# What are the effects of incentives on plug-in electric vehicle sales in Europe?

Patrick Plötz
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Straße 48
76139 Karlsruhe
Germany
patrick.ploetz@isi.fraunhofer.de

Till Gnann
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Straße 48,
76139 Karlsruhe
Germany
till.gnann@isi.fraunhofer.de

Frances Sprei
Chalmers University of Technology, Energy and Environment
Hörsalsvägen 11
412 96 Göteborg
Sweden
fsprei@chalmers.se

## Keywords

## Abstract

Plug-in electric vehicles (PEV), both as battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV) have noteworthy potential to reduce global and local emissions. Governments around the world have implemented monetary and non-monetary policies to accelerate PEV market diffusion. However, empirical estimates of their effectiveness are scarce. Here, we analyse data on PEV sales from 30 European countries from 2010–2016 with respect to direct subsidies, tax rebates, and other incentives. We apply panel data regression models and control for several other influencing factors such as income and fuel prices. We find income, diesel prices and both direct and indirect subsidies to positively influence PEV adoption. The aim of the present paper is to contribute to the discussion on policy-aided market evolution using empirical evidence about electric vehicles and alternative fuel vehicles in general.

## Introduction

Plug-in electric vehicles (PEV), both battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV) are supported by governments worldwide by monetary and non-monetary policies. Several studies indicate that direct purchase incentives can stimulate the market diffusion of PEV. Yet, how large the effect direct subsidies have on sales is unclear and the overall effect of non-monetary incentives is still under debate. The aim of the present paper is to contribute empirical evidence to the discussion on policy-aided market evolution of electric vehicles. Here, we use linear regression of PEV sales and stock from Europe on policy measures and other factors. Policy measures that are expected to impact PEV market diffusion are, among others, direct subsidies (rebates, tax exemptions, tax credits, state credits), indirect incentives (fuel tax exemptions, charging equipment installation incentives, vehicle inspection exemptions, parking incentives, reduced license tax, reduced registration fees, vehicle-to-grid energy credits, idle reduction technology tax credits, reduced toll road rates) and public charging infrastructure.

Analysing the effectiveness of policy instruments is a broad field of research. De Shazo et al. 2014 analysed the performance of rebate designs in California. With a representative data sample for California, 1,261 respondents of a survey, they set up an optimization model for the political program evaluation. The most important findings were that without a rebate PHEVs would be prioritized over BEVs in purchase decisions, while high-income consumers were more likely to buy any PEV even without a rebate. Thus, income-dependent rebates could increase the number of buyers yet the vehicle purchase price is still relevant. Sierzchula et al. (2014) study the PEV adoption of 30 national EV market shares in 2012 in a multiple linear regression analysis. They find financial incentives, charging infrastructure, local presence of production facilities to be positively correlated and significant. Yet in their analysis, charging infrastructure is the most important for EV adoption. They also point out that neither financial incentives nor charging infrastructure is enough to ensure high electric vehicle adoption rates (Sierzchula et al. 2014). Tal et al. (2013) base their results on a survey with 1,201 households who purchased a

PEV in 2011 and 2012 in California to identify the most important influence factors in the buying decision. A comparison of the survey data with the National Household Travel Survey (NHTS) showed that PEV owners are more likely to own a detached house while the other results were not conclusive. Lieven (2015) studies monetary policy measures, traffic regulations, and investments in charging infrastructure for PEVs. In a conjoint analysis paired with the Kano method to determine policy programs, they look at 20 countries from five continents totalling 10,981 data sets. He finds the installation of fast charging networks on freeways to be a necessity while high vehicle subsidies can be replaced by lower subsidies providing additional charging infrastructure is created.

Not only PEV but other alternative drive trains have been analysed, too, mostly through regression analysis to identify which factors have may have influenced their sales. For example, Chandra et al. (2010) focused on hybrid vehicles (HEVs) sold in Canada from 1989–2006. They found, that rebates had effect, but at the same time they subsidized people who would have bought HEVs anyway (free rider effects). Thus, the way rebates were granted was not the most effective way of introducing HEVs. However, the structure of rebates is also important, which was confirmed by Sprei (2013). She analysed flex fuel vehicles in Sweden where sales were increasing until 2008 and decreasing after 2008 and until 2011. In her regression for vehicle sales in 2002–2011, she found the changing rebate structure to be the most important factor paired with a removal of the exemption from congestion charging and negative media reports on flex fuel vehicles. Gallagher and Muehlegger (2010) study the effect of different tax incentives and the use of HOV lanes on HEVs in the US for different policy levels (federal, state, local). Also, a correlation with fuel prices is tested for the years 2000–2006. In a regression, they used the log per-capita sales as the dependent variable, finding that feebates, (i.e. a combination of rebates and fees), were the most effective policy measure. The effects of HOV lanes remained unclear while gas prices were positively correlated with HEV sales (i.e. higher gas prices are connected to higher HEV sales).

Norway is the country with the highest sales share of PEVs in the world. Unsurprisingly, therefore, there are a number of studies that have specifically looked the effect of incentives on consumers in Norway. Mersky et al (2016) performing regression analysis on municipal and regional level found that access to charging infrastructure, being adjacent to a major city and regional income to be the most significant factors when predicting BEV sales.

Zhang et al (2016) look at the effect of incentives on car specifications of vehicles sold in the various municipalities in Norway. They find a positive effect on technology improvement from toll waivers and charging station density. Ryghaug and Toftaker (2016) take a more qualitative approach and interview various stakeholders, finding that economic incentives can lure the public into electro-mobility. Fearnley et al (2015) study BEV incentives with a specific focus on Austria and Norway. They found direct financial incentives to be effective but the subsidy level and duration must be high to achieve a major adoption. Free BEV parking was found to be the least effective policy.

Most previous studies have focused on North America, with some international comparison. In this study we focus on Europe and address the question: What is the effect of incentives,

both direct and indirect, on EV sales shares in the European context? We do this through an ex-post analysis of policy measures for EV market diffusion in Europe with a panel data methodology covering all European countries. To our knowledge this is the first of its kind. The outline is as follows. Section 2 contains the data used for our analysis and the methodology. Results will be given in section 3, followed by a summary and conclusion in section 4.

## Data and methodology

### DATA

We collected data on PEV sales differentiated by country from the European Alternative Fuel Observatory (EAFO) website (www.eafo.eu). EAFO is supported by the European Commission and aims to provide alternative fuels statistics and information (electricity, hydrogen, natural gas). The website provides an overview of all markets and more specific information on the direct and indirect subsidies active in different countries. We added information on the historic change of subsidies and incentives from the European Automobile Manufacturers Association (ACEA). Control variables such as net income and fuel prices have been obtained from Eurostat.

Figure 1 and 2 give an overview of the available EV sales data. In some cases, sales dropped from 2015 to 2016. For the Netherlands, the EV incentives were reduced in 2014 and again in 2016. For Denmark, existing incentives were reduced with effect from the beginning of 2016 leading to increased sales at the end of 2015. Slovakia has announced tax reliefs for 2017 which may have led to planned purchases being delayed to 2017.

### METHODOLOGY

We use panel data regression to analyse the effect of direct and indirect incentives on PEV sales shares. Panel data matches the clear panel structure of the data and the country fixed effects panel data model captures unobserved country specific factors.

The log of PEV sales shares is used as the dependent variable. Direct incentives are direct financial subsidies measured in thousands of Euros. Other incentives such as use of HOV or bus lanes, car registration exemptions, no road tolls etc. are categorised as indirect incentives and the total number of indirect incentives per country is treated as numeric variable.

## Results

### DESCRIPTIVE COMPARISON

Despite the limited number of PEVs worldwide, direct subsidies and indirect incentives are expected to have a positive effect on PEV sales. Figure 3 analyses the effect of an increasing number of indirect incentives active in the different markets on PEV sales. The figure shows the mean of PEV sales shares with 95 % confidence bands for a varying number of indirect incentives. We observe a tendency towards higher market shares with a growing number of indirect incentives in place. Of course, not only the total number of indirect incentives but also the specific type and duration is important. Yet the overall increase of EV sales shares with the number of indirect incentives in-
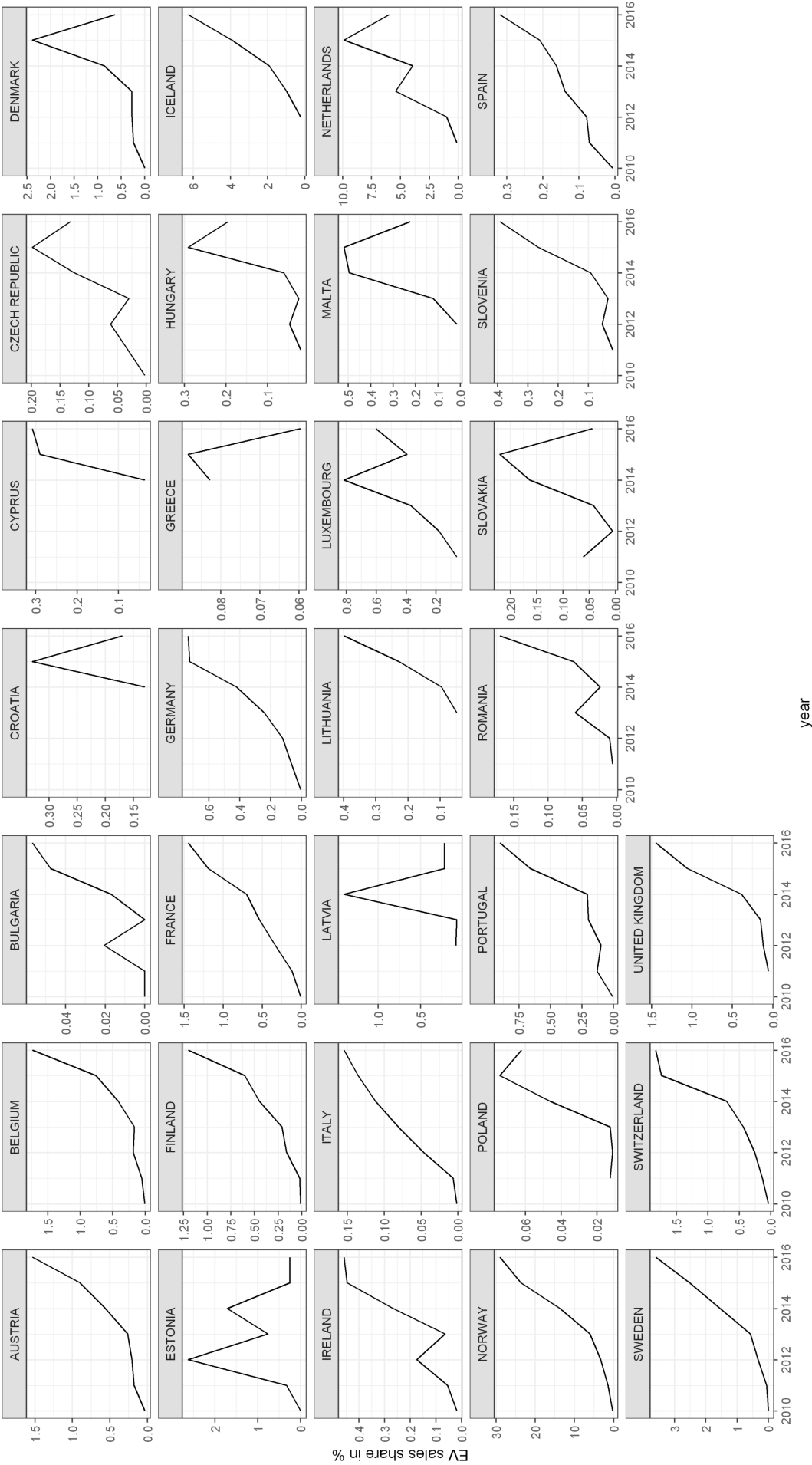
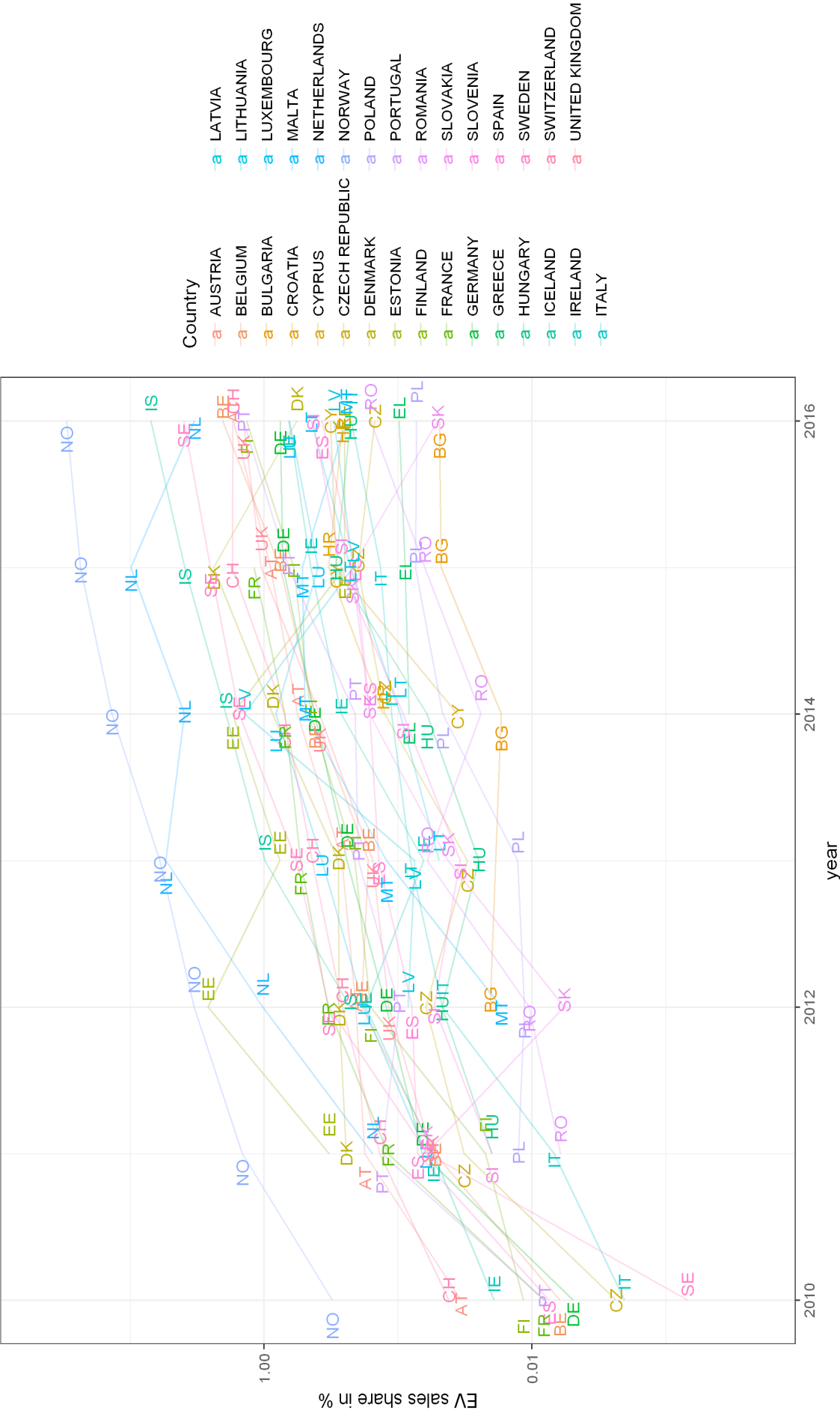*Figure 1. Overview of PEV sales shares data over time.*

*Figure 2. Overview of PEV sales shares data over time. The position of the time variable has been slightly changed to avoid overlapping country codes as far as possible.*
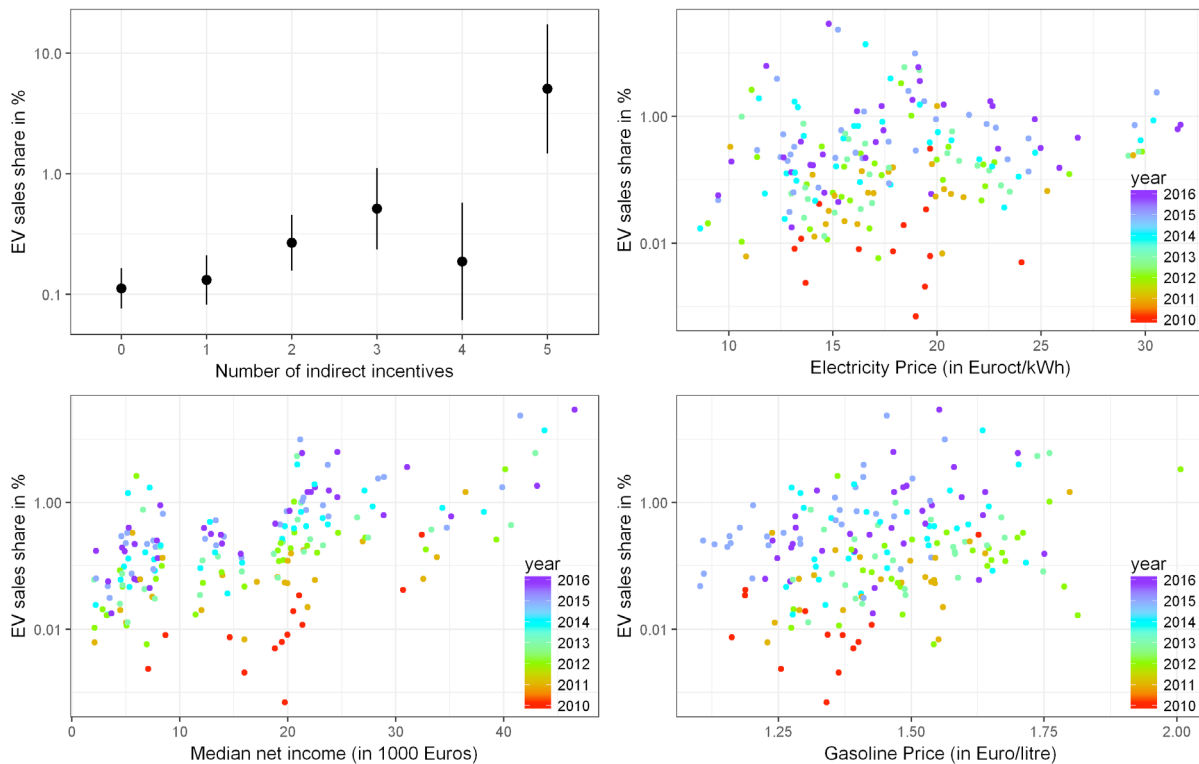
*Figure 3. EV sales in percent in relation to number of indirect incentives (top left), electricity price (top right), Median net income (bottom left) and Gasoline price (bottom right).*

dicates their effectiveness. However, we see that in the case of four indirect incentives the sales shares decrease. This illustrates that there are other factors that might influence sales as well, such as electricity prices and other incentive structures. Thus, it is important to look at different factors at the same time in a regression model.

Figure 3 also shows EV sales shares as a function of electricity and gasoline prices as well as the median net income differentiated by year (to take into account that EV sales shares can generally be expected to grow with time). For fixed year, a positive correlation between EV sales shares and gasoline prices as well as EV sales shares and net income is apparent from Figure 3.

In summary and when analysing the individual connection between average income, the electricity price and the gasoline price as well indirect subsidies on PEV sales shares, a positive impact of these factors is observed. However, the figure also demonstrates the complexity of the effects and the need for more quantitative analysis.

**PANEL REGRESSION ON PEV SALES SHARES**

The last section has shown that individual factors, such as income, gasoline prices, etc. can have a positive impact on PEV sales. However, the joint effect of several variables can render the individual effect insignificant. We use panel regression to analyse the joint effect of electricity, gasoline and diesel price, net income, direct and indirect in incentives on PEV sales shares to identify their effect on PEV sales. We use three different regression models. The first one combines the data from the different countries and years and performs an ordinary least square (OLS) regression (column 1 in Table 1).

The second model is a panel regression with country fixed effects, i.e. the fact that there might be country-specific aspects that are not captured in the other variables is taken into account (column 2 in Table 1). In the third model, differences between years is included as well, i.e. we have a panel regression with year and country fixed effects (column 3 in Table 1). All models are highly significant and explain between 12 and 43 % of the variance in sales shares (denoted as adjusted $R^2$ in Table 1).

The second model – panel regression with country-fixed effects (i.e. a binary variable for each country is added in the regression is added for country specific effects) – has the highest explained variance (largest R-squared). This result is not surprising since the country-fixed effects should be stronger than time-fixed effects for the present case: a rapidly evolving PEV market where specific aspects in different countries, such as the presence of a car manufacturing industry or a certain car culture will not have been captured by the included variables. Thus, the country-fixed effects model is preferable in the present case since it includes other unobserved country specific factors and has the highest explanatory power.

The regression results on PEV sales shares confirm the expected outcomes: higher income, higher diesel prices as well as direct and indirect incentives have a positive effect on PEV sales shares. All significant influences have the expected signs. However, the effect of the incentives is interesting: 1000 Euro higher subsidy will increase the PEV sales share by about 16 % (with 95 % confidence band 1–31 %) according to the country-fixed effects model (model (2) in Table 1), e.g. from 0,2 % PEV sales share without incentive to 0,23 % with 1,000 Euro incentive (keeping all other factors fixed).

Table 1. Regression results for PEV sales shares.

| Model | (1) OLS | (2) Panel regression country FE | (3) Panel regression country-year FE |
|---|---|---|---|
| Electricity Price (in EuroCent/kWh) | -0.031 (0.038) | 0.314*** (0.072) | -0.044 (0.044) |
| Gasoline Price (in Euro/litre) | 1.195 (2.523) | -13.035*** (4.430) | -2.539 (2.270) |
| Diesel Price (in Euro/litre) | -0.797 (2.044) | 11.380*** (3.761) | 4.868*** (1.677) |
| Net income (in 1000 Euros) | 0.075*** (0.017) | 0.442*** (0.073) | 0.106* (0.060) |
| Direct Incentives (in 1000 Euros) | 0.052 (0.046) | 0.159** (0.075) | 0.040 (0.060) |
| Indirect Incentives (number of incentives) | 0.245** (0.127) | 0.675*** (0.177) | 0.299** (0.142) |
| Constant | -8.045*** (1.234) | | |
| Observations | 185 | 185 | 185 |
| Country fixed effects | No | Yes | Yes |
| Year fixed effects | No | No | Yes |
| R2 | 0.327 | 0.549 | 0.172 |
| Adjusted R2 | 0.314 | 0.436 | 0.131 |
| F Statistic | 14.402*** (df = 6; 178) | 29.808*** (df = 6; 147) | 4.897*** (df = 6; 141) |

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05*

## ROBUSTNESS CHECKS

We applied several robustness checks to our models. Since the effect of incentives might be different to the very first group of buyers – the innovators – we left out data from 2016, building on the assumption that the second major group of buyers (the early adopter) started to purchase PEV in 2016. Yet the coefficients of all regression models changed only slightly, implying that either there is no big difference in the effect of incentives between innovators and early adopters or that the market is still dominated by innovators. On the other hand, further analysis use sales shares to distinguish between user groups. Furthermore, we used panel regression in first differences as an alternative to the panel data regression. That is, we create new variables containing the annual change in each variable within a country. The results are similar to the two fixed effects models discussed above, yet the explanatory power is much smaller and the whole model is no longer significantly different from a constant model without any impact from external factors. The latter suggests that a finite difference model is not suited to describe the EV market and incentives data.

## Discussion

Our results come with some uncertainty. Firstly, the aggregation of sales data to state or national levels ignores variances at the city or regional level. In many cases, several major cities have introduced additional incentives for PEV users which have not been accounted for here. Furthermore, the number of charging stations per capita can vary significantly between different regions and charging station data has also not been included here. However, consistent data sets on levels below states or nations are difficult to obtain. An analysis on municipal and regional levels would presumably be rather qualitative and render the quantitative analysis by regression applied here

difficult, since it might be hard to generalize and quantify all the incentives and initiatives taken at local level.

Secondly, direct and indirect incentives could have been included in the regressions in several ways, e.g., indirect incentives could be translated to monetary units instead of a categorical or numerical variable. Additionally, all indirect incentives could be included as separate categorical variables and thereby analysing, e.g. the effect of tax incentives, HOV lanes or charging subsidies directly.

## Conclusion

We analysed the effect of different controlling factors and policy measures on PEV adoption measured as PEV sales shares. Our results show that controlling factors such as income and fuel prices should be included in the analysis of incentives since they help explain variance in PEV adoption rates. Further factors that should be analysed in future work include taxes, garage ownership and public charging infrastructure. From a policy perspective, both direct and direct incentives seem to have a positive effect on PEV adoption.

Given no other changes an incentive of 1,000 Euro would increase the EV sales share by about 16 % (relative increase of a given sales share). From the regression analysis alone, the effect of introducing indirect incentives seems to be quite strong compared to a direct financial incentive of 1,000 Euros. Still this result is hard to generalize and needs further inquiry since we do not differentiate between the indirect incentives and cannot assess which ones are most effective. However, the efficiency of different measures and the effect of public charging infrastructure remain open issues for further research require additional methodological care given the complex causal structure (does charging infrastructure lead to more PEV or do more PEV lead to more charging infrastructure?).

## References

Chandra, A., Sumeet G., and Milind K. (2010),"Green drivers or free riders? An analysis of tax rebates for hybrid vehicles," Journal of Environmental Economics and Management, 60 (2): 78–93.

Clinton, B., Brown, A., Davidson, C., Steinberg, D. (2015): "Impact of Direct Financial Incentives in the Emerging Battery Electric Vehicle Market: A Preliminary Analysis" National Renewable Energy Laboratory, Department of Economics, University of Colorado – Boulder, February 2015.

DeShazo, J. R., Sheldon, T. L., & Carson, R. T. (2014). Designing Policy Incentives for Cleaner Technologies: Lessons from California's Plug-in Electric Vehicle Rebate Program. Working paper.

Fearnley, N., Pfafeenbichler, P., Figenbaum, E., Jellinek, R., (2015). E-vehicle policies and incentives – assessment and recommendations. TØI report 1421/2015. Oslo.

K.S. Gallagher, E. Muehlegger, Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology, J. Environ. Econ. Manage. (2010), doi:10.1016/j.jeem.2010.05.004

Lieven, T.(2015), Policy measures to promote electric mobility – A global perspective, Transportation Research Part A: Policy and Practice, Volume 82, December 2015, Pages 78–93, ISSN 0965-8564, http://dx.doi.org/10.1016/j.tra.2015.09.008.

Lutsey, N (2015).: "Transition to a global zero-emission vehicle fleet: A collaborative agenda for governments", International Council on Clean Transportation (ICCT) White Paper, September 2015.

Mersky, A.C., Sprei, F., Samaras, C., Qian, Z. (2016). "Effectiveness of incentives on electric vehicle adoption in Norway". Transportation Research Part D, 46: 56–68.

Ryghaug, M., Toftaker, M. (2016). "Creating transitions to electric road transport in Norway: The role of user imaginaries". Energy Research & Social Science, 17: 119–126.

Sierzchula, W., Bakker, S., Maat, K., van Wee, B., 2014. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. Energy Policy 68, 183–194. http://dx.doi.org/10.1016/j.enpol.2014.01.043.

Sprei, F. (2013): "Boom and bust of flex-fuel vehicles in Sweden" In: Lindström, T.: European Council for an Energy-Efficient Economy (eceee), Paris: Rethink, renew, restart. eceee 2013 Summer Study. Proceedings: 3-8 June 2013, Toulon/Hyères, France. Stockholm: eceee, 2013, p. 1031–1039.

Tal, G., Nicholas, M.A., Woodjack, J., Scrivano, D. (2013): "Who Is Buying Electric Cars in California? Exploring Household and Vehicle Fleet Characteristics of New Plug-In Vehicle Owners", Institute of Transportation Studies, University of California, Davis, February 2013.

Zhang, Y., Qian, Z., Sprei, F., Li, B. (2016). "The impact of car specifications, price and incentives for battery electric vehicles in Norway: Choices of heterogeneous consumers". Transportation Research Part C, 69: 386–401.

## Acknowledgments