Getting Electric Cars on the Road

Analysis of the Effects of Cantonal PEV Incentive Schemes on New Vehicle Registrations and average CO2 Emissions in Switzerland

Master Thesis

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Bern, 24.08.2020

Abstract

In Switzerland the implementation of policies promoting the adoption of electric vehicles falls into the responsibility of the 26 cantons. In Swiss tradition, the cantons follow different approaches in accomplishing the goal of increasing the market share of electric vehicles. Three main categories of incentive schemes can be identified: purchase premiums, tax rebates on circulation taxes and subsidies for the construction of charging stations. I find positive but non-significant effects for all three categories of incentive schemes. The results are in line with the current state of the literature. The induced reduction in CO2 emissions comes with a very high price tag and the avoidance costs per tonne of CO2 are larger than the incurred social cost of carbon. If policies promoting electric vehicles are adopted, they should be implemented in the form of purchase premiums as they seem to have the biggest effect for a given amount of money. Non-financial incentives, not currently implemented in Switzerland, should also be considered. Public knowledge of both the incentive schemes in place and on the advantages of PEVs in general plays an important role and should not be underestimated.

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1 Introduction

Climate change is one of the most discussed topics of today's media, politics and society in general. The main contributor to our changing climate are the ever rising levels of so called "greenhouse gasses", especially CO2 (IPCC 2014). That greenhouse gas emissions and the change in climate they cause are problematic has well been established in the ever growing body of literature that concerns itself with the topic. They are a classic example of a market failure in the form of negative externalities. The cost for greenhouse gas emission are borne globally and that cost is not incorporated into the emitter's decision making process, leading to an inefficiently high emission of greenhouse gasses. The sources of greenhouse gases and their relative importance are different from country to country. Overall, transportation is responsible for around 25% of total worldwide CO2 emissions stemming from fuel combustion. Of those 25%, around 75% are caused by road transportation. In Switzerland the numbers are even more skewed towards (road-)transportation standing at 42% and 98% respectively, according to data published by the International Energy Agency (IEA) in 2017. In absolute terms: Switzerland emits around 37 megatons of CO2 per year and 16 megatons are emitted in transportation, making transportation the main single source of pollution in Switzerland. Expressed in the terms established above the problem can be stated in the following way: Driving a car, including the fuel needed to operate it, is too cheap because the total societal cost of the car's CO2 emissions is not internalized but borne by society. This leads to an inefficiently high amount of kilometers driven/cars bought and inefficiently high amounts of CO2 emitted. This also means that vehicles with high CO2 emissions are inefficiently cheap and thus over represented in the market and vice versa vehicles with low emissions (e.g. electric and hybrid) are under represented.

Such market failures present governments with an opportunity or even obligation to become active and resolve the inefficiencies. The classical solution for the problem of externalities is the introduction of Pigovian transfers/taxes. In the case of CO2 emissions, such a tax could be levied on fossil fuels, bringing their perceived costs in line with their actual global cost for society. In fact some countries already introduced such taxes under the names "energy tax", "carbon tax", "fuel tax" or other, similar terms(Cansier & Krumm 1997; Felder & Schleiniger 2002). While this solution theoretically leads to an efficient amount of emissions, it may be hard to implement for political reasons (Aldy et al. 2010). Another approach, when direct taxation is not feasible, is to promote the replacement of existing technologies, reliant on fossil fuel, with technologies that don't produce any greenhouse gasses or not as much. As these "clean" technologies may be more expensive compared to the "dirty" ones, governments may choose to subsidize adoption of clean technologies, possibly financed by Pigovian transfers from dirty technologies. This sort of financing is sometimes referred to as a "feebate" system; a fee has to be paid by the users of dirty technology and a rebate (often tax rebates) is given to users of clean technologies. Applied to the problem of transportation this could mean that drivers of high-emission vehicles have to pay a fee which is then given as a tax rebate to drivers of low- or zero-emission vehicles such as hybrid-vehicles or EVs. Other approaches include direct financial support when adopting clean technology (subsidies) or giving preferential treatment to users of the clean technology. Once again applied to transportation: Governments could decide to subsidize the purchase of EVs and could give them special (non-financial) treatment like free parking in certain zones.

Promoting the adoption of electric and hybrid vehicles through different kinds of incentive schemes, as described above, has become increasingly popular in the western hemisphere. Especially Scandinavian countries in Europe and the state of California in the USA have led the charge in government support for these new technologies. Switzerland also mentions the support of electric vehicles as part of its national strategy on energy development called "Energiestrategie 2050". In this strategy paper the Swiss government does not directly set targets for electric vehicles but rather has put a limit on average CO2 emissions. The current goal sits at 95 gCO2/km; a goal that may prove hard to achieve as will be shown later in this thesis. The three main goals that are formulated in the national energy strategy are: 1. an increase in energy efficieny, 2. investment in renewable energy sources, 3. shutdown of all nuclear power plants (Bundesamt für Energie, 2018). The average annual energy usage per person is aimed to decrease by 43% compared to the year 2000, the yearly production from renewable energy sources is set to be increased to over 11'000 GWh by 2035. Measures specifically aimed at the promotion of electric vehicles are not mentioned in the energy strategy. This may be due to the fact that possible measures to do that fall into the jurisdiction of cantonal governments. In fact the Swiss cantons have been very active - at least during the last ten years - in introducing policies to support the adoption of electric and hybrid vehicles. Many of them introduced tax rebate systems, some introduced subsidies for the construction of charging stations and some even introduced purchase premiums for buyers of electric vehicles. A more detailed overview of the measures currently implemented is shown in a later section of this thesis. The numbers of electric and hybrid vehicles have indeed been rising ever since they were offered by more and more manufacturers around 2010. But the question remains if the measures that were implemented had anything to do with this increase or there is another dynamic at play.

As always, when potentially large sums of money are spent by enthusiastic governments on an emerging technology, the question arises if these incentive schemes are even effective, and if yes, if they are also an efficient use of taxpayers' money. In this thesis I will try to answer these questions. First I will give an overview of the current state of the literature on different types of incentives and their effects on the adoption of electric vehicles as well as their efficiency in terms of CO2 avoidance. In the second part of my thesis, I carry out my own analysis of the topic for Switzerland using the latest available data on vehicle registrations. I estimate the effects of the mentioned incentive schemes on the share of electric vehicles of newly registered vehicles and also the effect of the incentive schemes on CO2 emissions and fuel economy. In a third part I try to combine the evidence from literature and my own results to give advice for policy makers in Swiss cantons to improve their incentive schemes in order to achieve their ultimate goal of reducing CO2 emissions from traffic.

Given what I established in the introductory section, the research questions I try to answer in the following sections of this thesis can be summed up as follows:

1. What effect do purchase premiums, tax rebates and charging station subsidies have on the

share of new vehicle registrations that are electric?

2. What effect do the same incentives have on average CO_2 emissions and on the fuel economy of newly registered vehicles?

3. Given these effects: what are the avoidance costs per tonne of CO_2 through implementation of these measures?

2 Literature Review

Economic theory on monetary (and also non-monetary) incentives on the consumption of (durable) goods has been well developed and applied to a broad range of subjects, including the energy and transportation sector. With the goal of promoting clean "green" energy or electricity a number of different strategies and incentive schemes have been implemented in European countries, mainly in the form of tax rebates on personal income tax, corporate tax, property tax, VAT etc. (Cansino et al. 2010).

Incentive schemes promoting the adoption of electric vehicles have also been popular across the globe with the USA and Scandinavia leading the charge. That, in general, positive financial incentives lead to an increase in consumption of the incentivized goods is clear from a theoretical point of view. How large these effects are in practice is unclear and there may be certain adverse effects to such incentive programs. In the USA one program that has been studied exhaustively is the Cars Allowance Rebate System (CARS) implemented in 2009. The program was better known under the unofficial name "Cash for Clunkers". It offered car dealers up to $4'500 for every fuel inefficient vehicle ("clunker") that was traded in by their customers for a new, more efficient vehicle. It was initially designed as a stimulus program for a slumping economy but at the same time was one of the first programs that incentivized the adoption of fuel-efficient vehicles. The program led to a short-term increase in the sale of fuel-efficient vehicles that was quickly reversed in the months following the end of the program (Mian & Sufi

2012). It also sheds light on the importance of differentiating between durable goods and non durable goods when talking about such effects. Cars are durable goods and their intertemporal elasticity thus tends to be larger than that of a non-durable good (e.g. Ogaki & Reinhart 1998). This means that the effects of short term subsidy programs have to be evaluated over a longer period of time as short term gains in sales may be "borrowed" from future periods (Mian & Sufi 2012). Another problem that has to be accounted for is that of free-riding. Li, Linn & Spiller (2010) find that, while the program increased sales in the short them, most of the subsidies paid out through the CARS program went to buyers that would have purchased a new vehicle anyway, even in the absence of the program. They also find that the reduction in CO2 emissions caused by the sale of more fuel-efficient vehicles comes at a rather high price per ton of CO2 (between $91/tCO2 and $288/tCO2).

Similar free riding is described by Chandra et al. (2010) who analysed a tax rebate program for hybrid-vehicles in Canadian provinces. They too find that the Canadian program increased the sales of eligible vehicles but only 26% of hybrid vehicle purchases were caused by the program. The remaining 74% of sales were "unnecessarily" subsidized and thus the reduction in CO2 emissions caused by the program also comes with a big price tag ($195/tCO2). Clinton & Steinberg (2019) use national (USA) level data on vehicle registrations and state-level data on offered financial incentives to estimate the effect of the latter on EV adoption. They find that EV purchases are increased by 8% per 1000$ offered as direct purchase premiums. They conclude that between 2011 and 2015 financial incentives were the cause for an increase in overall EV sales of around 11%. In their analysis they also estimate the net welfare effects of the mentioned financial incentives and find that they are *not* welfare-improving when only the benefits of the associated emission avoidance are considered. Additional welfare-enhancing effects like long term impact on market share and the generation of positive network externalities could potentially change this conclusion. Jenn et al. (2018) investigate different forms of financial and non-financial incentives in US states. They find that every 1000 dollars offered as purchase premiums or tax rebates lead to an increase in EV sales of 2.6%. HOV (High Occupancy

Vehicle) lane access, depending on the traffic density on the relevant lanes, can also increase EV sales by around 4.7%. They also capture a new measure of consumer knowledge on EVs and identify consumer awareness as a critical factor in the success of EV incentive programs. In a later analysis, Jenn et al. (2020) use survey data to determine the most important factors in the purchasing decision of EVs. They find that tax credits and access to HOV lanes are the driving factors in EV adoption and, as the technology becomes more 'main stream' and moves away from early adopters, incentives may become even more important. That consumer awareness and knowledge of incentive schemes and PEVs in general may be lacking is shown by Krause et al. (2013). In their survey analysis they find that over two thirds of participants gave wrong answers to factual questions on PEVs and that almost 95% of people were not aware of the local or state incentive schemes for the purchase/use of PEVs currently in place where they live. Facing such an uninformed public, any policy program must first make sure that its target population knows about it.

Earlier research mainly focused on the USA and Canada. Later research also widened the scope to other countries, especially northern European countries. Figenbaum (2017) traces the success of Norway in increasing its EV market share to over 17% of registrations and 2.7% of all registered vehicles in 2015 and thus being the leading EV market in the world. He shows that a lot of the incentives put in place (some since 1990) only started to become effective once traditional manufacturers started offering competitive EVs beginning in 2010 and the success of Norway may not be easily transferable to other countries since it relied on a specific constellation of so called 'windows of opportunity' that may not be replicable in another context. Ciccone & Soldani (2019) put a bit of a different focus on their analysis. They show that there may be asymmetrical responses associated with EV incentive schemes; tax *decreases* for low-emission vehicles are more than twice as effective as corresponding tax *increases* for high-emission vehicles in increasing the market share of low-emission vehicles. They estimate elasticities of -1.99 for decreases and 0.77 for increases.

Münzel et al. (2019) give a good overview on financial incentive schemes implemented globally but with a focus on Europe. Their review of 32 studies concludes that financial incentives have a positive effect on PEV sales and that the inclusion of trend variables in econometric analysis proves important to capture the dynamics of the diffusion of this new technology. This is something I will also show later in my analysis. Hardman (2019) provides a similar review for reoccurring and non-financial incentives. He shows that most of the studied incentives can have positive impacts on PEV sales. The current consensus in the literature, based on the two mentioned reviews, is that financial incentives are expected to have a positive impact on EV sales and that, while for some of the non-financial incentives the effects are unclear, infrastructure development certainly also has a positive impact on EV sales. It has to be noted however, that though some of the estimated elasticities seem large, the low baseline quantity of electric vehicles means that even with large elasticities, there may only be a small absolute increase in sales of EVs (Muehlegger & Rapson 2018).

In Switzerland, most measures adopted by the Federal Government and the cantons are financial in nature, with some measures supporting the expansion of charging networks being implemented in certain cantons. Alberini & Bareit (2019) exploit cantonal differences in the federal circulation tax rules and find a positive, albeit small effect of tax rebates ("bonuses") on the number of new registrations of efficient and low emission vehicles. They point out, that the same increase could be achieved with even a modest increase in fuel taxes and that bonus systems may even increase net CO2 emissions because they trigger an overall increase in new car sales. Apart form this paper, there seems to be a lack of research on Switzerland specifically. Alberini & Bareit (2019) also only look at cantonal differences in taxes and include all fuel-efficient cars, even gasoline powered, in their analysis. In addition to that, the data they use covers the time period of 2005-2011. One could argue, that the 'rise' of EVs only ever started after 2010 and that they missed the most interesting period in their research. It therefore seems to me, that there is an opportunity for further research on Switzerland using an approach more specific to EVs and using the most recent data on their sales. This is what I try to accomplish in the following sections of this thesis. As with almost any policy topic there are as many different implementations in Switzerland as there are different Cantons. This variation in cantonal incentives can be exploited to try and identify causal effects of such incentive schemes on the number of newly registered electric vehicles. Starting with differences in tax regimes, I also include incentives at the time of purchase and incentives for charging infrastructure development. I use the most recent vehicle registration data available, up to 2019 to estimate the effect of these different forms of incentives on the number of new EV registrations. In a next step I then also estimate the effects of the variables of interest on average CO2 emissions and on fuel economy and try to give an approximation of the avoidance costs per tonne of CO2 that arise through these incentives.

3 Data

3.1 Swiss Car Market

All the data on the number of new vehicle registrations and the current stock of registered vehicles has been provided by the MOFIS (Motorfahrzeug Informations System) database of the Swiss Federal Road Office (ASTRA). The data provided records every vehicle registered in Switzerland since January 1st 2010 until December 12 2019. Recorded are the make and model of the car, its type identification number (Typengenehmigungsnummer), technical details of the car, the ZIP code of the car's owner and the energy efficiency category of the vehicle according to Swiss standards. This information lets me construct accurate monthly numbers of registrations per canton. Using the type identification number I can also append additional technical information on CO2 emissions and fuel economy of every vehicle using the TARGA (Technische Angaben Rauch Geräusche Abgas) database, also provided by the ASTRA. Information on vehicle prices have been provided by the Centre for Public Management and Policy (KPM) of the University of Bern. I would classify the data as "semi-public", as there are versions of both MOFIS and TARGA that are available for free but access to them has to be requested. The MOFIS data used here is not freely available and had to be bought from the ASTRA. The price

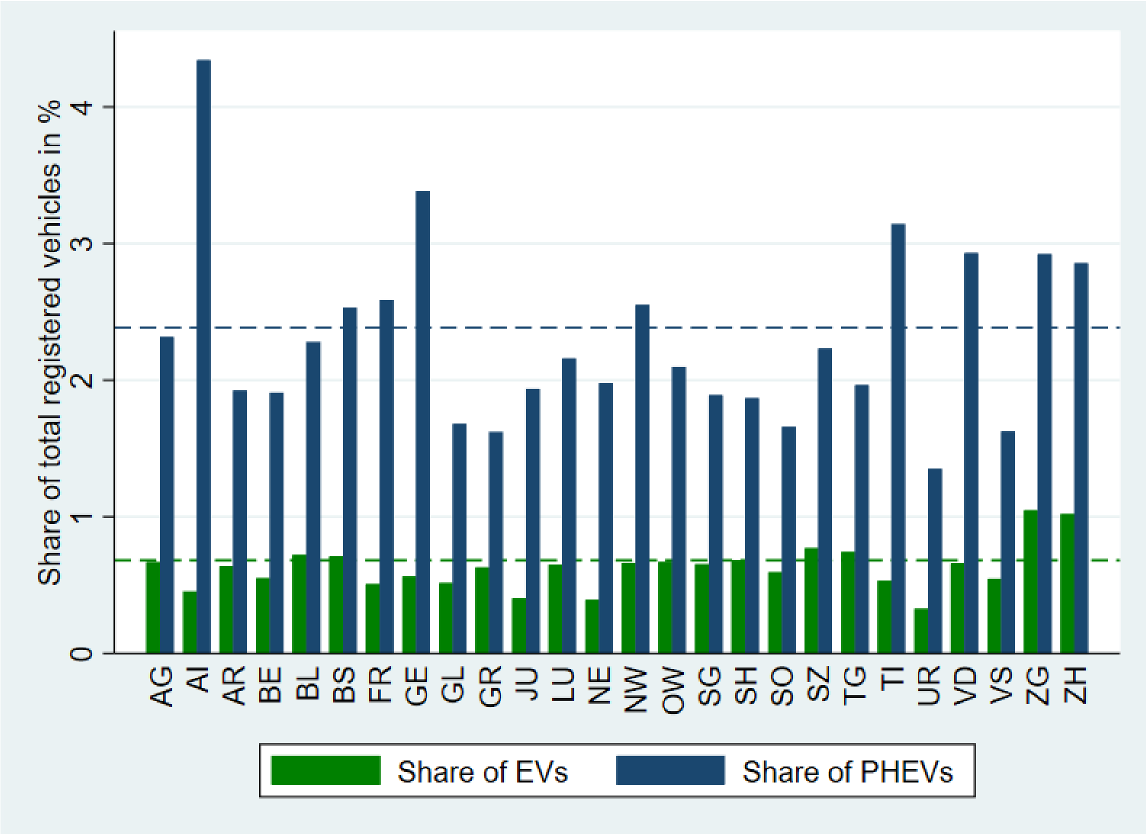

Figure 1: Cantonal EV/PHEV shares of registered vehicles and national averages

Source: MOFIS

data also is not publicly available and had to be bought from a research agency by the KPM and was thankfully provided to me for the sake of this thesis.

Currently, as of January 2020, there are a total of 4.6 million registered personal vehicles in Switzerland. The share of electric and hybrid vehicles in the current fleet of vehicles are 0.68% and 2.38% respectively. The term "electric vehicle" (or EVs) refers to purely electric vehicles, also called BEVs (Battery Electric Vehicles). Hybrid vehicles include all cars that have either a gasoline or diesel powered main powertrain that is supported by an electric motor. There is two subgroups to hybrid vehicles: ones that can be charged off the electric grid via a plug and ones that solely charge their batteries during use (e.g. through braking). Hybrid vehicles with electric plugs are more commond. They are often referred to as PHEVs (Plug-In

Hybrid Electric Vehicle). Together with BEVs they form the group of PEVs (Plug-In Electric Vehicles). For the rest of my thesis I will use the terms "EV", "PHEV" and "PEV" to refer to electric cars, hybrid cars or both[1] In 2012, the last available point of comparison with a total of 4.25 million registered cars in total, these shares were much lower at 0.03% for EVs and 0.64% for PHEVs. In relative terms, there was a huge increase in the share of EVs and PHEVs, in absolute terms and compared to the whole car market the increase was not that impressive. Looking at their increasing shares in new registrations will lead to these percentages increasing in the future, should the current trend continue. The most EVs and PHEVs (in absolute terms) are registered in the Canton of Zurich with 7'200 EVs and 20'300 PHEVs. In terms of share of total registered cars, the Canton of Zug is slightly ahead of Zurich with an EV share of 1.05%, compared to Zurich's 1.02%. The Canton of Uri has the lowest shares of EVs at 0.33%. The numbers for PHEVs, all the other Cantons and the national averages (dashed lines) can be seen in figure 1. For EVs, the most popular car manufacturer is Tesla with over 13'000 registered cars as of January 2020. The most popular model is the Tesla Model 3, followed by the Tesla Model S. For PHEVs the most popular manufacturer by far is Toyota with over 50'000 registered cars in 2020. Their most popular models are the Toyota Auris, Prius and Yaris with over 10'000 registered vehicles each. The market shares of the most popular manufacturers of EVs and PHEVs can be seen in figure 2 where the top six manufacturers for electric and hybrid cars are shown. Tesla and Toyota currently lead the pack in their respective markets with a comfortable lead over their competitors. Currently more and more 'traditional' manufacturers start including EVs and PHEVs (either new models or 'electrified' versions of existing models) in their product lineups and it will be interesting to see how the markets for electric and hybrid vehicles continues to develop in the coming years.

Between 2010 and 2019 4.11 million vehicles have been registered in Switzerland. Of those,

[1] There are also other forms of "hybrid" vehicles. Examples include gasoline/ethanol, hydrogen/electric, natural gas/gasoline and other combinations of energy sources. Also not included in my definition of hybrid vehicles are electric vehicles with range extenders as their numbers are very low and they are not considered in most policies.

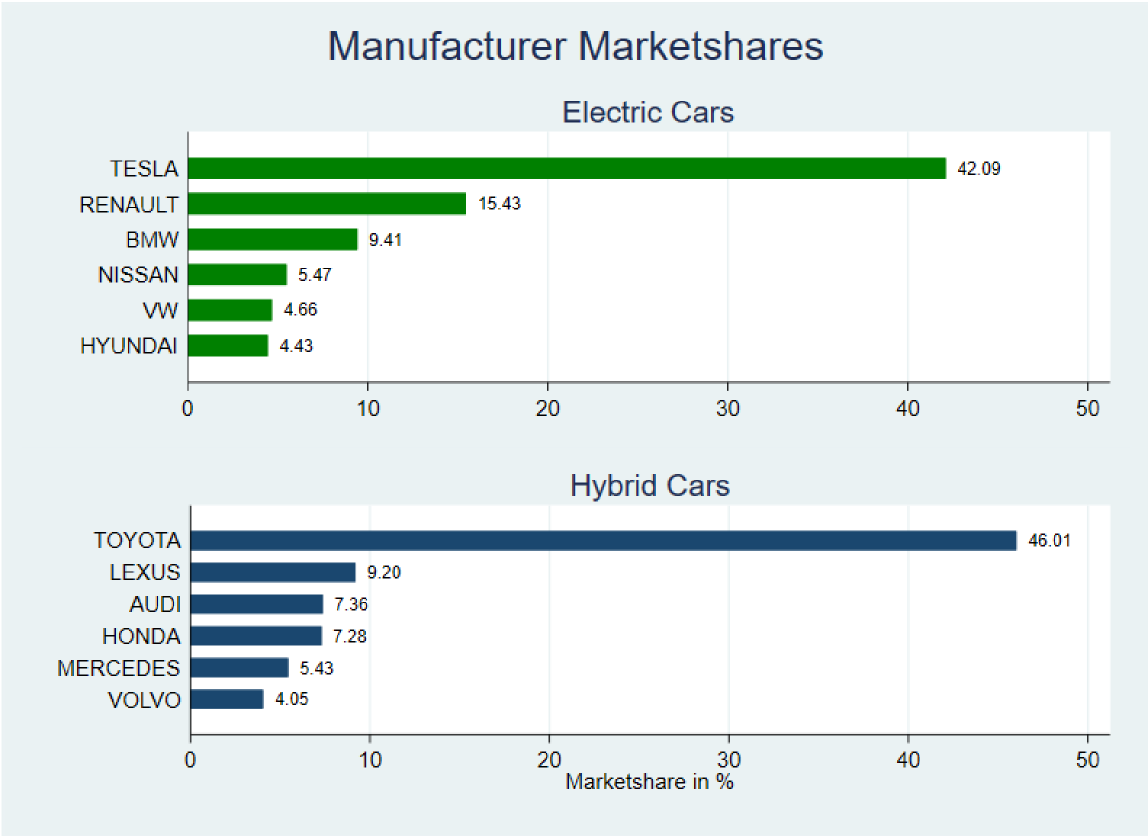

Figure 2: Marketshares of the top six manufacturers for electric and hybrid vehicles

Source: MOFIS

3.15 million are passenger cars both privately and commercially owned. The yearly number of registrations has been relatively stable at around 315'000 vehicles with the most vehicles being registered in 2012 (336'230 registrations) and the lowest number being registered in 2010 (297'865 registrations). The share of EVs and PHEVs has, however, increased a lot during the relevant time period (see figure 3) from close to 0% to over 4% for EVs and from under 2% to over 8% for hybrid vehicles. . Paradoxically, the average CO2 emissions for newly registered cars only seems to decrease until 2016 and then starts to increase again substantially. This increase is also reported by the Swiss government (Bundesamt für Energie 2019). This means that the federal goal for CO2 emission of new vehicles of 130gCO2/km implemented in 2015 (that has not been met in past years) will be even harder to meet in the future. The target CO2

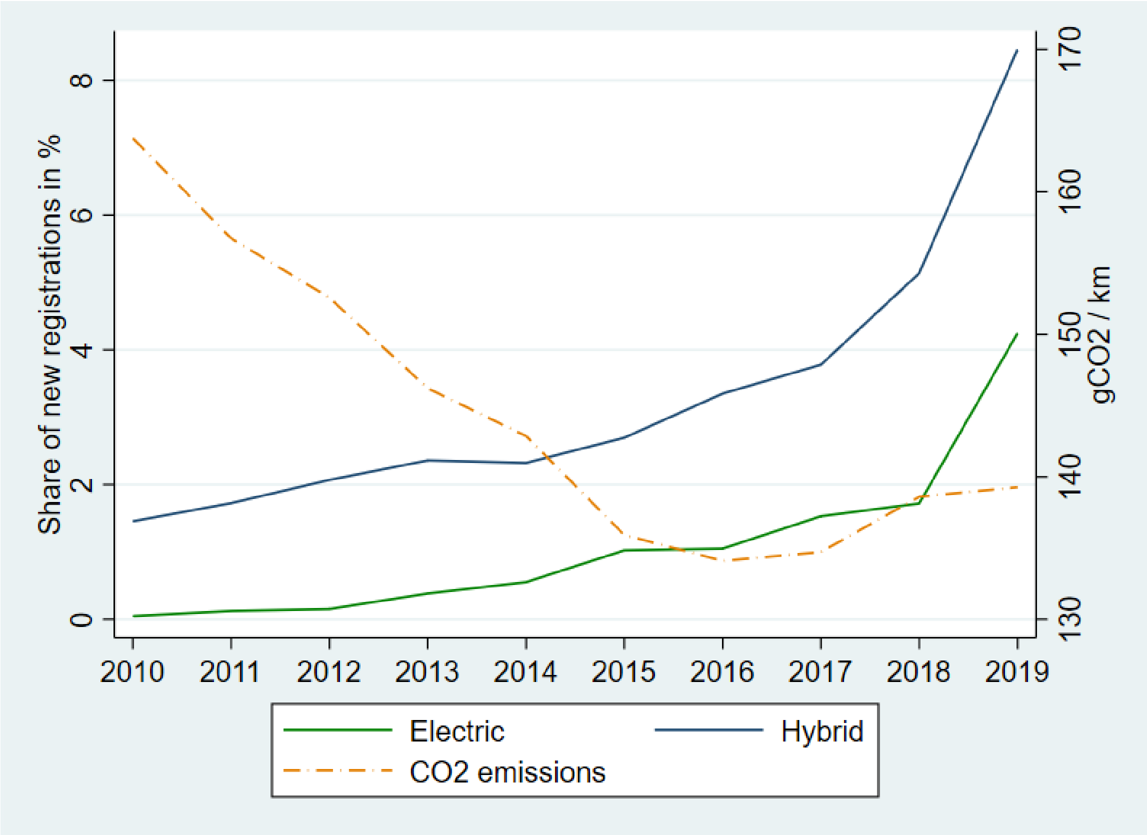

Figure 3: Share of new registrations of electric and hybrid vehicles and average CO2 emissions of newly registerd cars

Source: MOFIS / TARGA

emissions will even be lowered to 95gCO2/km in 2020. The increase in average emissions can be explained by the increase in the share of all-wheel-drive vehicles (they consume more fuel) and the reduction in the share of diesel vehicle in favour of more polluting gasoline vehicles. Another reason could be a new way of calculating CO2 emissions that led to higher values for certain vehicles (Bundesamt für Energie 2019).

3.2 Cantonal Incentive Schemes

In Switzerland, a number of different schemes to incentivise the purchase of EVs and PHEVs have been implemented. A few measures were implemented on the national level but, as with most policies in Switzerland, most measures were implemented on the cantonal level by cantonal executives or lawmakers. On a national level, the push for an electrification of the vehicle fleet is part of the "Energy Strategy 2050" adopted by the Swiss Federal Government in 2018. On the topic of personal mobility the strategy defines a reduction of CO2 emissions of personal vehicles to under a limit of 95 gCO2/km. So far, apart from an exemption from the automobile-tax (that my not even be passed on to customers by car dealers), there have been no other measures taken by the Federal Government. The Cantonal governments are free to implement each their own set of incentives for EVs, should they chose to implement any at all. Table 1 gives an overview of all the measures currently implemented by Swiss Cantons.

The most widely implemented measure are tax rebates on vehicle circulation taxes as used in Alberini & Bareit (2019). Currently some form of tax rebate is implemented in 20 of 26 cantons. They vary in magnitude from 20% to 100% and apply to either low emitting vehicles (standards defined by the canton), vehicles that have a certain energy efficiency label (federal standards) or to specific types of vehicles, e.g. only EVs. Solothurn and Zug implemented tax exemptions for electric vehicles very early (1990 and 1987) at a time where electric vehicles were nowhere near a state of mass production. This also reflects in the relevant passages in the regulations where 'solar and electric vehicles' are mentioned. Apart from these exceptions most of the rebate schemes were introduced around 2010. Only a few cantons chose to implement other possible types of incentives. In Berne, Geneva and Thurgau the construction of charging infrastructure in private homes or at the workplace is financially incentivised. Only in the Cantons of Basel-City, Ticino and Thurgau there were and are direct purchase premiums when purchasing an eligible vehicle. The most generous can be obtained in Ticino where up to CHF 4'000 can be recieved when purchasing a vehicle of a participating manufacturer from a participating dealership. While talking to Cantonal officials to obtain the relevant information on Cantonal incentive schemes most of the cantons that have not implemented any measures so far indicated a willingness of their respective executives or legislatives to consider implementing measures in the future. On the other hand, there are also some cantonal officials saying that the current tax rebates may not stay in place in the longer term. As more and more people drive electric vehicles the loss in tax revenues will be too big and road infrastructure still needs to be maintained - often financed by taxes on vehicles. Completely missing so far in Switzerland are non-monetary measures in the form of certain privileges for drivers of electric and hybrid vehicles. Such privileges could include access to bus- and HOV-lanes, special EV parking spots etc. and are implemented in some US states and some northern European countries (Hardman 2019). Currently such non-financial incentives are not part of the political debate and it seems unlikely that they will be implemented in the (near) future.

Canton	Incentive	Description	Eligibility
AG	Charging Stations	Available charging stations at two buildings of the cantonal administration	-
AI	none	-	-
AR	none	-	-
BE	Tax Rebate	60% tax rebate for the year of registration and the three following years	EVs
	Charging Stations	Cantonal Subsidies for construction of charging stations. CHF 1'500 for one charging port, CHF 3'000 for two	-
BL	Tax Rebate	Feebate system with low emitting vehicles' tax being reduced by up to CHF 300 and high emitting vehicles paying a fee of CHF 300	All vehicles
BS	Tax Rebate	EVs are only taxed on their "Leergewicht" (weight when empty) and receive an additional rebate of 50%	EVs
	Subsidy	Subsidy for taxi companies when they purchase an EV: 20% of the vehicle price up to CHF 10'000	EVs
FR	Tax Rebate	Tax exemption for vehicles with the best energy efficiency label in the year of registration and the following two years	All vehicles
GE	Tax Rebate	Three year tax exemption for vehicles emitting less than 40 gCO2/km. 50% feebate for vehicles > 200gCO2/km and < 120gCO2/km	All vehicles

	Charging Stations	Financial Support for Construction of Charging Stations: CHF 2'000 for public stations, CHF 1'000 for private stations.	-
GL	Tax Rebate	Feebate system based on energy efficiency label. Categories A and B get 100% and 75% rebate, categories F and G get 20% and 30% feel	All vehicles
GR	Tax Rebate	Tax rebate of 80% for low emission vehicles (as defined by the canton)	All vehicles
JU	Tax Rebate	50% tax rebate for electric vehicles.	EVs
LU	none	-	-
NE	Tax Rebate	Electric vehicles only pay base-tax of CHF 235. Tax is calculated as $Tax_{base} + A * Emissions$.	All Vehicles
NW	Tax Rebate	Tax exemption for 36 months after registartions for vehicles with the best energy label according to federal guidelines.	All Vehicles
OW	Tax Rebate	Differing tax rebates for 24 months after registration based on federal energy label. 50% rebate for best label, 25% for second best.	All vehicles
SG	Tax Rebate	Tax exemption for vehicles with the best energy efficiency label in the registration year and the three following years	All vehicles
SH	none	-	-
SO	Tax Rebate	Tax exemption for electric and solar powered vehicles (*since 1990*)	EVs
SZ	none	-	-

TG	Tax Rebate	Feebate system based on efficiency label. Four year Rebate for A and B (50% and 25%), lasting fees for F and G (50%).	All vehicles
	Subsidy	CHF 3'500 subsidy for the purchase of a purely electric vehicles.	EVs
	Charging Stations	CHF 500 per existing parking spot that is fitted with charging ports.	-
TI	Tax Rebate	Tax exemption for electric vehicles	EVs
	Subsidy	CHF 4'000 for electric vehicles. Half is paid by the Canton, the other half is paid by the participating car dealer. CHF 2.5 millions in total.	EVs
	Charging Stations	CHF 500 per charging station. CHF 500'000 in total.	-
UR	Tax Rebate	Battery powered vehicles only pay two thirds of the regular tax	EVs
VD	Tax Rebate	75% rebate for vehicles emitting less than 120gCO2/km. Electric vehicles only pay a tax of CHF 25	All vehicles
VS	none	Energy Agenda 2030: subsidies for purchases of EVs and PHEVs and the installation of charging ports are planned to be implemented in 2020	-
ZG	Tax Rebate	50% tax rebate for vehicles with electric motors.	EVs
ZH	Tax Rebate	80% tax rebate for best energy label and 50% for second best (A and B)	All vehicles

Table 1: Overview of the currently implemented incentive schemes for electric, hybrid and low-emission vehicles

Sources: Cantonal laws, information provided by Cantonal officials or published on official websites

4 Methodology

4.1 Variable Selection

I try to approximate the methodology used in Alberini & Bareit (2019) insofar as that I will also try to exploit cantonal policy differences to estimate the causal effects of these policies on the number of PEV registrations. My thesis will, however, differ in a few key aspects from the work of Alberini & Bareit (2019). I will look not only at taxes but include other types of financial incentives; namely purchase premiums and charging station subsidies. I will also focus my research solely on electric cars and leave out hybrid and gasoline powered vehicles. The reason why I choose to only focus on EVs and not include hybrid vehicles is that it is much easier to construct comparable tax rebate and purchase premium variables. The tax systems in the cantons are vastly different and even for electric vehicles, which usually profit from the most generous rebates and subsidies, it is quite complicated to get comparable data. The process could certainly also be repeated for hybrid vehicles but it is not that straightforward. In the section on CO2 emissions all cars are considered, so it is only in my analysis on the effects on registration shares that PHEVs are excluded and only EVs are considered.

To conduct my research, I use the data provided by the Federal Road Office (Bundesamt für Strassen, ASTRA) from their MOFIS (Motorfahrzeug Informationssystem) database, containing entries for all newly registered cars in Switzerland from at least 2009-2019. I combine this dataset with further technical information on the individual cars (including detailed information on emissions and fuel economy) as well as price information provided by the KPM. Information on the different forms of cantonal incentives (the independant variable) were manually collected from either publicly available records or requests to the responsible cantonal institutions (often the Departments for Energy or Environment). The detailed information on every registered vehicle, including geographic information on the owner of the vehicle, allow me to match every registered car with the incentive scheme that was in place in a given canton at the time of registration. This allows for analysis on the cantonal level. Since the data from MOFIS is provided on a daily per vehicle basis I had to aggregate the data to obtain monthly numbers. This works well with the introductions of new cantonal laws and regulations that usually come into effect at the beginning of a month or a year.

The formalization of the different cantonal incentive schemes presents a challenge as they are constructed very differently from one another. I broke them down into three main categories: purchase premiums in CHF, yearly circulation tax rebates in CHF and charging station subsidies in CHF. In fitting all the different forms of incentives into these three categories i may not have done all of them perfect justice but the simplification makes the following analysis a lot easier and there is probably no perfect way to capture every detail of every incentive scheme. Purchase premiums and charging station subsidies were the easiest as they are more easily comparable between cantons. The main problem lies in the calculation of the tax rebates in CHF. To do this, I first calculated the 'tax-level' for a Tesla Model S 75D in all the cantons. The Tesla Model S 75D was chosen because it is also the reference electric car that the TCS (Touring Club Schweiz - the biggest Swiss motorists club) uses in their tax comparisons[2]. The tax-level is constructed as the taxes the owner of the car would have to pay if there were no rebates for electric or low-emission vehicles in place. There are huge differences in this tax-level across cantons. For electric vehicles there are two reasons for this: firstly there are rather large differences in 'baseline' circulation taxes between cantons for all types of vehicles to begin with and secondly electric vehicles are often subject to harsh taxation due to their heavy batteries (circulation taxes are sometimes based on weight) or due to high conversion rates from electric power to an artificial measure for engine displacement or horsepower (also possible tax bases).

The variables of control that I include in the model are inspired by Clinton and Steinberg (2019) who use a combination of demographic/social and economic control variables in their analysis. I used similar indicators that are available for Switzerland during the relevant time period. The economic controls I apply are the tax-level in CHF in the different cantons, a self-constructed price index for electric vehicles and the average taxable income by canton. The

[2] https://www.tcs.ch/de/testberichte-ratgeber/ratgeber/umwelt-mobilitaet/motorfahrzeugsteuer.php

price index is calculated as a weighted average of vehicle prices supplied by the KPM. The weight used is the number of sales by manufacturer per month. Using this index I try to capture a possible increase in demand for electric vehicles induced by sinking prices or vice versa. Since, as mentioned earlier, the most popular electric cars are manufactured by Tesla and are known to be rather expensive, I include a measure of 'wealth' in my model. This should help capture the fact that the popular electric cars may not be affordable for lower-income cantons and their number may thus be lower. Data on cantonal average taxable income is available from the Swiss Federal Statistical Office (Bundesamt für Statistik, BFS).

Apart form the economic controls I also include a few other variables capturing more demographic or social dimensions. Firstly, I include the voter share of the green parties (GP and GLP) in the last federal election in the model. It could be expected that in regions with higher shares of green party voters the propensity to buy electric vehicles would be higher since green voters may value the lower CO2 emissions of electric vehicles more highly in their purchase decision. Federal elections are only held every four years, thus I assumed a linear change in voter share between the known data points. This may not perfectly capture the real change of this variable over time but it is the most practical and feasible way to include the variable in my model. To capture a degree of urbanity of a given canton I include the population density in the model. More densely populated cantons may favour electric cars through better infrastructure or shorter distances that have to be travelled. The last social control I include is the share of people in the total population that have finished a tertiary education. In Switzerland this means they graduated from universities or finished another higher education program. Better education may lead, as one example, to more awareness regarding ecological problems and thus to a higher share of electric vehicles being purchased. More highly educated people may also be more prone to adopt new and emerging technologies (compare Lleras-Muney & Lichtenberg, 2002, for medical technology). I think the chosen variables of control capture a broad range of possible interfering influences on the variable of interest. Summary statistics for both the variables of interest and the variables of control can be found in table 4.1.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	mean	sd	min	max
Monthly Registrations	3,120	965.1	988.6	51	6,014
Monthly Reg. (electric)	3,120	10.55	28.87	0	640
Share of electric	3,120	1.009	1.598	0	13.00
Purchase Premiums (CHF)	3,120	40.38	415.3	0	5,000
Charging Station Support (CHF)	3,120	16.35	158.8	0	2,000
Circulation Tax (p.a.)	3,120	724.9	1,101	96	7,158
Tax Rebate (CHF)	3,120	223.8	239.8	0	922
Avg. Taxable Inc. (1000CHF)	3,120	68.82	12.69	49.38	133.2
Wt. Avg. Price (1000 CHF)	2,860	54.58	13.46	27.83	88.07
Population	3,120	316.4	330.7	15.66	1,539
Population Density (Resid./km2)	3,120	499.9	1,003	27.06	5,283
Green Party Share (%)	3,120	11.05	7.392	-12.04	30.33
Tertiary Education (%)	3,120	29.06	6.415	16.34	47.69

Table 4.1: Summary statistics for key variables

4.2 Econometric Model

The main econometric model used in the analysis is shown in equation (1). Using a panel-regression with two-way (cantonal and year) fixed effects I estimate the share of electric vehicles of new car registrations $eshare_{ct}$ as a function of the purchase premiums PP_{ct}, tax rebates TR_{ct} and charging station subsidies CS_{ct} where c denotes the cantons and t the time (monthly increments).

$$eshare_{ct} = \beta_1 * PP_{ct} + \beta_2 * TR_{ct} + \beta_3 * CS_{ct} + FE_{ct} + \boldsymbol{\delta} * \boldsymbol{CTRL}_{ct} + e_{it} \tag{1}$$

Included in the model is a set of cantonal and yearly fixed effects denoted by FE_{ct} as well as a vector of controlling variables denoted by $\boldsymbol{CTRL}_{ct}$. The controlling variables include the previously mentioned tax-level, electric car price index, average taxable income, green party voter share, population density and the share of the population with tertiary education.

The dependent variable, the share of electric vehicles of new car registrations, was chosen over the absolute number of electric vehicles registered because it makes the different cantons more comparable. Without this approach the size of the car markets would also have to be taken into account. If one were interested in the number of additional electric vehicles being registered because of the incentive schemes in place, the same methodology with a few minor changes could be easily applied to the absolute numbers. The independent variables PP_{ct} and CS_{ct} are denoted in 1000CHF and TR_{ct} is denoted in 100CHF. The scaling to 1000CHF and 100CHF makes the results a bit easier to interpret as the effects per single franc would become very small.

In a second step I estimate the same model but I exchange the left hand side variable with the average CO2 emissions and the average fuel economy of newly registered cars as calculated with the use of TARGA data on the registered vehicles.

$$CO2_{ct}^{avg} = \beta_1 * PP_{ct} + \beta_2 * TR_{ct} + \beta_3 * CS_{ct} + FE_{ct} + \boldsymbol{\delta} * \boldsymbol{CTRL}_{ct} + e_{it} \tag{2}$$

$$fuelecon_{ct}^{avg} = \beta_1 * PP_{ct} + \beta_2 * TR_{ct} + \beta_3 * CS_{ct} + FE_{ct} + \boldsymbol{\delta} * \boldsymbol{CTRL}_{ct} + e_{it} \tag{3}$$

The simplicity of the model makes it easy to understand and also more accessible for someone wanting to adapt it. It could be expanded to allow for different effects for different makes and models of cars as well as different interactions between them, years and cantons through the introduction of additional multi-way fixed effects.

5 Results

5.1 Main Regression Results

Table 2 shows the results of the main regression output. As a robustness check I used five total different specifications of the model to see how the coefficients of the main variables of interest (PP_{ct}, CS_{ct} and TR_{ct}) would change. The first specification includes just the variables of interest and cantonal-level fixed effects. Model (2) also includes yearly fixed effects. Model (3) includes both fixed effects and the set of economic control variables. The fourth model includes both fixed effects and the set of social control variables. Finally, model (5) includes the full set of control variables and both cantonal and yearly fixed effects.

As we can see, the purchase premiums have a highly significant effect in every model specification with coefficients ranging from 0.296 to 1.071. This would mean that increasing purchase premiums for electric vehicles by CHF 1000.- leads to an increase of 0.296 to 1.071 percentage points in the share of electric vehicles of new car registrations. Seeing that the share of new registrations that were electric vehicles was only around 4% in 2019, this represents a rather sizeable effect even with the smaller estimate of the preferred full model specification. Purchase premiums could therefore prove to be an effective, though probably rather expensive, measure to promote electric vehicle sales. The charging station subsidies only have a significant effect in the very basic specification and lose all significance in the other, more detailed models. Tax rebates also only have a significant effect in the basic specification of model (1).

Looking at the variables of control there are some interesting things to note. Firstly, the price index variable has a significant, albeit small, *positive* effect on the share of electric vehicles in new registrations. In the full model, an increase in the weighted average price of electric cars by CHF 1'000.- would lead to an increase in their share in new registrations of 0.0286 percentage points. Prima facie this seems paradoxical, as an increase in price is usually associated with a decrease in demand for a good. I think this could at least partly be explained by the somewhat strange structure of the Swiss electric car market. The best-selling models from Tesla are very

Table 2: Main Regression Output

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Base	Base - 2FE	Economic	Social	Full
PP_1000CHF	1.071***	0.369***	0.368***	0.296***	0.296***
	(0.0677)	(0.0512)	(0.0521)	(0.0528)	(0.0537)
CS_1000CHF	0.904***	0.217	0.239	0.142	0.159
	(0.222)	(0.166)	(0.170)	(0.166)	(0.170)
taxrebate_100CHF	0.299***	-0.0324	-0.0395	-0.0428	-0.0541
	(0.0420)	(0.0318)	(0.0337)	(0.0318)	(0.0337)
tax_chf			-2.86e-05		-2.51e-05
			(3.56e-05)		(3.54e-05)
avg_prc_1000CHF			0.0285***		0.0286***
			(0.00211)		(0.00210)
income_1000CHF			-0.00359		-0.00534
			(0.00953)		(0.00956)
pop_density				0.00523***	0.00561***
				(0.000967)	(0.00109)
edu_tertiary_prct				-0.0476**	-0.0645***
				(0.0234)	(0.0245)
green				-0.00319	0.000241
				(0.00586)	(0.00679)
Observations	3,120	3,120	2,860	3,120	2,860
Adjusted R-squared	0.118	0.536	0.549	0.540	0.553
Cantonal FE	YES	YES	YES	YES	YES
Year FE	NO	YES	YES	YES	YES

Standard errors in parentheses - *** p<0.01, ** p<0.05, * p<0.1

expensive compared to their counterparts from other manufacturers. Cars in the Tesla price range are often a status symbol and could therefore react to pricing like a luxury good with increased demand at a higher price. This somewhat strange interaction could be an interesting topic for further research. Income on the other hand is not significant in the full model and also insignificant in the reduced model with only economic control variables.

Of the three 'social' variables of control two seem to have a significant effect on the share of electric vehicles. The population density that I included as a measure of 'urbanity' seems to positively effect the share of electric vehicles. the effect seems to be stable in different specifications at a 0.00523-0.00561 percentage point increase per additional resident per square kilometer. This effect should not be underestimated as there are huge differences between the population densities of different cantons (minimum is 27.06 residents/km2, maximum is 5'283 residents/km2) and should therefore be considered carefully. The second social control variable that has a significant effect on the share of electric vehicles is the percentage of the population that finished a tertiary education (college level). Its effect is significant at the 5% level for specification four and significant at the 1% level in the full model specification. In the full specification an increase in the tertiary education variable by one percentage point leads to a*decrease* in the share of electric vehicles of new registrations of about 0.0645 percentage points. This, coupled with the negative (but insignificant) effect of income leads me to believe that people with better education that earn more on average don't tend to buy electric vehicles; or at least don't tend to buy more of them compared to the rest of the population. Still, the size of the coefficients is very small, even compared to the already small share of electric vehicles. For that reason this specific interpretation should be used with caution.

A Hausman specification test revealed that the null-hypothesis of no systematic difference between a fixed- and a random-effects specification is rejected at the 5% level. This means that a (potentially more efficient) random effects specification is not consistent. Further, a modified White-Test for heteroskedasticity revealed that the null-hypothesis of homoskedasticity is resoundingly rejected and my sample is indeed heteroskedastic. For this reason I use robust standard errors in the following analysis. For comparison I also calculated a model with bootstrapped standard errors. Further it has to be noted that, though not reported in table 2, almost all the yearly dummies are highly significant and have large effects ranging from a coefficient of 0.438 in 2011 to a coefficient of 4.333 in 2019. The fact that these yearly effects are increasing from year to year indicates that there is an underlying upward trend in the share of electric vehicles that is not reflected in any of the other included variables. I therefore decided to include a trend-variable in my next analysis to capture the magnitude of such an underlying effect. This trend variable simply starts at the value 1 in 2010 and increases by 1 for every additional year. Per construction its coefficient then represents the average annual increase or decrease in the share of electric vehicles over the whole period.

The results of these corrections (shown in table 3) completely eliminate any significance of the coefficients of the variables of interest. Reported are only select variables, the specification is the same as the full model with the addition . The newly included trend variable however is highly significant and indicates that the increase in the share of electric vehicles of new car registrations seems to be in an upward trend that has nothing to do with the other included explanatory variables. Possible explanations could be that more and more car manufacturers recently started to offer a wider selection of new electric vehicles or that people started to become more conscious about the environment (but don't vote more 'green'). Another explanation would be that electric vehicles are just 'en vogue' and that the recent upward trend doesn't necessarily have a fully rational basis. The reported results from the main regression have to be used carefully in light of this corrected analysis.

5.2 Effects on CO2 emissions

As I stated earlier in this thesis, I am not only interested in the direct effect of the different cantonal incentive schemes on the share of electric vehicles being sold but also on their impact on average CO2 emissions. Using the same methodology but changing the dependent variable from the share of electric vehicles to the average CO2 emissions of all vehicles registered in

Table 3: Robust Standard Errors

	(1)	(2)	(3)
VARIABLES	electric_share	electric_share	electric_share
PP_1000CHF	0.296***	0.296	0.296
	(0.0537)	(0.206)	(0.278)
CS_1000CHF	0.159	0.159	0.159
	(0.170)	(0.314)	(0.966)
taxrebate_100CHF	-0.0541	-0.0541	-0.0541
	(0.0337)	(0.0660)	(0.121)
avg_prc_1000CHF	0.0286***	0.0286***	0.0286***
	(0.00210)	(0.00258)	(0.00252)
pop_density	0.00561***	0.00561**	0.00561
	(0.00109)	(0.00243)	(0.0122)
edu_tertiary_prct	-0.0645***	-0.0645	-0.0645
	(0.0245)	(0.0510)	(0.0475)
trend	0.481***	0.481***	0.481***
	(0.0275)	(0.0392)	(0.0575)
Constant	-3.095***	-3.095	-3.095
	(0.963)	(1.870)	(3.106)
Observations	2,860	2,860	2,860
Std. Errors	standard	robust	bootstrap

Standard errors in parentheses - *** p<0.01, ** p<0.05, * p<0.1

that specific month I can estimate that effect. By using the same explanatory variables (at the same values) as in the analysis on electric vehicles any effect I find will probably be an overestimation as especially tax rebates are not as generous for other low-emission vehicles (like hybrid or low emitting fossil fuel vehicles). To obtain a more realistic estimate for every registered vehicle the applicable tax rebate would have to be calculated. This is certainly doable but is not necessarily a trivial task because of the 26 different tax systems that have to be taken into account. For my calculations I will not address this problem and thus the estimates I obtain have to be considered with that in mind. Since most of the cantons that offer the highest tax rebates to electric vehicles also offer more generous tax rebates for other low-emission vehicles I suspect the difference between my simplified approach and the 'correct' approach would not be too big. Data on the average CO2 emissions have been calculated by assigning each registered vehicle its CO2 emission value from the TARGA database and then taking the weighted average of all registrations. The same was done for the average fuel efficiency.

As we can see, the effects on the share of electric vehicles translate into an effect on average CO2 emissions in g/km and also an effect on average fuel economy measured in l/100km. The results shown here are obtained through an estimation of the full model with robust standard errors but only the coefficients of the main variables of interest are reported in the table. Purchase premiums, charging station subsidies and tax rebates all have negative but insignificant (at the 5% level) effects on CO2 emissions. Only the purchase premiums are significant at the 10% level. The trend variable is highly significant and shows an average reduction of over 2 gCO2/km per year. It is important to note, that this is the average reduction per year over the whole time period (per the construction of the trend variable explained earlier). The true values for the average CO2 emissions are shown in figure 3. As can be seen, the average CO2 emissions of registered cars actually *increased* in recent years and target emissions were not met.

The reported variables also all have negative effects on the fuel consumption per 100km (an *improvement* in fuel economy) but as with the CO2 emissions, only the purchase premiums have a significant (only at the 10% level) effect. Purchase premiums seem to improve fuel economy by approximately 0.03 litres per 100km. The trend variable is once again highly significant and over the sample period on average the fuel economy improved by 0.0685 litres per 100km per year.

Table 4: Effects on CO2 emissions and fuel usage

	(1)	(2)
VARIABLES	CO2 [g/km]	Fuel [l/100km]
PP_1000CHF	-0.643*	-0.0294*
	(0.348)	(0.0164)
CS_1000CHF	-0.0973	-0.00504
	(0.567)	(0.0253)
taxrebate_100CHF	-0.0901	-0.00130
	(0.119)	(0.00559)
trend	-2.015***	-0.0685***
	(0.175)	(0.00696)
Constant	177.8***	7.243***
	(5.067)	(0.206)
Observations	2,860	2,860
R-squared	0.842	0.827

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Of the variables that are not reported in the table only two more showed significant effects. Population density has a significant (at the 5% level) negative effect on CO2 emissions and the weighted average price has a highly significant negative effect on both CO2 emissions and fuel usage. The full regression table can be found in the annex.

5.3 Discussion

The results presented in this thesis do not paint incentive schemes for electric vehicles in the best light. The data does support the anticipated positive effect of the incentive schemes but they lose all or most of their significance when adjusting standard error calculation to the heteroskedasticity in the sample. In the following section I will discuss my findings in the context of previous research and show the limitations of my analysis and future research avenues that may present themselves.

Overall I would argue that my results fit in with the overall research context. The most easily comparable analysis by Alberini & Bareit (2019) that analysed only tax rebates also finds positive but small effects on the registration numbers of efficient vehicles. My thesis supports these results as I also found small but positive (though not always significant) effects of circulation tax rebates on the number of electric vehicle registrations. Similar effects have also been found by other authors for different countries (e.g. Clinton & Steinberg, 2019). The consensus in the literature seems to be that (at least) subsidies at the time of purchase have a positive effect on EV sales (e.g. Muehlegger & Rapson, 2018; Münzel et al., 2019). My analysis also supports these findings, though my estimated coefficients and thus the associated effects of the variables of interest seem to be smaller. My results also seem to support the presumed difference in effects sizes of payments at the point of purchase compared to tax rebates that manifest later in the year at the time of filing taxes as reported by Galagher & Muehlegger (2011).

Since the effect of purchase premiums and tax rebates is not that big (if even significant), I would like to put them into perspective by looking at the cost they may incur. To do this I will look at the two cantons that currently have implemented ongoing purchase premium programs, the canton of Ticino and the canton of Thurgau. Both of their programs started in 2019 (Thurgau in January, Ticino in July). In Thurgau, buyers of electric vehicles are eligible to receive up to CHF 3'500.- as a purchase premium, in Ticino they can receive up to CHF 4'000.- where half is paid for by the canton and the other half is paid by the participating car dealership. Assuming that all the buyers in those two cantons claimed their purchase premium in the relevant time period we are looking at a cost of CHF 2'145'500.- in Thurgau and CHF 632'000.- in Ticino. In Thurgau the CHF 3'500.- purchase premium has, according to my results, increased the share of electric vehicles of newly registered vehicles by about 1.1% meaning that without the premiums it would have a share of 6.3% in 2019 instead of the 7.4% it actually had. Compared to an electric share of only 1.99% in 2018 the jump to 7.4% is very large; in fact it is the single biggest jump in a single year in the whole sample. This large jump in electric share can not only be explained by the introduction of the purchase premiums. In Ticino the CHF 4'000.- purchase premium would be expected to raise the share of electric vehicles in new registrations by around 1.25%. Since it was only active in the second half of 2019 its effects may not have fully manifested yet. In the first half of 2019 the share of electric vehicles of new registrations was 1.88% and in the second half of the year it increased to 3.23%, a 1.35% difference. The third canton that introduced purchase premiums, but only for a limited time in 2019, is Basel-Stadt. During 2019 they offered up to CHF 5'000.- per vehicle for firms that wanted to change parts of their vehicle fleet to electric vehicles. The allocated funds quickly ran out and according to an official from Basel-Stadt the last payments were made in January of 2020. Basel saw an increase in the share of electric vehicles from 4.01% in 2018 to 5.37% in 2019, a 1.36% difference. The expected effect of a CHF 5'000.- purchase premium would be 1.565%. In Basel the cost of this program is estimated to be about one million Swiss Francs. It is unclear if this program will be renewed sometime in 2020, at the time of writing this it wasn't.

Previous research by Chandra, Gulati & Kandlikaer (2010) shows that over 70% of the subsidies of a Canadian incentive scheme went to people who would have bought an eligible car even without the program. This free-riding could be a big problem for such programs as it makes them very cost-inefficient. At least in Ticino and Basel-Stadt the problem does not seem to be that big as the actual increases in the electric share of registrations are somewhat in line with the expected increases through the introduction of purchase premiums. In Thurgau however, the increase is much larger than what we would expect through the introduction of purchase premiums. This indicates that a lot of the increased demand for electric vehicles was not induced by the purchase premiums but the buyers still profited from them (free-riding). On the other hand the increase in the electric share of vehicle registrations in recent years does not really seem to align with changes in tax rebate regimes. A few cantons showed drastic changes in tax rebates during the sample period. Fribourg increased the rebate from 0% to 100% in 2018, Geneva increased it from 0% to 100% in 2019, Zurich introduced an 80% rebate in 2014, Bern introduced a 60% rebate in 2013 and a few smaller cantons also increased their rebates. In none of these cantons the higher rebates are able to explain the even larger rise in the share of electric vehicle registrations. This indicates that especially for tax-rebates there seems to be the potential for a lot of free-riding. This is especially problematic as the annual circulation tax on vehicles is usually used to finance road infrastructure maintenance. Roads are used in the same way and deteriorate in the same way from use through electric or through fossil fuel powered cars. It may thus be hard to defend tax rebates for electric cars in a world where they largely benefit free-riders and don't offer a big enough incentive to actually increase the share of electric cars being sold.

Let us now take a look at the results on CO2 reduction and fuel economy improvements that may be induced through the cantonal incentive schemes. The effects are mostly insignificant and not too large but I want to put these 'small' effects into the correct perspective. Because of the size of the car market even small reductions in CO2 emissions and small improvements in fuel economy can have huge overall effects. Let us first look at the only significant (at the 10% level) effect in the regression, the -0.0103 g/km reduction per percentage point of tax rebates. A full tax exemption for electric vehicles would thus induce an average reduction of CO2 emissions of 1.03g/km for newly registered vehicles. This seems like a small change but if you apply it to the whole car market in Switzerland this perception changes. The last official publication on the average number of kilometers driven by cars in Switzerland puts it at 11'828km (Bundesamt für Raumentwicklung 2015). If we multiply this number by 1.03g/km we get an average reduction of CO2 emissions per car per year of 12'182g or 12.18kg. This still does not sound like a lot until you take into account the fact that there are 4.64 million cars registered in Switzerland and over 300'000 are registered every year (MOFIS 2020). This means that this small reduction in CO2 emissions per car can lead to much bigger overall effects. In the first year alone, the 300'000 newly registered cars will produce 3'654 tonnes less CO2 than the cars that would have been registered without the tax incentive. Over the course of 10 years this first batch of cars alone will have emitted over 30'000 tonnes less CO2. If over time we would manage to reduce the average CO2 emissions by 1.03g/km for all registered cars we could achieve an overall yearly reduction in CO2 emissions of 56'528 *tonnes*.

To transform this amount of CO2 into a monetary figure we have to use an estimate of the social cost of carbon (SCC). This construct aims to measure the total cost of CO2 emissions on society through pollution, long term environmental damage, etc. The most used estimate of the SCC is that of the US Environmental Protection Agency. It puts the SCC for 2020 at 42 2007-$ which translates to just over 50$ today (US Interagency Working Group 2016). Surveys among experts seem to indicate that the true SCC is much higher, possibly more than twice as high. An analysis focussing on Switzerland by the research agencies Infras and Ecoplan (2019) puts the Switzerland-specific SCC somewhere between 69CHF/t and 214CHF/t with a median of 121CHF/t. For the 50$ value the avoidance of 56'528 tonnes would spare society a cost of over 2.8 million dollars which is (at the time of writing this) approximately equal to 2.6 million Swiss Francs. If the actual SCC is indeed higher than that, as the results of the survey done by Howard & Sylvan (2015) indicate (see figure 4), this number may be doubled or even tripled. For the mean value calculated by Infras and Ecoplan, the avoidance of 56'528 tonnes of CO2 would spare Switzerland a social cost of at least CHF 3.9 million and up to almost CHF 12.1 million per year. It is important to note that all of these calculation of the SCC are done under high uncertainty and have to be used carefully. Calculating the cost of the implementation of the described tax exemption of all electric vehicles in Switzerland is a bit harder and not necessarily a straightforward process. These complications are caused by the very different tax regimes implemented in the 26 cantons. The circulation tax strongly varies in amount and basis of calculation. I will once again use the yearly circulation tax values for a Tesla Model S 75D that I already used earlier in my analysis. For 2019, a tax exemption for electric vehicles would cost the Swiss cantons approximately seven million Swiss francs. Assuming that the cars registered in 2019 will indeed produce the reduction in CO2 emissions of 30'000 tonnes over ten years then the avoidance cost per tonne of CO2 is approximately 230CHF/tCO2. If cars are used longer than ten years the value will be lowered. An avoidance cost of 230 CHF/tCO2 is

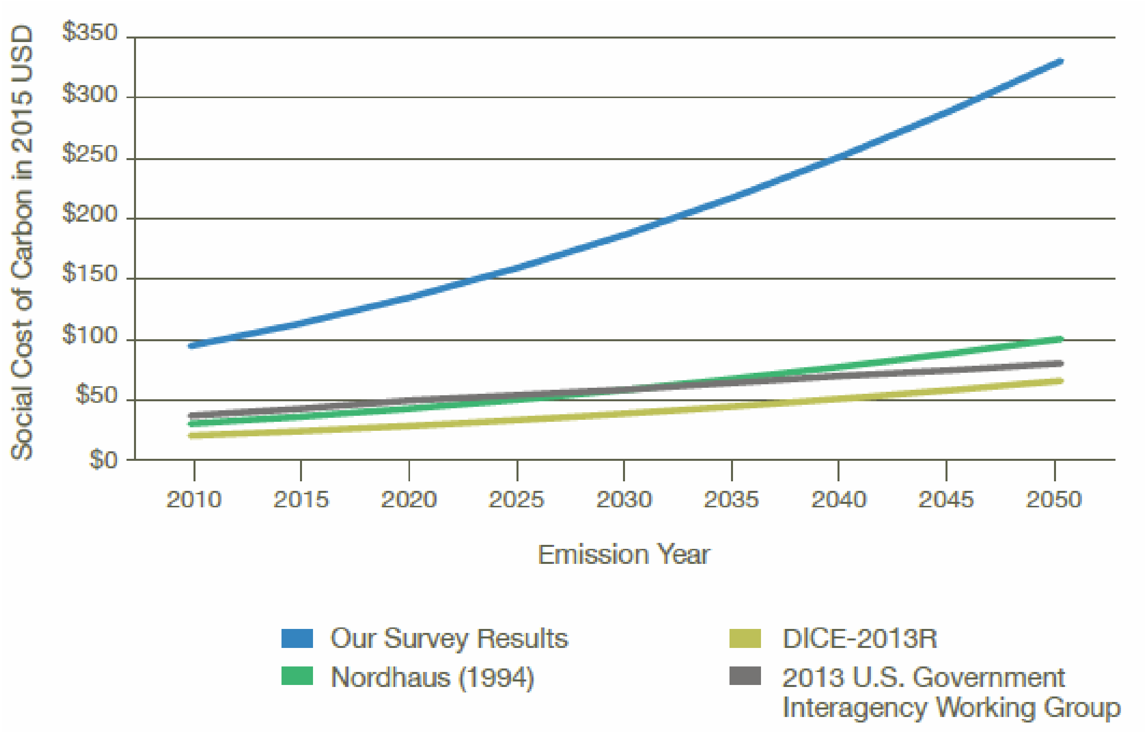

Figure 4: Different Estimations of the SCC

Source: Expert Consensus on the Economics of Climate Change (2015)

rather high but in line with other literature that puts the avoidance cost of electric car incentive schemes between 91$/tCO2 and 288$/tCO2 (Berensteanu & Li, 2011; Chandra et al., 2010; Li et al., 2010). Compared to the SCC incurred by the 30'000 tonnes of CO2 valued between CHF 2'070'000.- and CHF 6'420'000.-, depending on the chosen value of the SCC, this avoidance cost of seven million francs seems too high. It is therefore questionable if public funds are well spent on tax rebates for electric vehicles, if the main goal is to reduce CO2 emissions. Though emissions are indeed reduced, they could be reduced elsewhere at a lower cost leading to more efficient public spending. Since the atmosphere is indifferent to the source of CO2 this comparison makes sense and policymakers should, if possible, strife to employ CO2 reducing policies in areas where they are cheaper.

5.4 Limitations

My thesis has certain limitations caused by some methodological shortcomings that I was not able to correctly address in the scope of this project. I will try to explain them here, show if and how they could be resolved and what effect I think they had on the results of my analysis.

The first problem with the analysis is the there is little variation over time in the explanatory variables during the sample period. A lot of the tax rebates in place were already introduced before 2010 and never changed after that. Of the cantons that introduced tax rebates during the relevant time period almost none of them changed the values of their policies after the introduction. It is interesting to note that some cantons already made electric vehicles exempt from circulation taxes in the 1990s, long before they reached any level of mass adoption (these tax exemptions mostly still stand today). A similar problem arises for the analysis of purchase premiums: all of the purchase premiums were introduced on January 1st 2019 at the earliest. This means I realistically only had one year of data and only three cantons in which they were introduced to observe any kind of effect. The same is true for charging station support, though it was introduced a few years earlier. This ties in to the overall problem of the electric car market really only taking off in the last few years. Before 2016 the share of newly registered cars in Switzerland that had a purely electric motor was still under one percent. When numbers are that low even small shocks to the electric car market can heavily skew any analysis. It would be interesting to repeat my analysis in 5-10 years to see how policies impact a more mature electric car market.

The next limitation of my data is the fact that data for the controlling variables is not available on a monthly basis for all variables. This means i had to interpolate between yearly datapoints to obtain monthly data. I assumed a linear change between the known points. This is not unreasonable but may not capture 'abnormal' and non-linear changes between the known points. I think there is no reason to believe that variables like average income, the share of tertiary education and population density should change non-linearly. The one variable that may be subject to more 'erratic' changes is the voter share of the green party(ies) which I was only able to capture every four years on a national level. For this variable I am not sure if a linear interpolation between known points makes sense but it is also not obvious why it should not.

The third limitation is based on the fact that I only observed incentive schemes on a cantonal level and ignored the communal level. There is a number of, mostly wealthy, cities and villages that offer additional financial incentives to buyers of electric vehicles. My data on vehicle registrations would allow me to explore these communal level incentives as I know the ZIP code of the owner of every registered vehicle. The problem lies in collecting data on communal incentives as there is no available systematic collection of such incentives and even the cantons themselves do not keep records on such initiatives either. The communal level, I think, would provide interesting insights into the potentially increased adoption of electric vehicles causes by financial incentives. Some of these incentives are rather generous. Citizens living in Waldkirch (SG) recieve 10% of the purchase price, up to CHF 5'000.- as a purchase premium. Most cities or villages that have implemented such incentives offer purchase premiums between CHF 1'000.- and CHF 3'000.-

6 Policy Implications

I think the literature discussed in this thesis as well as the results produced by the presented analysis have important implications for policymakers in Switzerland. The electrification of personal mobility is a part of the national energy strategy *Energiestrategie 2050* but there are no clearly defined goals on a national level. This means that, through the overarching principle of subsidiarity, its promotion and support fall into the responsibility of the cantons. Cantonal lawmakers so far implemented a number of measures to promote electric mobility as already shown in this thesis. Three forms of incentive schemes have emerged: purchase premiums, tax rebates and subsidies for the construction of charging stations. The most used incentives, as listed in table 1 are tax rebates. More recently some cantons introduced purchase premiums and a few cantons also started subsidizing the construction of electric charging ports in recent years. The usually stated goal of these incentives is to get more people to buy electric cars. Indirectly this aims to reduce CO_2 emissions and reduce reliance on fossil fuels. In the next few paragraphs I will try to show if and how these measures can be effective to accomplish these goals based on previous research and my own analysis.

Purchase Premiums

Purchase Premiums are probably the kind of financial incentive that the most research has been done about. That such premiums can have a positive effect on electric vehicle adoption has been shown in a number of studies in the recent years (e.g. Clinton & Steinberg 2019; Muehlegger & Rapson 2018; Jenn et al. 2018; Mian & Sufi 2012). A good overview of such studies can be found in Münzel et al. (2019). Though the reported elasticities differ in magnitude, the overall consensus seems to be that purchase premiums foster the adoption of electric vehicles in the mass market. This is also in line with standard economic theory on subsidies that would predict an increase in demand as the relative price of electric cars is lowered compared to conventional cars. The analysis carried out in this thesis can confirm or at least support the consensus on positive effects.

For policy- and decision makers this means that the introduction of purchase premiums provides an avenue through which they can effectively promote the adoption of electric vehicles in their cantons. The problem is that it may not prove to be the most *efficient* way to do so. Purchase premiums come at a high cost for cantons as I mentioned in the discussion of my results. The canton of Thurgau for example potentially paid out over 2.1 million francs in the last year alone. Seeing that the effects of purchase premiums are dwarfed by an overall trend towards more electric vehicles and if the share of newly registered cars that are electric continues to grow at the pace that it has in the last few years the cost to maintain purchase premiums may rise higher and higher, straining cantonal budgets.

In conclusion: it seems that it may be reasonable to introduce purchase premiums to 'kick-start' the adoption of electric vehicles in a canton if the share of electric cars is low and then fade them out as the cost of maintaining purchase premiums for vehicles that reached the mass market becomes too high.

Tax Rebates

Tax rebates are the most common incentive scheme implemented in Switzerland. They are also widely used in other countries, the USA included, and have therefore also been the subject of many research projects. There is a distinction between flat, one-time tax credits (sometimes more comparable to a delayed purchase premium) and recurring, flat or percentage-based tax rebates. The most recent literature on the topic seems to indicate that tax rebates are also able to increase electric vehicle demand (e.g. Jenn et al. 2020; Alberini & Bareit 2019; Clinton & Steinberg 2019; Li et al. 2017; Chandra et al. 2010). If tax rebates are paid out as a one-time flat tax credit they work in the same way as a purchase premium would, though their effect may be diminished because of the fact that the tax benefit is not immediately 'impactful' like the purchase premium (Galagher & Muehlegger 2011). Recurring tax rebates are studied less and their effects are not understood as well as those of one-time tax rebates. Some authors find that they are not as important to consumers and may only have small effects (Lieven 2015) while others find that they are an important factor in the purchase decision (Figenbaum 2017). The analysis in this paper only finds small positive and mostly insignificant effects of rebates on the annual circulation tax.

In light of the state of the current literature as well as my own analysis I conclude that tax rebates, if they are considered, should be implemented as an annual rebate and not a one-time payment. While one-time payments are better understood and offer potentially bigger effects than annual rebates, they are less effective than just implementing a purchase premium of the same amount. Though annual tax rebates are already widespread in Switzerland, they may prove to become a point of political debate again once the share of electric vehicles rises higher. Circulation taxes are often used to finance maintenance of cantonal roads. Electric vehicles use roads the same as conventional vehicles and it may thus prove hard to argue why they should profit from tax rebates or even tax exemption. In a lot of cantons a way to get around this is to limit the tax rebate to a period of a few years after purchase of the vehicle. This may solve the political debate but may make the associated rebates even less effective in increasing the demand for electric vehicles.

Charging Station Subsidies

Subsidies for the construction of charging stations are probably the least understood of the incentives currently implemented in Switzerland. To understand the effects of such subsidies it is important to distinguish between two distinct effects: the effect of the subsidies on the construction of charging station and the subsequent effect of the availability of these charging stations on buyer's decisions on the purchase of electric vehicles. The literature often focusses on the second effect only and finds that access to charging infrastructure can play an important role in mass adoption of electric vehicles (Mersky et al. 2016; Lieven 2015; Sierzchula et al. 2014) and is often listed as one of the main contributing factor in the diffusion of electric vehicles. There are also interesting indirect network-effects at play. They are indirect because drivers of Teslas for example do not directly benefit from the other Tesla drivers but they profit from the more widespread charging infrastructure caused by more people driving Teslas which in turn will increase incentives to construct Tesla charging stations. Li et al. (2017) investigate these network effects and find that investment in charging infrastructure could have proved more than twice as effective as other financial incentives of the same value. In my analysis I find no effect of subsidies for the construction of charging stations on the share of electric vehicles of new registrations. My analysis 'skips' the middle step of the aforementioned three-step process of subsidies, charging stations and EV adoption. This does not mean that better charging infrastructure would not lead to increased EV adoption but indicates that the translation of subsidies into higher EV adoption may not be efficient. The literature suggests that the problem does not lie in the second part, the effect of charging infrastructure on EV adoption, but in the first part, the effect of charging station subsidies on the construction of additional charging stations.

In light of these findings it may make more sense to shift cantonal policies away from incentivizing the construction of (mostly private) charging stations by private citizens or firms to the cantons constructing a network of publicly available charging stations themselves. Interoperability between different car manufacturers and charging systems should be a high priority as network effects seem to play an important role in buyer's decisions on EV purchases. The more manufacturers use 'the same plug', the higher these positive network effects are. Policies enforcing common standards may prove just as effective as financial incentives and and at the same time put less strain on public budgets.

Non-Financial Incentives

Though not part of my analysis, non-financial incentives are part of many research projects in recent years and are often analysed side by side with financial incentives. The range of possible non-financial incentives for drivers of EVs is potentially limitless, in practice only a few different variations have emerged on a larger scale. The most prominent example of such incentives is the access to HOV-lanes (high occupancy vehicle lanes, bus lanes). HOV access is a privilege that is mainly implemented in the USA and in Norway. Hardman (2019) gives a very good overview of the state of the literature with a focus on non-financial incentives. The reported results range from HOV access not being important for the purchase decision (Hardman & Tal 2016) to it having a very large impact on EV adoption (Jenn et al. 2020, Jenn et al. 2018). In Switzerland, such non-financial incentives are nowhere to be found and, according to a representative of Swiss E-Mobility, are not likely to be introduced in the near future as the political will to implement them is not present. Because there are no example for these incentives in Switzerland they were not part of my analysis.

Even if there is no evidence for Switzerland specifically, the literature seems to mostly favour the introduction of non-financial incentives like HOV-lane access to promote the adoption of EVs. The obvious advantage lies in the name: they are non-financial and thus do not directly impact public budgets. This advantage should not be underestimated as these non-financial measures may pose an opportunity to make EVs more attractive for a very low cost. Obviously, if EV numbers keep rising, HOV-lane access may become problematic as the advantage of those lanes is that they are (currently) not or almost never congested. This could change if they start being used more by EVs rather than by HOVs. Other than access to HOV-lanes the introduction of different non-financial incentives often requires introducing disadvantages for other drivers. If, for example, we would want to introduce EV-only parking spaces we would probably have to convert some existing parking spots (as construction of new parking spots can be difficult in cities). This could be hard to implement politically as long as conventional cars keep their spot as the market-leaders and drivers of them represent a majority of citizens.

Informing the Public

All incentive schemes, no matter how they are designed, depend on being noticed by the public they are targeted at. As Krause et al. (2013) showed, there may still be a lot of ground to be gained in this regard. That consumer awareness plays an important role for the mass market adoption of PEVs is also supported by the findings of Jenn et al. (2018). This discrepancy provides the opportunity for an 'easy win'.

In Switzerland there are multiple organisations that try to educate the public on the advantages of electric vehicles and the possible cost savings that come with them (TCS, Swiss eMobility) and they are also present in the political debate. How the implementation of new policy measures is communicated by official governmental institutions on a national, cantonal or local level and how it is perceived by the public would provide an interesting avenue for further research. From my own crude observation I think there is still a lot of potential to better inform the Swiss public but this is more a gut feeling than an objective assessment. Anecdotal evidence tends to indicate a lack of information on electric vehicles in the more rural parts of Switzerland. Information on key features of electric vehicles like range or access to charging infrastructure seems to be missing or wrong.

A more widespread information campaign could prove useful in harvesting the 'low-hanging fruits' in the adoption of PEVs on the mass market. Information campaigns certainly are a lot cheaper than additional financial incentive programs or the expansion of existing ones. The combination of increasing public awareness about the advantages of PEVs combined with increasing awareness of existing policies supporting them could prove an (cost-)effective strategy in increasing their market shares.

7 Summary

E-Mobility is advancing fast with more and more manufacturers expanding their product lineups with fully electric or hybrid cars. Over the last few years the share of electric cars overall and especially the share of electric cars of new registrations have increased substantially and seem to increase even further in the years to come. Electric cars promise a cleaner future that is less reliant on fossil fuels. Trying to capitalise on this promise, different states started implementing policy measures to promote the adoption of this new technology in the mass-market. Switzerland is no exception in this. E-Mobility is part of the national energy strategy but the realisation of these goals falls, in federalistic tradition, into the competence of the 26 Swiss cantons. In the same tradition, the 26 cantons implemented 26 different incentive schemes promoting electric car adoption. To understand which of them are effective and efficient this thesis sought to: give an overview of the Swiss car market and the incentive schemes currently in place in the Swiss cantons, give an overview of the current state of the literature on such incentive schemes and expand this literature with an original analysis on Switzerland using the most recent data available.

The share of electric vehicles in Switzerland is rising fast but is still on a relatively low level. In 2019, only a little more than 4% of registered vehicles were purely battery powered. On a national level, the overall share of electric vehicles is still below 1% but is bound to increase over time thanks to the increases in the electric share of registrations. Interestingly, the average CO2 emissions of newly registered cars has been *increasing* again since 2016 (due to the SUV-trend), missing emission targets year after year (see fig 3). The measures in place to further increase the share of electric vehicles can be fit into three main categories: purchase premiums, tax rebates and subsidies for the construction of charging stations. The magnitude of these incentives, if they are implemented, vary strongly from canton to canton. The most widespread measure implemented are tax rebates on the yearly vehicle circulation tax. These are formulated as percentage or flat rebates with the effective rebate, depending on the base 'tax-level' in a canton, ranging from approximately CHF 100.- to over CHF 900.- Even without rebates, there are huge differences in the amount of circulation taxes that has to be paid in different cantons. These differences are often caused by different calculation methods for the circulation tax, mainly the chosen tax-base (horsepower, engine displacement, weight etc.). Electric vehicles with powerful motors are often adversely affected, or used to be affected, by these calculation methods as they produce a lot of power, weigh a lot due to batteries being heavy and sometimes face harsh conversion factors for their characteristics into an artificial measure of engine displacement (electric vehicles have no physical engine displacement) and thus have to pay much higher taxes than comparable fossil fuel vehicles. Tax rebates have been implemented for a long time with some cantons having introduced tax exemptions for electric and solar vehicles in the 1990s already.

Purchase premiums as well as charging station subsidies are a more recent phenomenon and have only been implemented in a few cantons. In 2019 three cantons (BS, TG, TI) started implementing purchase premiums. The most generous premiums were implemented in Basel-Stadt where buyers of electric vehicles could get up to CHF 5'000.- but the fund to finance these premiums already ran out of money and the program was stopped at the end of 2019 and according to administrative officials it is unsure if it will be renewed. In Thurgau buyers of electric cars receive up to CHF 3'500.- and in Ticino they can get up to CHF 4'000.- where half is paid by the canton and the other half is paid by the participating car dealership. The canton Wallis is planning to implement purchase premiums in the near future. Charging station subsidies are currently implemented in four cantons: Bern, Geneva, Thurgau and Ticino. They vary from CHF 500.- per charging station to CHF 1'500.- per charging station with up to CHF 3'000.- if multiple charging ports are installed. Here too, the canton Wallis plans to implement incentives in the near future. Other cantons currently seem reluctant to introduce similar measures. Non-financial measures like HOV-lane access that are implemented in a lot of other countries are not currently found in Switzerland and are also not topic of the political debate at the moment.

These measures can be quite costly and it is therefore important to ask if they are indeed able to produce the desired effects on the adoption of electric vehicles. The literature on the topic, discussed in more detail earlier in this thesis, seems to mostly agree on the following key insights: purchase premiums lead to an increase in EV sales; tax rebates lead to an increase in EV sales but are less effective than a purchase premium of the same amount; charging station infrastructure is an important factor in the decision of consumers to buy EVs; non-financial incentives (like HOV-access) can have large effects on EV adoption (similar to financial incentives). My own analysis for Switzerland found only weak evidence to support these claims. The sign of my effects was always in line with the literature but the estimated effects were not significant. This may be due to the fact that there was not enough variation during the sample period and some of the incentives, like purchase premiums and charging station subsidies, were only introduced in the most recent years and there is not yet enough data on them to accurately assess their effects. There seems to be a strong 'trend' towards more electric vehicles that is not captured by any of the explanatory or controlling variables in my model.

Policymakers in Swiss cantons should adapt their incentive schemes to increase their efficiency. Purchase premiums could be introduced but have to be used carefully as they can quickly put a strain on public budgets. Currently implemented tax rebates could be transformed into purchase premiums of the same amount to increase the effect of the same amount of money. Charging station subsidies are only effective, if they lead to a large enough improvement of the charging station infrastructure. This effect has not been intensively studied so far and should be the topic of further research if more cantons decide to adopt charging station subsidy programs.

Alternatively cantons could choose to invest in public charging station infrastructure themselves and 'cut out the middle man'. Non-financial incentives, though not part of the current debate, should be considered as they may provide a cheaper, equally effective way to promote the adoption of electric vehicles.

The ultimate goal and the reason behind the movement to support electric vehicles is the reduction of CO2 emissions from traffic. Applying my model to the average CO2 emissions and the average fuel economy of newly registered cars leads to results that mostly mirror the effects found in the analysis on the effects on electric vehicle registrations. All the explanatory variables have negative effects but only the effect of purchase premiums are significant. It is important to keep in mind that with over 300'000 vehicles registered every year and over four million vehicles in circulation even small reductions in average CO2 emissions can lead to huge overall effects and large savings to society, strongly depending on the preferred estimate of the social cost of carbon. Incentive schemes to promote the adoption of electric vehicles do indeed reduce the CO2 emissions of the average registered car but they do it at an avoidance cost that is a lot higher compared to other CO2 reduction programs, mainly in the industrial sector. If our focus is indeed on the reduction of CO2 emissions and not just on an increase of the share of electric vehicles per se, it is questionable if the described incentive schemes are a good solution as they are rather inefficient.

All things considered, I think we still need to wait a few more years to see how the market for electric vehicles develops. Currently it is in a very dynamic upward trend and further support of EVs may not even be needed. More data will have to be collected in the coming years and similar analysis to the one carried out in this thesis will have to be repeated in the future to produce more conclusive results. The evidence for other countries can to some extent be transferred to Switzerland but specific answers for the country are not yet possible. As already mentioned, electric vehicles are on the rise and will probably continue to expand their market share year by year as more and more manufacturers include purely electric vehicles in their product lineups. In the mid- to long-term, support for these vehicles will probably prove to be too expensive and in the short term the effects are not absolutely clear. We will also have to decide if our goal is to increase EV market share because it is 'trendy' or to actually reduce CO2 emissions, in which case public money may be better spent elsewhere, on projects with lower avoidance costs per ton of CO2. As we get better, more precise measures for the SCC this decision should become less uncertain than it admittedly is today.

Further research should continue to try and estimate the effects of financial and non-financial PEV incentives as they become more widespread worldwide and the market for electric vehicles matures. Attention should also be paid to the relationship between infrastructure subsidies and the resulting improvements in infrastructure. How governments communicate their policy campaigns seems to be very important and additional analysis on how they have done and continue to do this may shed more light on the topic.

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Ich erkläre hiermit, dass ich diese Arbeit selbstständig verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche kenntlich gemacht. Mir ist bekannt, dass andernfalls der Senat gemäss dem Gesetz über die Universität zum Entzug der auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, 24.08.2020 ______________________________

Dario Schaller

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Ich erkläre hiermit, dass ich der Veröffentlichung der von mir verfassten Masterarbeit im Falle einer Benotung von 5.0 oder höher auf der Homepage des KPM zustimme. Die Arbeit ist öffentlich zugänglich.

Bern, 24.08.2020 ______________________________

Dario Schaller

Annex

A1: Full Regression Table (except FE) for the results shown in table 4

	(1)	(2)
VARIABLES	et_co2	et_fuelecon
PP_1000CHF	-0.643*	-0.0294*
	(0.348)	(0.0164)
CS_1000CHF	-0.0973	-0.00504
	(0.567)	(0.0253)
taxrebate_100CHF	-0.0901	-0.00130
	(0.119)	(0.00559)
tax_chf	5.98e-05	4.50e-06*
	(6.43e-05)	(2.40e-06)
wt_avg_prc1000	-0.0668***	-0.00261***
	(0.00637)	(0.000265)
income_1000CHF	0.0107	-0.00103
	(0.0219)	(0.00112)
pop_density	-0.0101**	-0.000207
	(0.00393)	(0.000155)
edu_tertiary_prct	-0.218	-0.00717
	(0.148)	(0.00554)
green	-0.0519	-0.00160
	(0.0480)	(0.00217)
trend	-2.015***	-0.0685***
	(0.175)	(0.00696)
Constant	177.8***	7.243***
	(5.067)	(0.206)
R-squared	0.842	0.827

Robust standard errors in parentheses - *** p<0.01, ** p<0.05, * p<0.1

```
. hausman fe re /*Hausman-Test for model specification comparing FE vs RE*/

Note: the rank of the differenced variance matrix (17) does not equal the number of
        coefficients being tested (18); be sure this is what you expect, or there may be
        problems computing the test.  Examine the output of your estimators for anything
        unexpected and possibly consider scaling your variables so that the coefficients
        are on a similar scale.

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |       fe           re         Difference          S.E.
-------------+----------------------------------------------------------------
  PP_1000CHF |    .2957949     .3687498        -.072955        .0151859
  CS_1000CHF |    .1589355     .1423675         .016568        .0759725
taxrebate_~F |   -.0541148    -.0168648         -.03725        .0236579
     tax_chf |   -.0000251    -.0000186       -6.45e-06        .0000137
wt_avg_~1000 |    .0286045     .0284708        .0001336               .
income_100~F |   -.0053427     .0055841       -.0109268        .0075593
 pop_density |    .0056091     .0000793        .0055298        .0010877
edu_tertia~t |   -.0645477     .0025934       -.0671411        .0194494
       green |    .0002407     .0077089       -.0074682        .0034124
        year |
       2011  |    .4379465      .420848        .0170985               .
       2012  |    1.087343     1.034952        .0523911         .020749
       2013  |    1.218657     1.111853        .1068048        .0425381
       2014  |    1.407165     1.254076        .1530892        .0631039
       2015  |    1.512787     1.326266        .1865206        .0797084
       2016  |    1.284953     1.040286        .2446671        .1023436
       2017  |    1.931148     1.639197        .2919514        .1221891
       2018  |    2.619511     2.291026        .3284852        .1378179
       2019  |    4.332781     3.922414        .4103672        .1529847
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                 chi2(17) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =       37.23
                Prob>chi2 =      0.0031
                (V_b-V_B is not positive definite)
```

Figure 5: Results of Hausman model specification test

```
. xttest3 /*Modified White-Test for Heteroskedasticity*/

Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (26)  =      206.46
Prob>chi2 =      0.0000
```

Figure 6: Results of White-Test after main model FE Regression revealing heteroskedasticity