impact of the subsidy given to the purchase of electric vehicles in Finland between 2018-2022 is written as follows:

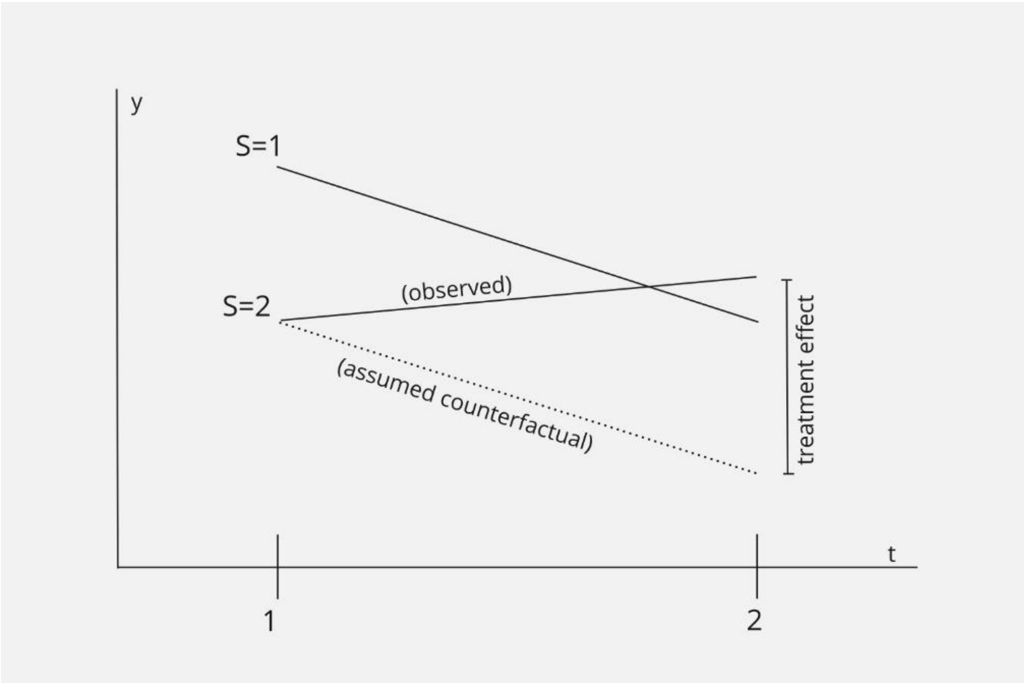
$$Y_{it} = \beta_0 + \beta_1 Treatment_i + \beta_2 Post_t + \beta_3 (Treatment_i \times Post_t) + \epsilon_{it}$$

Y_{it} represents the outcome variable for group *i* at time *t*. $Treatment_i$ is a binary indicator variable that equals 1 if group *i* is in the treatment group and 0 if not. $Post_t$ is a binary indicator variable that equals 1 for observations post-treatment period and 0 for the pre-treatment period. $Treatment_i \times Post_t$ is the interaction term between the treatment status and the given time period representing the difference-in-differences effect. ϵ_{it} is the error term. The coefficient on the interaction term, β_3, represents the average treatment effect on the treated (ATT). It indicates the difference in the change in the outcome variable between the treatment and control groups after the treatment is introduced.

With this empirical model, it is possible to determine the impact of the subsidy to the treatment group, and to see how much of the impact can be explained by the model.

4.1.2 Parallel trends assumption

The validity of a difference-in-differences analysis relies on couple of assumption, the most important one being the parallel trends assumption. Parallel trends assumption means, that the difference between the treatment and the control group would have remained the same over time if there was no treatment implemented. This is shown in Graph 9.



Graph 9: Parallel trends assumption.

S=1 line shows the control group, and S=2 the treatment group. The dotted line, named (assumed counterfactual) line shows the assumption of the parallel trends for S=1 and S=2 without the treatment. The blue line, observed, shows the results after treatment, and the treatment effect is the difference between the predicted outcome assuming the trends are parallel, and the actual observed outcome.

If the parallel trends assumption holds, the difference in the changes in the outcomes between the treatment and the control groups after the treatment can be attributed to the treatment, instead of other factors or circumstances. This allows causal interpretation of the estimated effect of the treatment, for example a policy implemented (Bertrand et al., 2004).

The validity of the parallel trends assumption can be tested. The most common and simple way is to compare the outcomes of the treatment and control groups repeatedly before the treatment is implemented, for example the outcomes of both the treatment and control groups one, two and three years prior to the treatment. At its simplest form the assumption can be made by just visually examining the data but is often further analysed with statistical testing. If the difference of outcomes is parallel before the treatment, it can be assumed that it would have been parallel also during the time of the treatment if no treatment was implemented (Gibson & Zimmerman, 2021). If the parallel trends assumption doesn’t hold, the validity of the difference-in-differences analysis should be questioned.

4.2 Data

As the aim of the thesis is to evaluate the effect of the subsidies given to the purchase of electric vehicles in Finland between 2018 and 2022, the data is of the new registered vehicles in Finland prior, during and after the treatment period. To evaluate the impact of the subsidy, a control group for which no such subsidies were given was needed. The initial thought was to use another Nordic country as a control group. However, all Nordics had a similar subsidy program in place that intersected the treatment period in Finland. In addition, all countries within the European Union had some type of subsidy given for purchase of electric vehicles that crossed the treatment period in Finland, so finding a country similar enough to Finland to use as a control group turned out to be more difficult than originally thought.

As no Nordic or European country without a subsidy between 2018-2022 was found, this thesis only uses data from Finland, and instead of comparing the number of electric vehicles registered during the treatment period to another country, it will be compared to the number of hybrid (petrol/electric) vehicles registered in Finland. The reason to use the hybrid vehicles as a control group is due to the fact, that hybrid vehicles are also considered more environmentally friendly option to combustion-engine vehicles, but were not subsidized during the treatment period, 2018-

2022. By comparing the number of registered vehicles in these two groups, we can evaluate the impact of the subsidy given to the number of electric vehicles registered.

For the empirical study, this thesis uses data of registered vehicles from Statistics Finland. The dataset used was “First registrations of cars by driving power, purpose of use and by possessor, monthly by Vehicle class, Region, Driving power, Purpose of use, Possessor, Information and Month”. Data from the overall registrations of private vehicles, registrations of private combustion-engine operated vehicles, private diesel operated vehicles, private electric vehicles, private hybrid (petrol/electric) vehicles and other type of private vehicles are used in this analysis.

The timeline of the data collected from Statistics Finland covers the time from January 2015 to December 2023. As the subsidies in Finland were available from January 2018 to December 2022, the situation both before and after the treatment period is examined in addition to the treatment period.

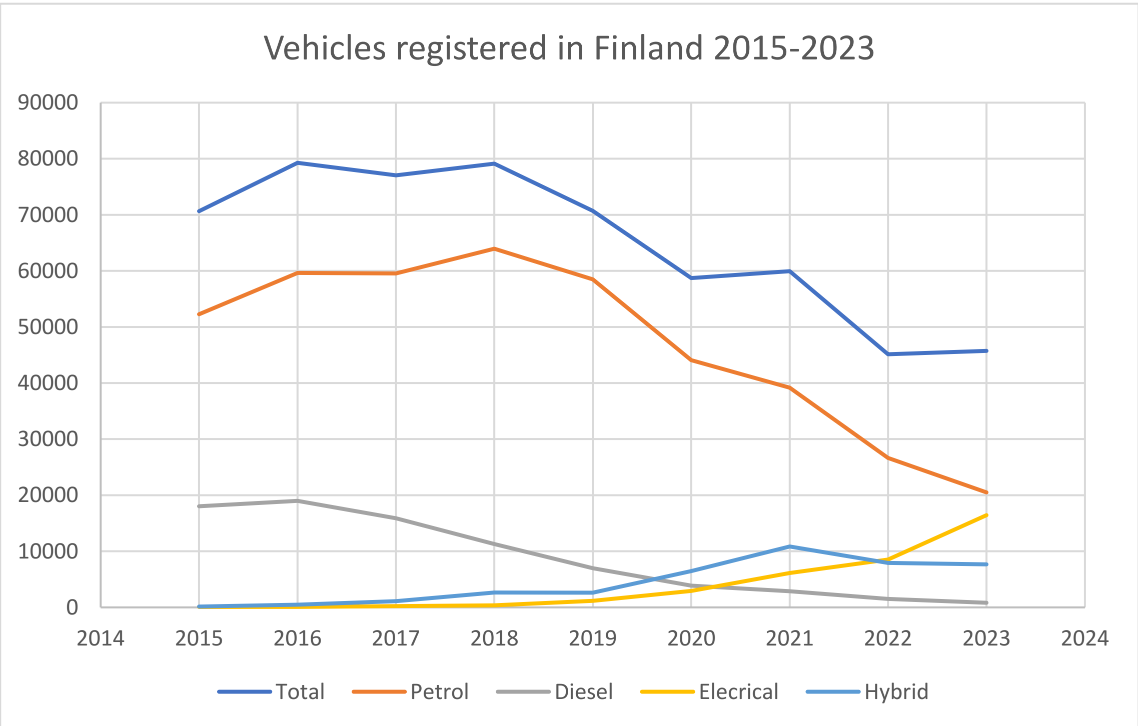


Chart 1:Vehicles registered in Finland 2015-2023 by type.

A visual observation of the data from January 2015 to December 2023 is show in Chart 1. The overall number of registered vehicles has declined since 2018, and so has the number of new petrol vehicles registered. Number of new diesel vehicles registered has also been in decline since 2016. The trends for hybrid vehicles and electric vehicles have been similar until 2021, with the number of registered vehicles increasing. In 2022 and 2023 the number of electric vehicles has kept on increasing, while the number of hybrid vehicles has slightly decreased. It can be seen, that since the treatment took place in 2018, the number of petrol vehicles and electric vehicles have slowly gotten closer to each other, and by 2023 are quite close in the number of new registrations.

From the overlook it is not however possible yet to say whether the subsidies given in Finland influenced the increased number of electric vehicles registered, and if they did, how significant the effect was. This is why further analysis is required, in this case a difference-in-differences analysis. For the difference-in-differences analysis the time points used will be monthly numbers of registered vehicles from 2016 to 2017, which is prior to the treatment, and the same between 2021 and 2022 which is after the treatment has been implemented.

The difference-in-differences could be analysed from the number or electric and hybrid vehicles sold, but as the totals in each year are different, this would not give an accurate estimation of the effect of the subsidy. However, if we compare the percentage of the total for each car type by month and take the mean of the pre- and post-treatment periods, we can have a better understanding of the effect of the subsidy.

The situation at the pre-treatment period, in 2016-2017, the percentage of electric and hybrid vehicles of the total number of vehicles registered in Finland are shown in Table 1.

2016-2017	Mean of the % of the total number of new registered vehicles in Finland
Electric vehicles	0.21%
Hybrid vehicles	1.04%

Table 1: % of registered electric and hybrid vehicles pre-treatment.

Table 1 shows the mean of the % of new registered electric and hybrid vehicles is very low in the pre-treatment period, with only 0.21% of new vehicles registered being electric, and only 1.04% being hybrid (petrol/electric) in 2016-2017. The percentual difference between the two types of vehicles is 0.83%, and according to the parallel trends assumption, we will use this as the estimate of what the difference would have been post-treatment, had there been no treatment.

The situation at post-treatment period, 2021-2022, the percentage of electric and hybrid vehicles of the total number of vehicles registered in Finland are shown in Table 2.

2021-2022	Mean of the % of the total number of new registered vehicles in Finland
Electric vehicles	15.18%
Hybrid vehicles	17.79%

Table 2: % of registered electric and hybrid vehicles post-treatment.

As Table 2 shows, the percentage of both types of vehicles has increased significantly. The percentual difference has also increased, making the post-treatment difference 2.61%. If the percentual difference would have remained the same between the two vehicle types, at 0.83%, the percentage of electric vehicles of the total number of registered vehicles would have been 16.96% (17.79-0.83=16.96). However, Table 3 shows the actual difference between electric and hybrid vehicles before and after the treatment. The change in the differences, the bottom rich column shows the difference-in-differences.

	Electric vehicles	Hybrid vehicles	Difference
2016-2017	0.21%	1.04%	0.83%
2021-2022	15.18.%	17.79%	2.61%
Change	14.97%	16.75	-1.78%

Table 3: %- difference of electric and hybrid vehicles in Finland pre- and post-treatment

As the simple calculation of the difference-in-differences shows, the difference between the number of new registrations of electric and hybrid vehicles has decreased in spite of the subsidy given to the purchase of electric vehicles. However, further analysis is still required to determine whether the result is significant.

As the second hypothesis suggests, the increase in the number of electric vehicles registered decreases the number of petrol vehicles registered, it is important to see similar numbers and percentages of the number of petrol and diesel vehicles purchased in Finland both pre- and post-treatment. These percentages of petrol and diesel vehicles are shown in Table 4.

	Petrol vehicles	Diesel vehicles
2016-2017	76.24%	22.31%
2021-2022	62.65%	4.19%

Table 4: % of petrol and diesel vehicles registered pre-and post treatment.

As Table 4 shows, vast majority of the vehicles registered in Finland in 2016-2017 were petrol and diesel vehicles, totalling to 98.55% of all new registered vehicles. However, the percentages have significantly changed post-treatment.

In 2021-2022, 66.74% of new registered vehicles were petrol or diesel vehicles. Especially the percentage of diesel vehicles has plummeted since 2016-2017, from 22.31% to 4.19%, marking a 18.12% decrease in the percentage of new registered diesel vehicles of the total number of vehicles sold in Finland. The percentage of petrol vehicles has decreased from 76.24% to 62.65%, marking a more modest decrease of 13.59% in new registrations of petrol vehicles.

As there is a significant increase in the percentage of new registrations of electric and hybrid vehicles and a similar percental decrease in the percentage of new petrol and diesel vehicles registered, it can be said by looking at these tables only, that the second hypothesis is confirmed. As the number of new electric vehicles registered has increased, it has decreased the number of new petrol and diesel vehicles registered. However, further analysis is still required to see the causal effects of the subsidy to the electrification of the car fleet in Finland.

5 Regression analysis

The regression analysis is completed with R Studio. The data input and results of the analysis are briefly explained, also how the parallel trends assumption is tested.

5.1 Testing the parallel trends assumption

To make sure the result of a difference-in-differences analysis will be valid, the assumption of parallel trends must be examined. Purely a visual comparison at the data prior to the treatment can already give some idea on whether the trends in the treatment and control groups have been parallel and could be assumed to have continued to be parallel without the treatment.

Chart 2 shows the monthly percentages of electric and hybrid vehicles between 2015-2017, three years prior to the start of the treatment, 2018. The chart is a plot made in R Studio from the monthly data on new registered electric and hybrid electric/petrol vehicles. In the chart, the X-axis shows values from 0 to 36, 1 being January 2015 and 36 December 2017. The Y-axis shows the percentage of the total number of new vehicles registered.

Based on the visualisation of the pre-treatment data the parallel trends assumption seems to not hold between the treatment and the control group prior to the treatment period. The percentage of hybrid petrol/electric vehicles has increased more rapidly, while the percentage of electric vehicles has remained in the same approximate level from 2015 to 2016, and only started to increase slowly in 2017.

What the analysis and visual examination of the data shows, is that the parallel trends assumption does not hold. Although there was increase in both vehicle type registrations, both the number and percentage of hybrid vehicles had significantly steeper increase than the electric vehicles, so the trends have not been parallel.

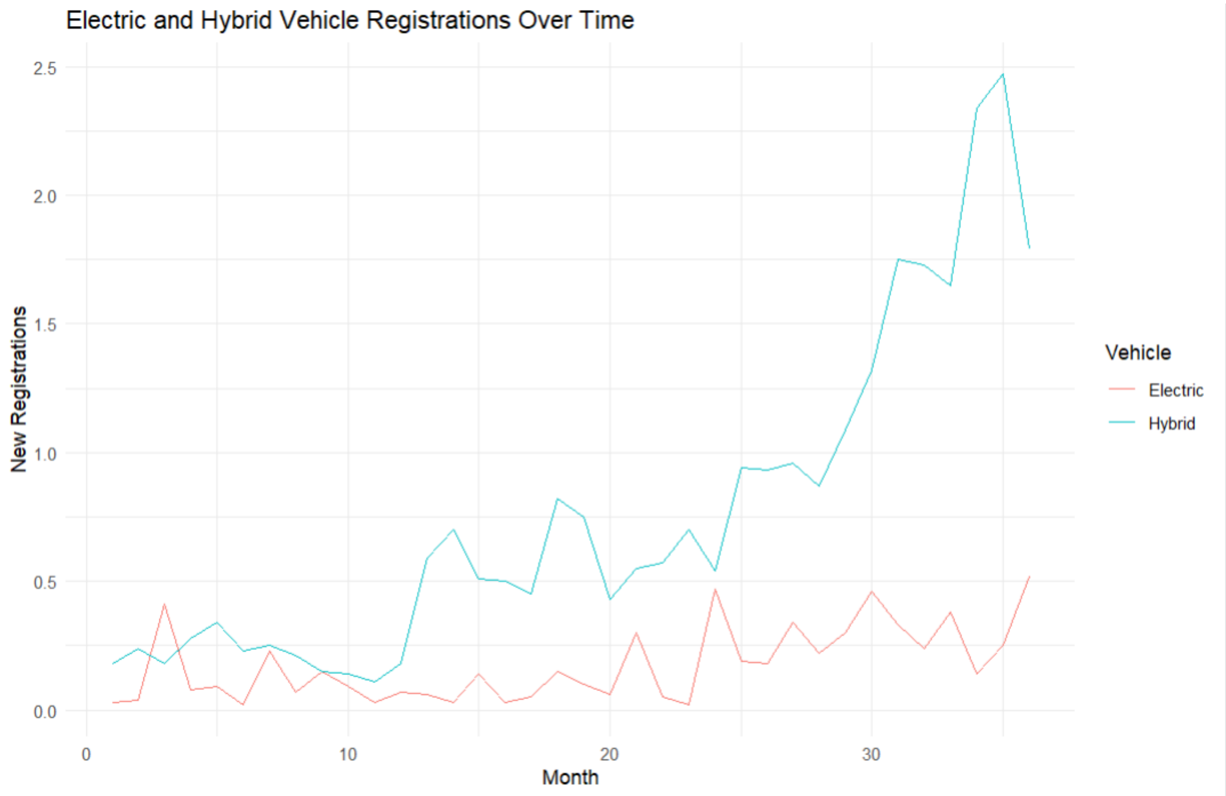


Chart 2: Monthly registrations of electric and hybrid vehicles 2015-2017.

To test the parallel trends assumption beyond the visual analysis, a Mann-Whitley U-test is conducted to see how the distribution of data differs between the treatment and the control group. The reason to choose the Mann-Whitley U-test instead of a T-test was due the assumption that the data was not normally distributed. As the test doesn't rely on any assumptions about the distribution of the data, it seemed more fitting than a T-test, which assumes that the data is normally distributed within each group.

The Mann-Whitley U-test was done with the `wilcox.test ()` function in R Studio, and it gave the following result:

	Test_Statistic	P_Value	Alternative_Hypothesis
W	163.5	4.96e-08	True location Shift ≠ 0

The Test statistic (W) is a numerical value that summarises the test result. In this case it is 163.5. The p-value measures the strength of the evidence that is against the null hypothesis. It represents the probability of observing data under the assumption that the null hypothesis is true. As the p-value is very small (4.962e-08), it indicates that there is strong evidence against the null hypothesis. The alternative hypothesis states what is being tested. In this case the alternative hypothesis is "true location shift is not equal to 0", which indicates that there is a difference in the median between the two groups being compared.

The results of the Mann-Whitley U-test verify what was already seen in the visual examination of the data: the parallel trends assumption does not hold. As the p-value is very small, the null hypothesis is rejected. This means, that there is a significant difference in the distribution of the percentage of new registrations of electric and hybrid petrol/electric vehicles in the pre-treatment period 2015-2017, meaning the trends are not parallel.

Although the parallel trends assumption does not hold, a difference-in-differences analysis will be conducted. The validity of the difference-in-differences analysis cannot be confirmed, but it is still interesting to see what the results are when the differences of the pre- and post-treatment results of the treatment and control group are compared.

5.2 Difference-in-differences analysis

The difference-in-differences analysis was made by using data from monthly registrations of electric and hybrid vehicles in Finland of two separate time periods; 2016-2017 for the pre-treatment period, and 2021-2022 for the post-treatment period.

There data is set to five columns: month, year, outcome, time and treatment. The month and year are describing variables, indicating which year and month the outcome variable connects to. The outcome variable tells the percentage of the car type purchased by each month, limited to two decimals. Time and treatment variables are binary variables. The treatment variable shows 1 for treatment group outcomes, and 0 for control group. Time variable shows 0 for observations pre-treatment, and 1 for observations post-treatment. In total, there are 96 observations, half of them treatment and half of them for control group.

The difference-in-differences analysis was used with the `lm ()` function, by using the mean of the outcome of both the treatment and control group. The difference of the outcome of the treatment and control groups pre-treatment was deducted from the difference of the outcome of the treatment and control groups post-treatment, and the result of the analysis is shown below.

```
===============================================
                        Dependent variable:
                    ---------------------------
                              outcome
-----------------------------------------------
Treatment                     -0.831
                              (1.107)

Time                         16.752***
                              (1.107)

Treatment:Time                -1.780
                              (1.566)

Constant                       1.040
                              (0.783)

-----------------------------------------------
Observations                    96
R2                             0.819
Adjusted R2                    0.813
Residual Std. Error       3.835 (df = 92)
F Statistic          138.879*** (df = 3; 92)
===============================================
Note:               *p<0.1; **p<0.05; ***p<0.01
```

The estimated intercept is 1.0396. This represents the outcome of the control group pre-treatment. The estimated coefficient for the Treatment variable is -0.8308. This indicates pre-treatment difference of the treatment and control groups and tells the average change in the outcome variable associated with a one-unit change in the treatment variable, holding other variables constant. The estimated coefficient for the Time variable is 16.7517. This represents the difference of the pre- and post-treatment outcomes of the control group and tells the average change in the outcome variable for a change in Time, indicating the difference that is expected also for the treatment group, should there have been no treatment. The estimated coefficient for the interaction between treatment and time (Treatment:Time) is -1.7800. This indicates the additional change in the outcome variable associated with both the Treatment and Time, beyond the individual effects of treatment and time. The Treatment:Time coefficient gives the difference-in-differences effect, which in this case indicated that the treatment had no positive impact on the treatment group as expected, but a negative, -1.7800 impact.

Based on the p-values, the coefficient for 'Time' is statistically significant at conventional levels ($p < 0.05$), while the other coefficients, for 'Intercept', 'Treatment' and 'Treatment:Time' are not statistically significant. Based on F-statistics, the overall significance of the model is strong. The adjusted R-squared value is 0.8132, which tells us that 81% variance in the dependent variable can be explained by the independent variable, meaning that 81% of the difference-in-differences can be explained by the subsidy.

Chart 3 visualizes the results of the difference-in-differences analysis. The dotted line "counterfactual" represents the expected outcome of the treatment group, should there have been no treatment implemented. What the visualization of the data shows is that the treatment actually decreased the percentage of new electric vehicles registered compared to the counterfactual, the predicted effect without the treatment. However, the analysis tells us that the treatment effect was not significant, meaning that either positive or negative effect is not due to the subsidy.

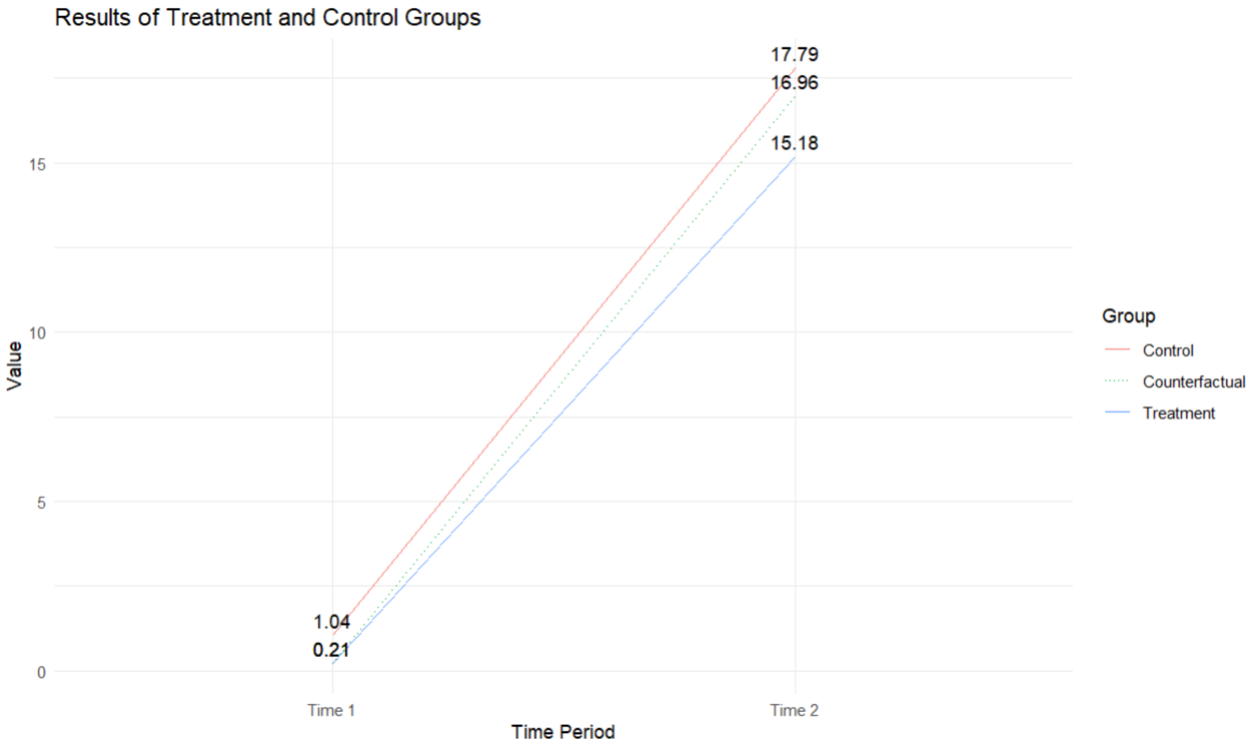


Chart 3: The difference-in-differences analysis with counterfactual.

6 Results

The main results of the thesis are drawn from the difference-in-difference analysis. However, as it has been established that the validity of the difference-in-differences analysis relays on the parallel trends assumption, it is important to also see if the assumption of parallel trends holds or not.

The assumption of parallel trends was first checked with a visual assessment. This was done by making a chart in R Studio, which presented the percentage of electric and hybrid petrol/electric vehicles registered between 2015 and 2017, throughout a three-year time span before the treatment took place from 2018 onwards. In addition, a Mann-Whitley U-test was conducted to test whether there was a difference in the distribution of data between the treatment and control groups.

Based on the visual assessment, the parallel trends assumption does not hold, as the trends of electric and hybrid petrol/electric vehicles are not parallel. Although both vehicle types had an increase both in number and percentage of new registrations from 2015 to 2017, the increase with hybrid petrol/electric vehicles was far steeper than with electric vehicles. The visual assession alone could have provided the needed results, but to be sure that the visual assessment holds, a test for the distribution of data was conducted. The Mann-Whitley U-test conducted supports the visual assessment and shows that the distribution of data varies between the treatment and control group, meaning they do not have parallel trends.

Although the assumption of parallel trends for the treatment and control group does not hold, a difference-in-differences analysis was conducted. As the parallel trends assumption does not hold, the validity of the difference-in-differences analysis is compromised. The results should therefore not be fully trusted. The results can however give an idea of the impact of the treatment, in this case the effect of the subsidy given to the purchase of electric vehicles in Finland.

The results of the difference-in-differences analysis show, that the treatment had no significant correlation with the outcome. This means, that based on the analysis, the subsidy given for the purchase of electric vehicles in Finland did not have a significant impact on the increase of the percentage of new registrations of electric vehicles. However, the model itself was significant based on the analysis, as according to the F-statistics, 81% of the difference-in-differences could be explained with the set model.

Another significant coefficient was the one indicating the correlation between the outcome and the time between the pre- and post-treatments. This shows that the increase in the percentage of electric vehicles registered was significant, although not due to the treatment, in this case the subsidy given. All other coefficients were insignificant and are therefore not discussed in more detail.

The hypotheses that were set for this thesis are the following:

- *Hypothesis 1. After the subsidy was introduced in Finland, the demand for electric vehicles increased.*
- *Hypothesis 2. When the subsidy for electric vehicles was introduces, the demand of alternative options, in this case petrol and diesel vehicles, decreased.*

The increase in both, the percentage and number, of new electric vehicles registered after the subsidy was in introduced shows that there was an increase in the demand for electric vehicles. Although the increase in the number and percentage of new registrations was not correlated to the subsidy based on the difference-in-differences analysis, after it was introduced in 2018 there was a significant increase in the demand.

As the number and percentage of new registrations of electric vehicles increased, the data shows that there was a decrease in the demand of petrol and diesel vehicles based on the number and percentage of petrol and diesel vehicles registered in Finland from 2018 onwards.

This means, that based on the difference-in-differences analysis and an overall look at the data, both hypotheses made for this thesis are confirmed.

However, the purpose of the thesis was to figure out whether the subsidy given in Finland for the purchase of electric vehicles in 2018-2022 had a positive impact on the increased demand for electric vehicles. As the parallel trends assumption did not hold, the validity of the difference-in-differences analysis is not confirmed. This means, that clear assumptions on the impact of the subsidy are impossible to make. Had the parallel trends assumption hold, the analysis would have shown that the subsidy had a negative impact on the demand of electric vehicles.

As the parallel trends assumption does not hold, the results of the difference-in-differences analysis cannot be trusted. This means, that the effect of the subsidy given for the purchase of electric vehicles in Finland to the demand of electric vehicles cannot be proven or disproven, but it remains unsolved for future research.

7 Conclusions

Global warming is a pressing issue, which needs to be slowed down to keep our planet viable. Global actions, including the ones agreed by most nations on the Paris Agreements, have been put into place, and it is important to take time to also evaluate the impacts of policies and motions, to make sure that the actions and policies are effective in helping in the slowing of global warming, and are also economically justifiable. One of the most common means of government intervention are different taxes and subsidies, with which the government can try to affect in the decision-making of consumers. When the taxed or subsidized goods are externalities, like in the case of CO2 emissions, the Pigouvian model for taxes and subsidies is often in use to correct the market.

The policy this thesis focused on was the Pigouvian subsidy that was given for the purchase of electric vehicles in Finland from 2018 to 2022. The subsidy was one part of the actions that were set to meet the goals to reduce the CO2 emissions caused by traffic in the "Roadmap for Fossil-Free Transport" by the Ministry of Transport and Communications (2021). The main goals of the roadmap are to reduce the emissions by half by 2030, and to reach carbon neutral road traffic by 2045. In the roadmap, electrification of the car fleet was mentioned as an effective tool in helping to meet the goals on reducing emissions.

What this thesis aimed to achieve, was to see whether the subsidies available between 2018 and 2022 were effective in increasing the demand for electric vehicles and increasing the percentage of electric vehicles in the car fleet in Finland. Previous studies made in other countries, such as the studies by Gallagher and Muehlegger (2011) and Beresteanu and Li (2011), had found that after subsidies were introduced, there was an increase in the demand for electric vehicles. In addition, Zheng et al. (2022) in China and Haan et al. (2022) in Germany, had found with difference-in-differences analysis, that the subsidies for purchase of electric vehicles had had a significant effect on the increase of the demand. The previous studies therefore supported the hypothesis that after the subsidy in Finland was introduced, there should have been an increase in the demand for electric vehicles. In addition, previous studies supported the theory that subsidies had a significant impact on the increase of the demand.

The theoretical framework also supported both hypotheses of the thesis. As the supply and demand model shows, when a subsidy for a good or a service is introduced, the demand should increase. In addition, the elasticity of cross-demand determines, that when there is an increase in the demand of one good, the demand for its substitutes decreases. The theory therefore supports the hypothesis that after a subsidy is introduced, the demand for electric vehicles should increase, and the hypothesis that once the demand of electric vehicles increases, the demand for the alternative, combustion-engine vehicles in this case, should decrease.

The empirical analysis on the effect of the subsidy was done with a difference-in-differences analysis, by using hybrid petrol/electric vehicles registered in Finland as a control group, and the electric vehicles as a treatment group. As the results show, both hypotheses were confirmed. There has been a significant increase in the percentage of new electric vehicles registered out of the total number of vehicles registered in Finland since 2018. In addition, the percentage of combustion-engine vehicles, meaning the petrol and diesel vehicles registered in Finland has decreased since 2018.

The interesting founding of the analysis was, that the subsidy did not have a significant effect on the increased percentage of new electric vehicles registered. If anything, the effect of the subsidy was deemed negative. This indicates that the change has been due to other factors.

The market has seen changes since the subsidy was implemented in 2018. There has been an increased supply in the electric vehicle market, as nearly all car manufacturers have introduced fully electric models, and there are a lot more options in all price ranges for consumers. In addition, the infrastructure has improved throughout the years in Finland, meaning there are much more loading stations all over the country, available for example in the parking lots of supermarkets. The increase in the price of gasoline after the war in Ukraine started could have also had an impact on the consumer decisions to lean more towards the electric options. There have also been new policies implemented withing Finland and the European Union which have had an impact on the market, and which continue to incentivise both car manufacturers and consumers to supply and consume electric vehicles instead of combustion-engine alternatives.

Although based on the analysis made on this thesis the subsidy didn't have a significant impact on the increase of the percentage of electric vehicles registered, it is possible that it still had a positive effect. There were limitations to the analysis of the thesis, and as the parallel trends assumption did not hold, the results of the difference-in-differences analysis are not valid. It can be questioned, whether there would have been different results, if the control group would have been different. Hybrid petrol/electric vehicles were chosen as a control group, as they are also seen as a more environmentally friendly option compared to the combustion-engine vehicles, but there could be a part of the market who don't consider fully electric vehicles as an option. As hybrid petrol/electric vehicles don't have to rely on the infrastructure of loading stations, or don't require consumers to install loading stations at home, they can also attract those consumers who are not willing to adopt electric vehicles. This is why the control group was perhaps not the best one for the analysis, in addition for it not having parallel trends with the treatment group.

The preliminary though was to use another Nordic country or another European Union member country as a control group. With a similar enough country without any subsidy scheme, the parallel trends assumption could have hold, and the results could have been both valid, and show an effect of the subsidy. However, as mentioned in the data chapter, during the treatment period 2018 to 2022, there was some type of subsidy model implemented in all other EU and Nordic countries as well, so finding a control group that would not have been contaminated proved to be impossible.

As the analysis made for this thesis did not provide results that would clearly indicate the effect of the subsidies for electric vehicles in Finland between 2018 and 2022, there is still a need to study the subject further. Some ideas for future studies are therefore presented.

As control groups for the percentage of electric vehicles registered in Finland proved to be hard to find, future analysis could be done between specific models. As based on the theoretical framework vehicles in different price ranges have varying cross-elasticity of demand, it would be interesting to see what kind of results could be drawn when comparing for example Teslas to Audis, or electric Toyotas to petrol or hybrid Toyotas. In addition, the effect of the subsidy with varying locations would be interesting to study. As subsidies tend to be used more by people living in urban areas, and people with relatively higher income levels, areal variation could be significant. Another idea is to include a third time period to the analysis, now that the subsidy has been discontinued. With an analysis on the pre-treatment, post-treatment and post end of the treatment, the results could also be interesting.

Due to the subsidies being mostly used by people with higher income levels, if such subsidies were to be introduced in the future, it would be beneficial to consider them being somehow dependent on the income level of consumers, with a progressive subsidization. A basic level of the subsidy could be available for all, but with income level of X the subsidy could be doubled, and with an income level of Y tripled for example. This could encourage those with more limited resources to consider electric vehicles as a viable option as well.

Overall, if the emission reduction goals set by the European Union and the Finnish government want to be met, there should be more tax incentives and/or subsidies for the low-emission options in road traffic, which take into consideration people with varying income levels and changes of rural and urban areas. As the nature of Pigouvian taxes and subsidies is that they need to be constantly under supervision, and must most likely be changed throughout the years, further analysis on the effects of them is recommended.

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9 Appendix

9.1 R-codes

The difference-in-differences analysis

```
summary(hybrid)
model <- lm(outcome ~ Treatment * time, data = hybrid)
summaryplot(treat, outcome)
summary(model)
plot(hybrid$Time, hybrid$outcome, type = "1", col = hybrid$Treatment)
mean(outcome$Time=0, Treatmen=1)
model <- lm(outcome ~ Treatment=0 * Time=0, data = hybrid)
```

The Mann-Whitley U-test

```
wilcox_test <- wilcox.test(New_Registrations ~ Vehicle, data = data_long)
wilcox_test
library(stargazer)
stargazer(wilcox_test)
```

Plot of the monthly registrations of electric and hybrid vehicles

```
ggplot(data_long, aes(x = Month, y = Sales, color = Vehicle, group = Vehicle)) +
  geom_line() +
  labs(x = "Month", y = "New Registrations", color = "Vehicle", title = "Electric and Hybrid Vehicle Registrations Over Time") +
  theme_minimal()
data <- data.frame(
  Month = 1:36,
  Electric = c(0.03, 0.04, 0.41, 0.08, 0.09, 0.02, 0.23, 0.07, 0.15, 0.09, 0.03, 0.07,
               0.06, 0.03, 0.14, 0.03, 0.05, 0.15, 0.10, 0.06, 0.30, 0.05, 0.02, 0.47,
               0.19, 0.18, 0.34, 0.22, 0.30, 0.46, 0.33, 0.24, 0.38, 0.14, 0.25, 0.52),
  Hybrid = c(0.18, 0.24, 0.18, 0.28, 0.34, 0.23, 0.25, 0.21, 0.15, 0.14, 0.11, 0.18,
             0.59, 0.70, 0.51, 0.50, 0.45, 0.82, 0.75, 0.43, 0.55, 0.57, 0.70, 0.54,
             0.94, 0.93, 0.96, 0.87, 1.09, 1.32, 1.75, 1.73, 1.65, 2.34, 2.47, 1.79)
)
data_long <- gather(data, key = "Vehicle", value = "New_Registrations", -Month)
```

Visualisation of the difference-in-differences analysis with counterfactual

```
ggplot(data, aes(x = Time)) +
  geom_line(aes(y = Treatment, group = 1, color = "Treatment"), linetype = "solid") +
  geom_line(aes(y = Control, group = 1, color = "Control"), linetype = "solid") +
  geom_line(aes(y = Counterfactual, group = 1, color = "Counterfactual"), linetype = "dotted") +
  labs(x = "Time Period", y = "Value", color = "Group", title = "Results of Treatment and Control Groups") +
  annotate("text", x = c("Time 1", "Time 2"), y = c(0.21, 15.18), label = c("0.21", "15.18"), vjust = -0.5, color = "black") +
  annotate("text", x = c("Time 1", "Time 2"), y = c(1.04, 17.79), label = c("1.04", "17.79"), vjust = -0.5, color = "black") +
  annotate("text", x = c("Time 1", "Time 2"), y = c(0.21, 16.96), label = c("0.21", "16.96"), vjust = -0.5, color = "black") +
  theme_minimal()
```

9.2 Excel data for analysis

The excel used for difference-in-differences analysis R Studio

month	year	outcome	Treatment	Time
JAN	2016	0.06	1	0
FEB	2016	0.03	1	0
MAR	2016	0.14	1	0
APR	2016	0.03	1	0
MAY	2016	0.05	1	0
JUN	2016	0.15	1	0
JUL	2016	0.10	1	0
AUG	2016	0.06	1	0
SEP	2016	0.30	1	0
OCT	2016	0.05	1	0
NOV	2016	0.02	1	0
DEC	2016	0.47	1	0
JAN	2017	0.19	1	0
FEB	2017	0.18	1	0
MAR	2017	0.34	1	0
APR	2017	0.22	1	0
MAY	2017	0.30	1	0
JUN	2017	0.46	1	0
JUL	2017	0.33	1	0
AUG	2017	0.24	1	0
SEP	2017	0.38	1	0
OCT	2017	0.14	1	0
NOV	2017	0.25	1	0
DEC	2017	0.52	1	0
JAN	2016	0.59	0	0
FEB	2016	0.70	0	0
MAR	2016	0.51	0	0
APR	2016	0.50	0	0
MAY	2016	0.45	0	0
JUN	2016	0.82	0	0
JUL	2016	0.75	0	0
AUG	2016	0.43	0	0
SEP	2016	0.55	0	0
OCT	2016	0.57	0	0
NOV	2016	0.70	0	0
DEC	2016	0.54	0	0
JAN	2017	0.94	0	0
FEB	2017	0.93	0	0
MAR	2017	0.96	0	0
APR	2017	0.87	0	0
MAY	2017	1.09	0	0
JUN	2017	1.32	0	0
JUL	2017	1.75	0	0

AUG	2017	1.73	0	0
SEP	2017	1.65	0	0
OCT	2017	2.34	0	0
NOV	2017	2.47	0	0
DEC	2017	1.79	0	0
JAN	2021	4.21	1	1
FEB	2021	4.30	1	1
MAR	2021	7.71	1	1
APR	2021	6.60	1	1
MAY	2021	10.35	1	1
JUN	2021	11.74	1	1
JUL	2021	9.63	1	1
AUG	2021	9.34	1	1
SEP	2021	11.88	1	1
OCT	2021	17.54	1	1
NOV	2021	14.44	1	1
DEC	2021	24.81	1	1
JAN	2022	12.32	1	1
FEB	2022	13.64	1	1
MAR	2022	18.03	1	1
APR	2022	14.03	1	1
MAY	2022	14.79	1	1
JUN	2022	15.54	1	1
JUL	2022	15.62	1	1
AUG	2022	23.64	1	1
SEP	2022	22.09	1	1
OCT	2022	20.39	1	1
NOV	2022	28.56	1	1
DEC	2022	33.13	1	1
JAN	2021	17.57	0	1
FEB	2021	20.20	0	1
MAR	2021	18.39	0	1
APR	2021	21.23	0	1
MAY	2021	19.71	0	1
JUN	2021	16.69	0	1
JUL	2021	15.95	0	1
AUG	2021	15.94	0	1
SEP	2021	15.02	0	1
OCT	2021	17.39	0	1
NOV	2021	21.20	0	1
DEC	2021	17.03	0	1
JAN	2022	16.75	0	1
FEB	2022	19.41	0	1
MAR	2022	17.78	0	1
APR	2022	17.58	0	1
MAY	2022	20.08	0	1
JUN	2022	19.84	0	1
JUL	2022	19.22	0	1

AUG	2022	15.12	0	1
SEP	2022	15.48	0	1
OCT	2022	18.83	0	1
NOV	2022	17.18	0	1
DEC	2022	13.40	0	1

The data used for the chart for parallel trends assumptions

	Electric	Hybrid
2015	0.03	0.18
2015	0.04	0.24
2015	0.41	0.18
2015	0.08	0.28
2015	0.09	0.34
2015	0.02	0.23
2015	0.23	0.25
2015	0.07	0.21
2015	0.15	0.15
2015	0.09	0.14
2015	0.03	0.11
2015	0.07	0.18
2016	0.06	0.59
2016	0.03	0.70
2016	0.14	0.51
2016	0.03	0.50
2016	0.05	0.45
2016	0.15	0.82
2016	0.10	0.75
2016	0.06	0.43
2016	0.30	0.55
2016	0.05	0.57
2016	0.02	0.70
2016	0.47	0.54
2017	0.19	0.94
2017	0.18	0.93
2017	0.34	0.96
2017	0.22	0.87
2017	0.30	1.09
2017	0.46	1.32
2017	0.33	1.75
2017	0.24	1.73
2017	0.38	1.65
2017	0.14	2.34
2017	0.25	2.47
2017	0.52	1.79