Norwegian School of Economics

Bergen, Autumn 2016

NHH

Analysis of Local Electric Vehicle Incentives in the Norwegian Car Market

A Multi-homing Approach

Charlotte B. Evensen and Visahan Koneswaran

Supervisors: Hans Jarle Kind and Morten Sæthre

Master's Thesis, MSc in Economics and Business Administration,

Economic Analysis (ECO)

NORWEGIAN SCHOOL OF ECONOMICS

Acknowledgements

The thesis has been an exciting project as it covers a current political issue. Moreover, it has been just as interesting to work with from an academic point of view. We have both enjoyed to dive deeper into industrial organization, and it was especially rewarding to unite theory and empiricism.

We would like to thank our supervisors, Hans Jarle Kind and Morten Sæthre, for contributing with their exceptional insights into competition analysis, multi-homing and empirical methods. We highly appreciate their availability, shown interest in our work and encouraging feedback.

We would also like to thank Timothy Wyndham for inspiring us to study multi-homing in the first place and for sharing with us his knowledge in the beginning of this process.

Bergen, December 2016

Charlotte B. Evensen

Charlotte B. Evensen

Visahan Koneswaran

Abstract

This paper analyse how the local incentives for electric vehicles affect the number of people that purchase both conventional and electric vehicles. After the threshold of 50 000 electric vehicles was reached in April 2015, there has been an ongoing debate regarding whether the incentives for electric vehicles should be withheld. The intent of the incentives is to develop a more climate friendly vehicle fleet. Although the incentives impact on joint purchase is important to understand how efficient the incentives are in achieving the policy objective, we are not aware of any research on this area up to this point. Our contribution is a theoretical model that allow consumers to purchase multiple differentiated product varieties, a behavior defined as multi-homing. The model predicts that multi-homing softens the competition between electric and conventional vehicles and partially absorbs the demand shifting effect of the incentives. Furthermore, we conduct empirical research on the car market to analyse how the car market historically has reacted to the incentives. Our findings coincide with the model's predictions at a satisfactory level. We find that all incentives increase the number of multi-homers. While our estimations shows that free ferry admission leads to an increased vehicle fleet, the introduction of toll stations, congestion charge and road toll lead to a reduction in the overall vehicle stock. The empirical results reveal that the incentives only seem to phase out sales of conventional cars if they are derivatives of policy instruments with a negative effect on the demand for conventional vehicles.

.

Contents

List of Figures

List of Tables

1 Introduction

Norway has become a country leading the way as an example regarding adaption of electric cars, even though climate conditions and geographical factors should imply the opposite. In addition to technological improvements, goal-oriented policies have made Norway a leading electric vehicle country during the last decade. In 2015 electric vehicles accounted for 17.1% of new car sales, implying that every sixth vehicle sold in Norway was electric.

Norwegian politicians have committed to develop a more environmentally- and climate-friendly vehicle fleet through the climate agreement from 2007 and 2012 (Meld. St. 34 (2006-2007) & Meld. St. 21 (2011-2012)). During the first quarter of 2016, the Ministry of Petroleum and Energy presented a parliamentary white paper articulating a goal of phasing out the sale of high-emission vehicles by 2025 (Meld. St. 25 (2015-2016)). Attaining the goal involves replacing petrol- and diesel-fuelled vehicles with hybrid and electric vehicles.

To achieve the climate goals, extensive incentives for buying electric vehicles have been introduced. The incentives stimulate both purchase and use of electric cars, and the intention is to shift demand from vehicles using fossil fuel onto electric vehicles. Range challenges and uncertainty related to the electric cars' lifetime and residual value make the survival of electric cars dependent on advantageous incentives (Oslo Economics, 2015). In addition, the incentives may contribute to a low-emission vehicle fleet by stimulating the technological development of electric cars such that they become more competitive in themselves. Because the incentives cause increased demand for electric cars, it becomes more imperative to invest in technology that increase the willingness to pay or reduce the production costs of the cars. The reason is that the higher profit margin would apply to more units. However, the global impact of increased demand for electric cars in Norway would probably not be sufficient to affect the car producers investment decisions.[1] Because other countries such as

[1] According to Cazzola and Gorner (2016), Norways global market share is below 5%.

Germany, Netherlands, UK and France also provide incentives for electric cars, it is possible that the countries' united contribution to increased demand for electric vehicles encourage technology investments.

As a part of the climate policy, electric vehicles have for a long period of time enjoyed national buying incentives in addition to local subsidies that target car usage. According to Fearnley, Pfaffenbichler, Figenbaum, and Jellinek (2015), national incentives that reduce purchase price and yearly costs are the most effective when it comes to increasing the market share of electric vehicles. Moreover, they find that bus lane access is the most effective time cost reducing incentive. Among the local direct subsidies, which reduce user costs and range challenges, they find that exemption from road toll payments has the greatest impact on demand for electric cars, followed by free parking, exemption from ferry fares and financial support of charging stations. A survey conducted a year later confirms that free toll-road outperforms other local incentives (Figenbaum & Kolbenstvedt, 2016).

The costs of providing the incentives increase concurrently with the size of the electric vehicle stock. For instance, an increased share of cars being exempted from road toll payments, parking fees and ferry fares will imply lower revenues for the government, road toll companies and ferry companies. The benefits were thus planned to be revised in 2017 or when 50 000 electric cars had been sold. The threshold number of cars were reached in April 2015, and initiated a debate concerning phasing out the incentives. As this thesis is written several policy interventions affecting electric vehicles have been made. The City Council of Trondheim decided to withdraw free parking in the city from 2017. In Oslo, the county municipality, city municipality and the government have agreed to incrementally introduce and increase congestion charge and road toll payments from 2017. Furthermore, the Norwegian Public Roads Administration currently restricts the access for electric cars to drive on certain public transport lanes in Oslo, to give way to road projects in the area.

Moreover, it would be costly to spend government resources on inefficient policies.

Fearnley et al. (2015) have investigated how effectively the incentives are increasing the stock and market share of electric vehicles relative to the costs of providing them.[2] They find that bus lane access is the most cost efficient incentive. Nonetheless, for the purpose of this thesis it is the absolute effects on the incentives that are of main interest. Although a particular incentive motivates many households to buy electric cars, it does not categorically help phasing out the sales of conventional cars. If enough households purchase an electric car as a second car due to the incentives, the overall car population increases and the replacement of conventional cars is obviously smaller. According to Figenbaum and Kolbenstvedt (2016), 79% of electric vehicle owners have multiple cars.[3]. This is a relatively low share compared to PHEV owners and ICEV owners, where the shares are 46% and 48% respectively.[4] Insight to the extent in which the incentives encourage people to buy multiple cars would improve the understanding of how efficiently the incentives meet the policy objectives. We thus believe that research on this area would be a nice complement to previous studies.

The concept of consumers purchasing multiple varieties of a differentiated products is referred to as multi-homing in the industrial organization literature. The alternative to multi-homing would be single-homing, which implies that consumers buy only one product variant. In this thesis we apply the concept of multi-homing and analyse how local subsides for electric cars affect the Norwegian car market. Our main contribution in this context is thus the multi-homing perspective.

To predict how the incentives affect multi-homing we derived a theoretical model. This model is somewhat different from the SERAPIS and Tobit models, which are used by Fearnley et al. (2015) to predict future electric car sales and market shares

[2]The reports use the abbreviation BEV for electric vehicles, ICEV for internal combustion engine vehicles and PHEV for plug in hybrid electric vehicles.

[3]71% have the combination BEV and ICEV, 4% have a BEV and a PHEV and the remaining 4% have two electric vehicles.

[4]In this paper we consider PHEV as conventional vehicles.

respectively.[5] The main difference is that our model includes the utility of a second car and enables predictions of the extent to which people buy multiple car types. In addition, we apply the model to different data sources. Fearnley et al. (2015) employ their models to analyze data they have collected through web surveys, while we base our analysis on the Motor Vehicle registry. Our theoretical model predicts that the incentives encourage people to convert from public transport to electric cars, stimulate owners of conventional cars to a buy a second car and affect the demand for conventional cars to a small extent. Consequently, the overall vehicle fleet increases and the incentives appear to be inefficient.

We conducted an empirical analysis to investigate whether historical observations support our model's predictions, which they to a satisfactory extent do. According to our empirical findings, exemptions from road toll payments, congestion charge and ferry fares all lead to increased numbers of multi-homers. However, the analysis revels that the efficiency is higher for incentives that are related to policy instruments that directly affect the demand for conventional cars. Consequently, increased road toll prices and introduced congestion charge reduce the demand for conventional cars to an extent that outweigh the increased demand for electric cars such that the vehicle stock decreases.[6] Allowing free ferry rides for electric cars, on the other hand, do not directly affect the costs and demand for conventional cars. Hence, increased demand for electric cars dominates the reduced demand for conventional cars and causes a larger car population.

The implications of the incentives contribution to multi-homing depend on several factors beside the size of the vehicle stock. Hawkins, Singh, Majeau-Bettez, and Strømman (2013) investigated the environmental life cycle assessments of conventional and electric vehicles. They decomposed the vehicles' global warming contributions into CO2-emissions produced in different stages of a vehicle's life cycle.

[5]Simulating the Emergence of Relevant Alternative Propulsion technologies in the car and motorcycle fleet Including energy Supply

[6]Increased road toll and congestion charge imply higher usage costs for conventional cars.

They find that the production of electric vehicles do pollutes about twice as much as the production of conventional cars, mainly because of the battery manufacturing.[7] The pollution from the production of electric vehicles is, however, compensated for during the vehicles' use phase, and in total the CO2-emissions are lower for electric vehicles. Völler, Wolfgang, and Korpås (2014) point out that the climate friendliness of electric vehicles also depends on the energy source of the electricity they run on. While Norway's electricity is foremost based on hydropower, European power plants are generally dominated by fossil energy sources. Norway is a net exporter of energy, which implies that higher energy consumption within the country lead to increased energy production in other European countries, and the proportion of renewable energy sources decrease. Thus, electric cars may indirectly contribute to CO2-emissions through their use of electricity. Völler et al. (2014) predict two main scenarios for 2020, given that the vehicle fleet continues to grow in the same pace as the last years and that half the car population will consist of electric cars. The first scenario assumes that the power plant capacity remains on today's level, and predicts that the electricity consumption of electric vehicles contributes to a energy production where CO2-emissions are equal to 73 CO2 g/km. In the other scenario, investments in wind power increase the energy capacity equivalent to the power consumption of electric vehicles such that the CO2-emissions do not increase.

Our findings suggest that the incentives related to policies that simultaneously affect the demand for conventional cars are efficient, despite of multi-homing. The incentives that do not directly affect the demand for conventional cars seem to be efficient in the short run, while their long term efficiency requires either no multi-homing or increased production capacity of renewable energy sources.

[7] They estimate the CO2-emission of production to be 43 g/km and 87-95 g/km for conventional cars and electric cars respectively. A cars lifetime is assumed to be 150 000 km.

1.1 Research Question

This thesis will analyze to what extent local subsidies affect the number of people that purchase both conventional cars and electric cars. It will further investigate the consequences of joint car purchase for the incentives efficiency in phasing out the sales of fossil-fuelled cars.

The aim with this thesis is to answer the following question:

How do local incentives for electric vehicles affect multi-homing, and what is the implications of this for the the incentives efficiency in achieving the policy objectives?

1.2 Data

The data we use to conduct our analysis is the Motor Vehicle registry obtained from the Norwegian Public Roads Administration. From the data files we could extract information about the registration history of the cars and technical car details. Moreover, this information enabled us to separate electric cars from conventional cars, identify ownership categories and distinguish between large and small cars. We were also able to generate different geographical entities from the data. To carry out the fixed effects analysis we collected supplementary data for level of education, unemployment and population from SSB. [8] Historical road toll prices and numbers of toll stations were collected from AutoPASS.[9]

1.3 Outline

This introductory section will be followed by a description of the market for new cars where we, among other topics, take a closer look at the market share of electric vehicles over the course. In section 3 we introduce the relevant theory, before we in section 4 define the market and derive our theoretical model. In section 5, we present

[8] Statistics Norway.
[9] AutoPASS is owned by Norwegian Public Roads Administration.

the econometric methods we utilize and conduct our analysis. Section 6 includes a discussion, where we incorporate our theoretical model with the empirical findings. Finally, in section 7, we conclude.

2 The Norwegian Car Market

In this section, we briefly describe new vehicles registration in the Norwegian car market over type and counties. The aim is to give the reader insight into how the market share of electric vehicles has developed the past years. In the second part we will take a closer look at the dynamics in the vehicle stocks and ownership categories in Norways' three largest cites, Oslo, Bergen and Trondheim. Moreover, we will present figures and arguments for why multi-homing seems to take place.

2.1 The Market for New Vehicles

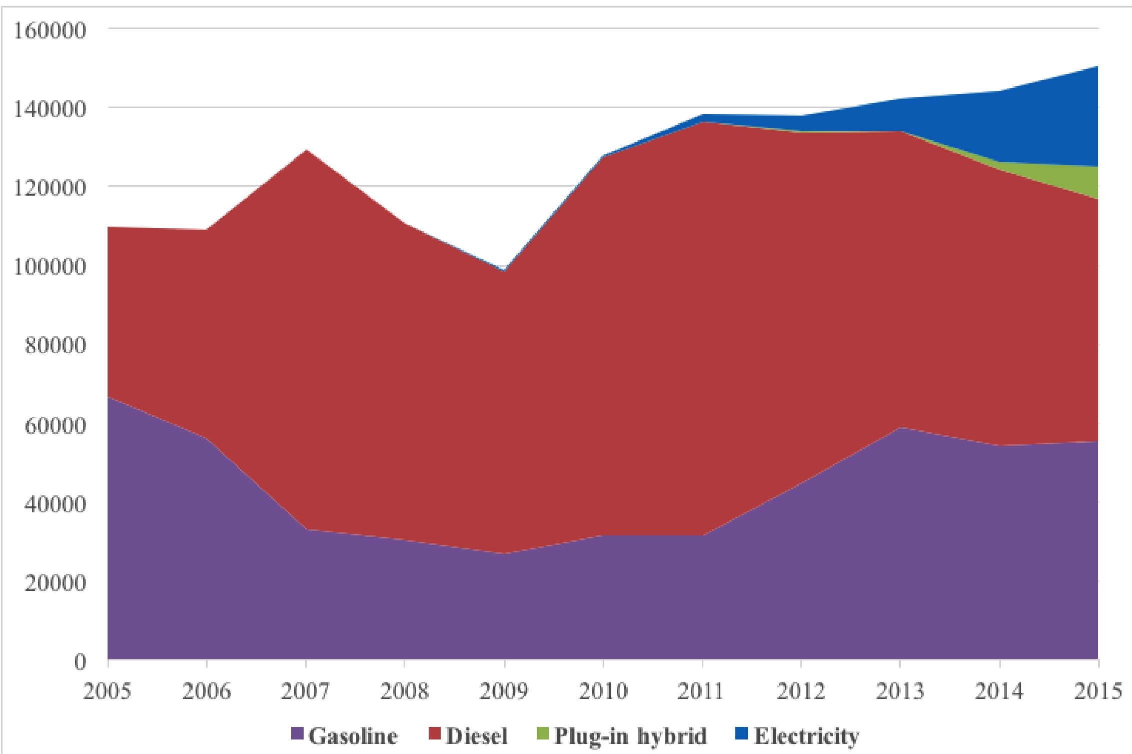


Figure 2.1.1: New car registration (OFV AS).

The market for new vehicles has since 2005 experienced some volatility, especially during the financial crisis in 2008 and 2009. This is not surprising as the automotive industry is moving together with the business cycle (OECD, n.d.). However, since 2013 the growth has been positive with the highest number of registrations of private vehicles since 1986 in 2015 (Sæter, 2016). According to data collected by OFV AS (Pål Bruhn, personal communication, October 7, 2016), a total of 150 686 vehicles were registered in 2015, equivalent to a 4.3% growth from the previous year.

Table 2.1.1: New vehicle registration over regions (OFV AS).

	2011		2012		2013		2014		2015	
	Count	%	Count	%	Count	%	Count	%	Count	%
Akershus	19 702	14,2	20 455	14,8	21 505	15,1	21 610	15,0	22 643	15,0
Aust-Agder	2 737	2,0	2 623	1,9	2 821	2,0	2 775	1,9	2 977	1,9
Buskerud	9 473	6,8	9 560	6,9	9 774	6,9	10 010	6,9	10 241	6,9
Finnmark	1 333	1,0	1 300	0,9	1 283	0,9	1 082	0,8	1 222	0,8
Hedmark	5 119	3,7	4 956	3,6	4 987	3,5	4 700	3,3	5 175	3,3
Hordaland	12 509	9,0	11 895	8,6	12 370	8,7	13 013	9,0	14 008	9,0
Møre og Romsdal	6 333	4,6	6 558	4,8	6 133	4,3	6 250	4,3	6 532	4,3
Nord Trøndelag	3 164	2,3	3 053	2,2	2 944	2,1	2 865	2,0	2 912	2,0
Nordland	4 292	3,1	4 445	3,2	4 537	3,2	4 167	2,9	4 783	2,9
Oppland	4 392	3,2	4 386	3,2	4 437	3,1	4 215	2,9	4 570	2,9
Oslo	15 910	11,5	16 321	11,8	16 532	11,6	17 957	12,5	18 329	12,5
Rogaland	11 994	8,7	12 283	8,9	12 927	9,1	13 002	9,0	12 835	9,0
Sogn og Fjordane	2 131	1,5	2 119	1,5	2 161	1,5	2 261	1,6	2 246	1,6
Svalbard	33	0,0	22	0,0	12	0,0	32	0,0	33	0,0
Sør Trøndelag	7 670	5,5	7 810	5,7	7 843	5,5	8 103	5,6	8 641	5,6
Telemark	5 288	3,8	4 885	3,5	5 198	3,7	5 240	3,6	5 484	3,6
Troms	3 771	2,7	3 770	2,7	3 834	2,7	3 571	2,5	3 867	2,5
Vest-Agder	5 891	4,3	5 445	3,9	5 798	4,1	5 870	4,1	6 226	4,1
Vestfold	6 339	4,6	6 363	4,6	6 838	4,8	7 112	4,9	7 302	4,9
Østfold	10 264	7,4	9 718	7,0	10 217	7,2	10 367	7,2	10 660	7,2
Totalt	138 345	100,0	137 967	100,0	142 151	100,0	144 202	100,0	150 686	100,0

In table (2.1.1) we present the registrations of new vehicles over regions. Akershus is the biggest single market followed by Oslo, Hordaland and Rogaland. In the time frame presented in the table, the four largest markets represent almost half of the new vehicles registrations in Norway.

Table 2.1.2: New electric vehicle registration over regions with (OFV AS).

	2011		2012		2013		2014		2015	
	Count	%	Count	%	Count	%	Count	%	Count	%
Akershus	633	31,7	1037	26,3	1503	19,1	3023	16,7	4322	16,8
Aust-Agder	21	1,1	28	0,7	97	1,2	259	1,4	454	1,8
Buskerud	125	6,3	233	5,9	471	6,0	884	4,9	1311	5,1
Finnmark	5	0,3	10	0,3	19	0,2	25	0,1	39	0,2
Hedmark	13	0,7	20	0,5	79	1,0	192	1,1	461	1,8
Hordaland	199	10,0	541	13,7	1116	14,2	2961	16,4	4061	15,8
Møre og Romsdal	59	3,0	161	4,1	240	3,0	503	2,8	743	2,9
Nord Trøndelag	21	1,1	39	1,0	119	1,5	267	1,5	356	1,4
Nordland	43	2,2	63	1,6	176	2,2	358	2,0	685	2,7
Oppland	21	1,1	23	0,6	54	0,7	152	0,8	322	1,2
Oslo	306	15,3	731	18,5	1564	19,8	3433	19,0	4334	16,8
Rogaland	190	9,5	349	8,8	712	9,0	1788	9,9	2394	9,3
Sogn og Fjordane	5	0,3	12	0,3	30	0,4	129	0,7	179	0,7
Svalbard	0	0,0	0	0,0	0	0,0	0	0,0	5	0,0
Sør Trøndelag	141	7,1	385	9,7	644	8,2	1452	8,0	1825	7,1
Telemark	14	0,7	16	0,4	108	1,4	343	1,9	624	2,4
Troms	22	1,1	14	0,4	59	0,7	111	0,6	295	1,1
Vest-Agder	60	3,0	131	3,3	331	4,2	716	4,0	1164	4,5
Vestfold	41	2,1	76	1,9	322	4,1	827	4,6	1153	4,5
Østfold	77	3,9	81	2,1	238	3,0	667	3,7	1052	4,1
Totalt	1996	100,0	3950	100,0	7882	100,0	18090	100,0	25779	100,0

Table (2.1.2) presents the registrations of electric vehicles over regions, which have experienced a steady growth since 2010. In total, only 117 cars were sold in 2010 and as much as 25 779 cars were sold in 2015. In 2015 the market share for electric vehicle was 17.1%, implying that more than every sixth vehicle sold was an electric. This is an increase in the market share from the previous year, where every eight vehicles sold was electrically driven. Similarly, with 7 982 vehicles sold in 2015, the market for plug-in hybrids stood for every twentieth sold vehicle.[10]

Counties in the northern part of Norway, accounted for less than 4% of electric vehicles sales in 2015.[11] One explanation is that longer and harsher winters in the north reduce the battery capacity of electric cars. The proportion of electric vehicles

[10] This is not shown in the tables.
[11] Finnmark, Troms and Nordland.

over counties reveals some volatility. One possible explanation to this volatility is that introduction of local incentives for electric vehicles affect the car sales. This assumption is not supported by the introduction of congestion charge in Trondheim, which did not cause any sudden growth in the sales of electric vehicles, even though electric vehicles are excepted from such payments. This could be explained by the fact that there were few suppliers of electric vehicles in 2010 and the electric cars were less developed relative to conventional cars than they are today. The launch of Nissan Leaf and Mitsubishi iMiev to the Norwegian market in 2011 could partly explain this years increased sales of electric cars. It seems reasonable that improved car features, like better technology or energy-efficiency, also affect the consumers purchase decision.

2.2 Vehicle Fleet and Multi-Homing

In this part chapter we present figures for the total number of electric cars, total number of conventional cars and the particularly interesting ownership categories. The figures are based on data from January 2011 to October 2015 for the three largest cities in Norway.[12]

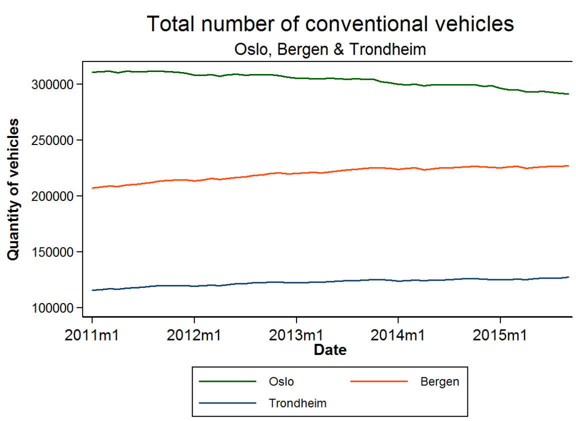


Figure 2.2.1: Total number of conventional vehicles in Oslo, Bergen & Trondheim.

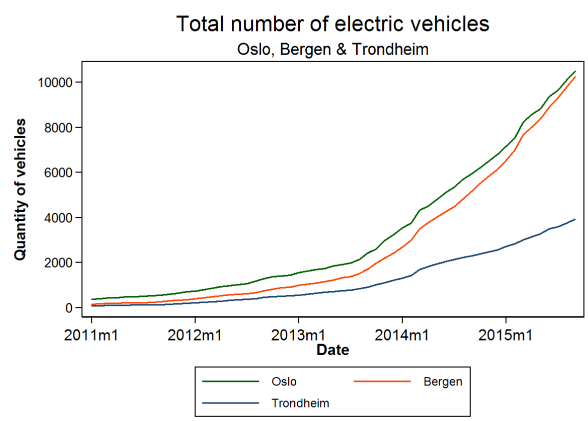


Figure 2.2.2: Total number of electric vehicles in Oslo, Bergen & Trondheim.

[12]The data is not complete for November and December of 2015.

Figure 2.2.1 shows that the total number of conventional cars is slightly growing in Trondheim and Bergen, but declining in Oslo. Moreover, all three cities are experiencing growth in their electric vehicle stock (figure 2.2.2). Interestingly, Bergen and Oslo possess almost the same amount of electric cars in the end of our data period.

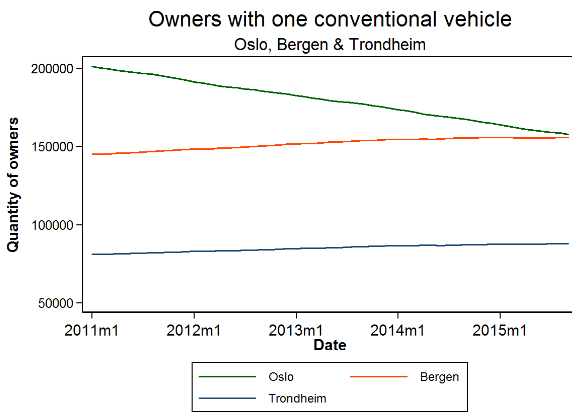


Figure 2.2.3: The number of owners with one conventional vehicle in Oslo, Bergen & Trondheim.

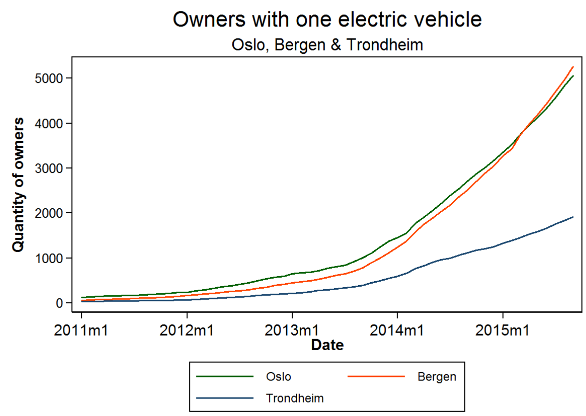
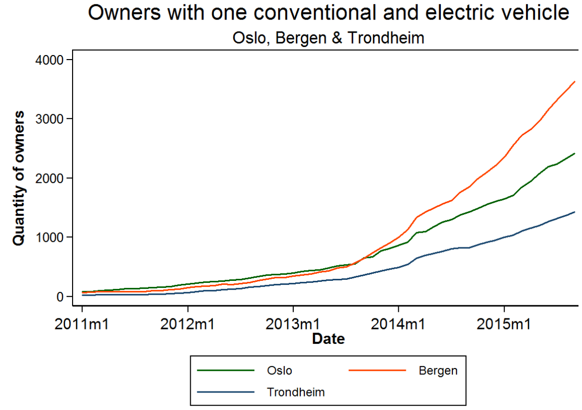


Figure 2.2.4: The number of owners with one electric vehicle in Oslo, Bergen & Trondheim.

Figures 2.2.3 and 2.2.4 reflect the trends presented in the previous figures (2.2.1 and 2.2.2). There are more owners holding one electric vehicle in Bergen relative to in Oslo, while Oslo has slightly more owners holding one conventional vehicle than Bergen.



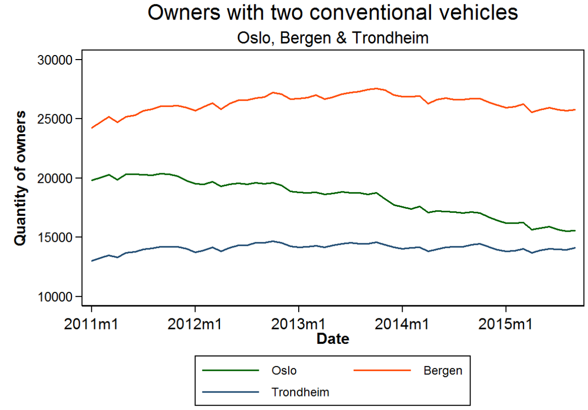


Figure 2.2.5: The number of owners with one conventional car and one electric car in Oslo, Bergen & Trondheim.

Figure 2.2.6: The number of owners with two conventional vehicles in Oslo, Bergen & Trondheim.

Multi-homing occurs more frequently in Bergen compared with Oslo and Trondheim, although it seems to be increasingly common to own both car types in all three cities (figure 2.2.5). The development of the number of owners holding two conventional vehicles is following a steady declining trend in Oslo. In Bergen and Trondheim a slight reduction of owners with two conventional cars is visible from the end of 2013. The number of owners holding two conventional vehicles is higher in Bergen than in Oslo. Figure 2.2.5 shows that multi-homing is taking place in all the cities we have presented and that the number of multi-homers is growing. Yet, multi-homing is a neglected topic in the debate regarding incentives for electric vehicles.

3 Theory

In this chapter we present the theories that constitute the foundation for our analysis. First of all, the theories are necessary to get a good grasp of the car market. Second, we must understand these theories in order to modify and extend them further. We will concentrate on the product differentiation subspace within the wider space of industrial organization. Following Lancaster (1979), it has become common among academics to distinguish between vertical and horizontal differentiation. The two different strategies will be outlined in section 3.1.

Section 3.2 is a recap of Hotelling's (1929) famous paper ”Stability in Competition”. His spatial competition framework is frequently used, both as a standard analytical tool in its original state and as a valid starting point for extended models. Variants allowing the consumers to multi-purchase are particularly interesting in this setting, and we will introduce this concept in section 3.2.1. In his paper ”Monopolistic Competition with Outside goods”, Salop (1979) derived a circular alternative to Hotelling's linear city, simplifying the analysis of oligopolies. Section 3.3 covers Salop's idea.

3.1 Product Differentiation

Analyses of markets characterized by price competition often begin with a standard Bertrand approach. The assumption of perfect substitutability implies that everyone perceives the goods offered to be identical, leading all consumers to purchase the cheapest product. The firms thus always have an incentive to undercut the price set by its rivals in order to capture the entire market. This behavior lasts until price equals marginal cost and all profit is gone. This outcome is often referred to as the Bertrand paradox.

Product differentiation is a potential way out of the paradox, and the firms can take a vertical or a horizontal approach. Vertical differentiation is characterized by diversification in a dimension objectively graded from best to worst. A typical example is supermarkets, where consumers face a trade-off between well branded products of superior quality and the supermarkets' own and cheaper versions. Horizontal differentiation, on the other hand, occurs when products differ in a dimension in which consumers disagree on what is best. An example is the decision of whether to buy grey or blue shoes. Without subjective preferences one cannot say that grey is better than blue. A third possibility is a mixed differentiation strategy, which is most easily applied to complex products that can exist in different sizes, qualities, functionalities, colors, styles etc.

Hotelling (1929) formalized the differentiation concept in his theoretical representation of spatial competition in a duopoly. In the remaining sections of the chapter we will go through his framework and look at a selection of supplementary material.

3.2 Hotelling's Linear City

The traditional way to illustrate Hotelling's framework is to tell the story of two ice-cream vendors on a beach. The two vendors are identical, except for their placement on the beach line. The consumers are uniformly distributed along the beach, and their decision of where to purchase ice-creams is solely based on their distance to the vendors. The longer a consumer has to travel, the lower utility he gets from buying the ice-cream. Given equal prices, the consumers choose the vendor closest to their own location on the beach. The literal perception of transportation costs in this example is an analogy to the general disutility from purchasing a good that do not exactly match ones preferences.

Normalizing the length of the beach (l) and the density of consumers (θ) to 1, Hotelling could present his spatial competition framework formally.

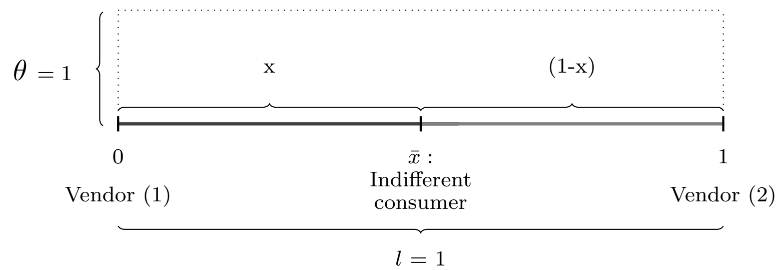


Figure 3.2.1: Hotelling's framework.

Figure (3.2.1) illustrate Hotelling 's framework. The model is based on an assumption of market coverage, which means that no consumer refrain from purchasing either one good or the other. The utility of buying ice-cream from vendor 1 for a consumer located at $\tilde{x}$ can be presented in a utility function as the one shown below:

$$U_1 = v - p_1 - t|a - \tilde{x}|$$

The utility this consumer would get if he bought the ice-cream from vendor 2 instead would be:

$$U_2 = v - p_2 - t|(1 - b) - \tilde{x}|$$

Where v represents the consumer's gross willingness to pay for ice-cream, p_1 is the price set by vendor 1 and p_2 the price set by vendor 2. We assume that vendor 1 is located at point a and vendor 2 at point $1 - b$, where $a \geq 0$, $b \geq 0$ and $1 - a - b \geq 0$. The transportation costs of travelling to vendor 1 and vendor 2 are $t|a - \tilde{x}|$ and $t|(1 - b) - \tilde{x}|$ respectively. The consumers decide which vendor to buy ice-cream from in a utility maximizing manner. The consumer located at $\bar{x}$ is characterized by his indifference towards which vendor to buy ice-cream from. The indifference is caused by U_1 being equal to U_2, which implies that the consumer at $\bar{x}$ would get the exact same utility of buying ice-cream from to vendor 1 as from vendor 2. The x consumers to the left of the indifferent consumer make up the demand for vendor 1, and the remaining $(1-x)$ consumers constitute the demand for vendor 2.[13]

Initially, both vendors charge the same price, and one of the ice-cream vendors parks his cart at one end of the beach, while the other vendor settles at the opposite extreme. This would imply that $a = 0$ and $b = 0$. Consequently, they serve one half of the beach each. This, however, is not a stable equilibrium when transportation costs are linear, as they are in the utility functions specified above. Both vendors know that they could get exclusive access to their own turf and half the market between the carts by pushing their own cart slightly towards the other. For that reason they will be tempted to do so until they are located right next to each other. Keeping in mind that location is the differentiation parameter in this example, it is comprehensible that Hotelling's outcome has become known as the Principle of Minimum Differentiation.

Hotelling's prediction of the vendors' tendency to gather at the midpoint can be shown formally. We emphasize that the transportation costs are linear and that the vendors choose their location. The demand functions can then be presented in this way:

$$D_1(p_1, p_2) = x = \frac{p_2 - p_1}{2t} + \frac{1 + a - b}{2}$$

$$D_2(p_1, p_2) = 1 - x = \frac{p_1 - p_2}{2t} + \frac{1 + b - a}{2}$$

Furthermore, we assume that the vendors are profit maximizing, with the following profit functions:[14]

$$\pi_1 = D_1(p_1, p_2) \times (p_1 - c)$$

[13]Notice how this implies that all consumers buy one, but only one, ice-cream. We will return to the assumptions of market coverage and single-purchasing later on.

[14]c represents the firms' marginal costs, and we assume that $c_1 = c_2 = c$.

$$\pi_2 = D_2(p_1, p_2) \times (p_2 - c)$$

It can then be shown that they set their prices according to the reaction functions below:

$$p_1^R(p_2) = \frac{p_2 + c}{2} + \frac{t(1 + a - b)}{2}$$

$$p_2^R(p_1) = \frac{p_1 + c}{2} + \frac{t(1 + b - a)}{2}$$

Finally, we maximize vendor 1's profits with respect to location:

$$\frac{d\pi_1}{da} = \frac{p_1 - c}{4} > 0$$

The equation above shows that it is optimal to increase a, which implies that vendor 1 moves towards the line's midpoint, and the same applies to vendor 2.[15]

Hotelling's argumentation is called into question in the paper *On Hotelling's "Stability in Compertition"* by D'Aspremont, Gabszewicz and Thisse (1979). They claim that the price competition that plays out when the firms imitate one another eventually result in the Bertrand paradox with zero profits. Following their logic, the Principle of Minimum Differentiation is at most a conditional state. Additionally, D'Aspremont et al. proved that by substituting Hotelling's linear transportation costs with quadratic transportation costs, the optimal strategy actually turns out to be maximal differentiation. Tirole (1988) identified two contradicting forces pulling the differentiation strategy in opposite directions. On the one hand, the demand effect causes the the firms to concentrate at the center in order to increase demand. On the other hand, the strategic effect supports divergence to upheld the price level. By differentiating their location, the vendors can avoid intense competition over the same consumers and soften the price competition. Clearly the framework is sensitive to its parameters, something that is important to bear in mind when working with

[15]The vendors' symmetrical functions imply similar behavior.

the model.

3.2.1 Multi-Homing

Although Hotelling's framework is extremely useful, it does not allow consumers to purchase more than one out of the product varieties. Ambrus and Reisinger (2006) discovered that the predictions from a single homing model could change considerably if multi-homers were added. Applying Hotelling's initial framework to multi-homing markets could therefore result in unreliable outcomes. Nevertheless, along with the last decades increased welfare it has become more common to acquire more than one variant of differentiated products. It is not unlikely that a ski enthusiast holds both a pair of classic skis and a pair of skating skies. Neither is it uncommon for a dedicated gamer to enjoy both an Xbox and a Playstation or a film lover to subscribe to both Netflix *and* HBO. The key point is that a second variant of a good provides the consumer with additional attributes, while another unit of the same good has no incremental value. Kim and Serfes (2006) addressed the issue of constraining the consumers to buy only one good and then analyzed multi-homing in the Hotelling framework. They demonstrated that under certain conditions Hotelling’s controversial Principle of Minimum Differentiation is restored.

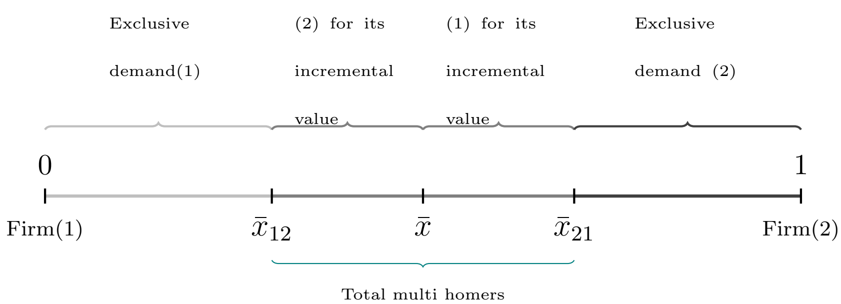


Figure 3.2.2: Hotelling's framework with multi homing.

Figure (3.2.2) is a multi-homing extended version of figure (3.2.1).

The consumers who buy just one good have the same utility functions as in the initial Hotelling model, while utility of multi-homing can be expressed by the following functions:

$$U_{12} = v_1 + \beta v_2 - p_1 - p_2 - t|a - \tilde{x}| - t|(1-b) - \tilde{x}|$$

$$U_{21} = v_2 + \beta v_1 - p_2 - p_1 - t|a - \tilde{x}| - t|(1-b) - \tilde{x}|$$

The multi-homing consumers pay for both products and they are exposed to transportation costs in both directions. Moreover, they can enjoy the unique features of both goods. However, if the goods have overlapping characteristics, the consumers value the secondary good lower than the primary good. For instance, if a person reads DN in the morning, he could still experience positive utility from reading Finansavisen at lunch, although the utility from reading Finansavisen is lower the more overlapping news. In this model, β is the parameter that adjusts the value of the secondary good whenever the goods share common characteristics. We assume that $\beta \geq 0$.

The closer to a firm consumers are located on the line, the more aligned are their preferences with the characteristics of this firm's good. The consumer that is indifferent towards buying just good 1 and both goods is located at $\bar{x}_{12}$. All consumers to the left of $\bar{x}_{12}$ thus prefer to buy good 1 over joint purchase, and they make up the exclusive demand for firm 1. Similarly, $\bar{x}_{21}$ represents the consumer that is indifferent between buying only good 2 and both goods. The consumers to the right of $\bar{x}_{21}$ rather buy only good 2 than both goods, and they represent the exclusive demand for firm 2.

The consumers that are located close to the line's center have less extreme preferences than the consumers towards the endpoints. These consumers still have stronger preferences for one of the goods, but they also assign a positive incremental value to the other good. The consumers between $\bar{x}_{12}$ and $\bar{x}$ have a preference for good 1, but they also buy good 2 for its incremental value. Similarly, the consumers between $\bar{x}$ and $\bar{x}_{21}$ buy good 2 as their primary product and good 1 as a secondary variant. The total of multi-homers are thus located in the interval between $\bar{x}_{12}$ and $\bar{x}_{21}$. A firm's total demand consists of its exclusive demand and the demand from the consumers purchasing both goods. Hence, firm 1's demand equals the customers to the left of $\bar{x}_{21}$, while 1- $\bar{x}_{12}$ makes up the total demand for firm 2.

A major implication of multi-homing is that prices are strategically independent, a fundamental difference from the complementary strategic relation present in the single homing model (Anderson, Foros, & Kind, 2016). The intuition behind the strategic independence can be illustrated in the case of a unilateral price decrease by firm 1. The price reduction increases the demand for good 1, although the exclusive demand is left unchanged. The consumers who preferred good 1 in the first place still buy it, and they get a higher consumer surplus. Because the market is covered, there are no new consumers in the market. The increased demand stems from new multi-homers, driven by increased incremental value of good 1. The new multi-homers are consumers who buy good 2 as their primary product, but who decide to buy good 1 in addition. Because the new demand is supplementary to good 2, rather than instead of good 2, the total demand for firm 2 remains the same. Since the demand for firm 2 is unaffected by the price decease of firm 1, there is no reason for firm 2 to adjust its price. In other words, firm 2's price setting is independent of firm 1's price setting. Multi-homers cancel the business stealing effect and reduce price competition.

Under certain circumstances, the multi-homing model restores the Principle of Minimum Differentiation. Firms might want to locate close to the midpoint on the Hotelling line to minimize their distance to as many consumers as possible. The firms then adapt to moderate preferences rather than meeting extreme preferences, and they attract the mass market instead of niche segments. If both firms pursue this strategy, they implicitly become more alike. In a single homing world the consumers buy either good 1 or good 2, and one firm's loss is the other firm's gain. Following D'Aspremont, Gabszewicz and Thisse (1979), the goods being minimally differentiated make the firms compete fiercely over the same consumers and heavy price competition might eliminate all profits. The chain of reasoning is different in a multi-homing setting, mainly because one firm serving a consumer does not exclude the other firm from doing the same thing. Thus, in principle, both firms approaching the mass market do not increase the competitive situation. As Kim and Serfes (2006) recognized, minimal differentiation could then be a rational move to increase the consumer group purchasing both products.

Mussa and Rosen (1978) proposed a framework for modelling vertical differentiation, and demonstrated that consumers have higher willingness to pay for products of better quality. However, producing products of higher quality increases the firms' costs. Taking the theory a step further, Gabszewicz and Wauthy (2003) added the possibility of multi-homing to the framework. They find that joint purchase alters the competition between a low-cost firm and a high-cost firm in two different ways. On one hand, multi-homing might induce the low-cost firm to sell one unit of its lower quality product to the "poors" plus one unit to the "richs", who end up purchasing two units in equilibrium. Such behavior enhances price competition and do possibly lead to multiple equilibria. On the other hand, multi-homing could prevent fierce competition over market shares by convincing the firms to focus on the rich consumers who are likely to buy both product varieties. This strategy would relax the price competition and yield higher equilibrium prices. Anderson et al. (2016) extended Gabszewicz and Wauthy's analysis, assuming that quality improvements are more appreciated the closer the product is to the consumers preferences. In their paper *"Hotelling competition with multi-purchasing"* the authors demonstrate how higher quality gives ambiguous answers to whether the optimal strategy is minimal or maximal vertical differentiation. Moreover, they show that higher quality do not necessarily contribute to multi-homing. To exemplify they look at a market with two competing newspapers, where better news coverage serves as the quality parameter. On the one hand, higher quality makes a newspaper more attractive and increases the likelihood of multi-purchasing. On the other hand, consumers might find it less important to read both newspapers when each of the newspapers covers more. It can thus be shown that the firms might be willing forgo some sales and rather charge a high price that prevents multi-homing when the quality levels are sufficiently high.

3.3 Salop's Circular City

Hotelling built his linear city for a duopoly, rejecting outside firms to enter the market. Salop (1979) discovered that by uniting the ends of Hotelling's line, analysing a market with multiple firms were feasible.

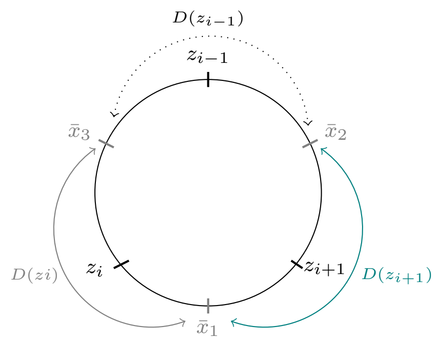


Figure 3.3.1: Salop's circular city.

Figure 3.3.1 illustrates an example of $n = 3$ equidistantly located firms.[16] One firm is located at z_i, the second at z_{i+1} and the third at z_{i-1}.[17] A unit mass of customers are uniformly distributed on the boundary of the circle, and they are only allowed to travel along the boundary. For simplicity, the circle's perimeter is set to 1. The model specifications imply that the firms have maximum two real competitors, their neighboring firm on each side.

The consumer that is indifferent between buying from the firm at z_i and the firm at z_{i+1} is located at $\bar{x}_1$. Equivalently, $\bar{x}_2$ and $\bar{x}_3$ act as the indifference points between their respective surrounding firms. The demand for a given firm can thus be found by calculating the distance between the indifferent consumer on the firm's left side and the one on its right side. The demand functions resemble the Hotelling demand functions, but unlike the functions in the linear city, the demand functions in the circular city account for tougher competition when the number of firms increases.

[16] In theory, n could be any number greater than or equal to two.

[17] The symmetrical distribution has only been justified in the case of quadratic transportation costs (Tirole, 1988).

A downside of the circular system is that a specifically nice feature of the endpoints gets lost, namely that the line goes from one preference extreme to the other extreme. On the other side, the absence of endpoints makes it possible to include firms that do not fit anywhere on a Hotelling line with one preference dimension. Furthermore, since the symmetrical spacing is vindicated only for models with quadratic transportation costs, location incentives should be discussed explicitly when Salop models with linear or exponential transportation costs are applied. Economides (1993) compared the linear city to the circular city and discussed their appropriateness. He emphasize that context and purpose is crucial for determining which model is best, although he claims that the linear city imposes the best structure for most product spaces.

4 A Model for Spatial Competition in the Car Market

Our intention is to develop a model that describes the car market in a functional and realistic manner. In particular, we are interested in the effects of electric vehicle incentives on the competitive situation between electric cars and internal combustion engine cars. Hotelling's linear city provides us with useful insight to the elementary market mechanisms, but the framework does not allow us to unite multi homing and an uncovered market. Considering the nature of the market, we preferably avoid such a trade off. As a matter of fact, many households own more that one car and there are a lot people capable of driving a car that choose alternative means of transportation. In an attempt to get around the trade off, we derive a spin-off model from Hotelling's linear city and Salop's circular city.

4.1 The Relevant Market

In essence, the market we are interested in equals the market for passenger cars. In line with the purpose of the thesis, we distinguish between electric vehicles and internal combustion engine vehicles.[18] Cars serve as the predominant mean of transportation for everyday travels (TØI, 2014), but travelers also find solutions to transport outside the car market. Because some of the people who do not travel by car in principle could buy a car if they wanted to, we cannot claim that the car market is covered. According to Hjorthol, Engebretsen, and Uteng (2014), the majority of the travelers that do not have a car use public transport. We define the transport market as the market including both cars and public transport. Furthermore, we assume that this market is covered, which implies that everyone with a need for everyday transportation make sure to either buy a car or access public transport. We do not deny the existence of cyclists and pedestrians, although we consider them as rather unlikely candidates to convert to cars. If cars or public transport became more competitive, we do not believe that people who currently walk to their workplace would

[18] Hereby referred to as conventional vehicles

enter the transport market in droves. In light of how most people meet their need for transportation, and what is actually considered as substitutes to cars, we find it legitimate to confine ourselves to look at the market for passenger cars and public transport.

In their competition over travellers, we assume that the means of transportation primarily compete on prices, as price is the most flexible parameter and thus the most likely factor to be adjusted in the short run. An attempt to change gross willingness to pay, marginal costs or quantities, on the other hand, often requires costly investments or contract renegotiations. Given these considerations, price stands out as the most reasonable strategic decision variable.

To what extent it is right to assume that public transport is a market actor in the same way as the car providers requires a short discussion. In comparison with privately held car firms, the public transport sector emphasizes profit maximization less and rather concentrate on efficient transfer of people, climate friendly travelling and improved social welfare. We still expect that the prices for public transport services react somewhat to the prices of alternative means of transportation. The implementation of congestion charges in Bergen is an event supporting this claim. When cars became relatively more expensive than public transport, due to the congestion charge, Hordaland County Counsil immediately raised the buss and tram prices in Bergen. Although it is plausible that a price increase would have taken place anyway, we suspect that the timing is not just a fortunate coincidence. On the other hand, the price of public transport also depends on regulations and statutory subsidies. Furthermore, the public transport service is shaped by policymakers and it is often adjusted in the wake of changed transport policies. For instance, to facilitate the conversion to low-emission transport, congestion charges are often accompanied by increased supply of public transport services. However, models are simplifications of the reality, designed to concentrate on features that are important for what one attempts to explain. The focal point in this thesis is the dynamics between electric cars and conventional cars, and we believe that including public transport in the model improves the qualitative outcome, although the quantitative measures might be imprecise.

4.1.1 Consumers, Preferences and Utility

The consumers of interest are the Norwegian inhabitants with a significant need for transport on a daily basis. These people have some underlying opinions and views that form their preferences. Many travelers are for instance concerned about convenience, some value flexibility the highest and others emphasize the importance of travelling environmentally-friendly. The specifications of a consumers preferences indicate this individual's preferred mean of transportation.

We assume that all travelers have a general inherent preference for range, which has traditionally been the achilles' heel for electric vehicles. The term "range anxiety" was established a few years ago, when electrical cars became more popular, to express the fear that a vehicle has insufficient range to reach its destination. Public transport seldom transfer people from door to door, and it does not take people everywhere, which also represents range limitations. Essentially, range preferences favor conventional cars. Nevertheless, there exist travelers who are willing to let the range considerations aside for other preferences. Some people do for instance care for the environment to an extent that make them prefer public transport or electric cars. Likewise, travelers with a high valuation of time and flexibility probably prefer cars to public transport. It is no secret that public transport often is more time consuming as one has to plan on waiting times, transfers and delays. Public transport is also less flexible than cars. It is for instance not as easy to stop by the grocery store on the way back from work.

Ultimately, the travelers choose the mean of transportation that gives them the highest utility possible, with positive utility being a strict requirement for any purchase to take place. The utility from a certain mean of transportation depends on several parameters. v_i is the gross willingness to pay, p_i is the price set by the car providers, and α is a parameter for the local incentives for electric cars. z_i and x_i are the locations in preference space of the transport options and the travelers respectively. Thus, $|z_i - x_i|$ is the distance between mean of transportation i's characteristics and traveler i's preferences. t ≥ 0 is a parameter for preference heterogeneity.[19] We have presented the single-homing utility function below:

$$U_i, x_i = v_i - p_i - t|z_i - x_i| + \alpha_i$$

Utility increase in v_i, the willingness to pay for a mean of transportation. Factors that could increase v_i are, for instance, higher quality, better fuel-efficiency and improved technology. Increased price implies that the travelers will have to pay more for the mean of transportation, and utility thus decrease in p_i. The further away an option is from the traveler's preferences, the greater is the subjective costs of purchasing that alternative. Hence, utility is decreasing in $|z_i - x_{ij}|$, and to what extent is determined by t. When t goes towards zero, preferences are less extreme and the disutility of a certain preference distance is lower.

4.1.2 Multi-Homing

In this section we present the arguments for why multi-purchasing should be accounted for and why we restrict multi-purchasing to the combination of electric cars and conventional cars.

A survey by Nenseth and Hjorthol (2007) investigates the factors explaining the use of public transport. The report reveals that having access to a car has the strongest explanatory power. Moreover, car access and use of public transport are negatively correlated, meaning that car owners travel by public transport significantly less than those without a car. Nenseth and Hjorthol's findings suggest that it is not very common to simultaneously own a car and use public transport. On the basis of their findings, we assume that joint purchase of cars and public transport can be omitted from the multi-homing model without major implications. A

[19] For mean of transportation i, $i = 1, 2, 3$.

neat consequence is that we achieve a distinction between public transport and cars, which turns out to be useful when taking market coverage into consideration. The uncovered car market less public transport then equals the served car market. Hence, someone converting from public transport to cars represents new individuals in the market for cars.

The *National Travel Survey* by Hjorthol et al. (2014) points out that a substantial and growing number of households have access to more than one car. This supports the claim of multi-homing being a non-negligible feature of the car market. A recent survey conducted by Figenbaum and Kolbenstvedt (2016) indicates that 71% of electric car owners got a conventional car as a supplement to their electric car. According to the same report, only 4% of the electric car owners have two electric cars while about one half of the owners of conventional cars have two cars of the same type. Neither related frameworks nor our model allow consumers to buy more than one unit of the same product variant. While the small percentage holding two electric cars probably could be ignored, we are more concerned about the great number of people owning two conventional cars. We expect that the convenience of having a small car combined with the benefits of a big car encourages people to acquire two conventional cars. By segmenting the car market into small cars and large cars, and then consider each segments in isolation, we believe that we can bypass the great percentage holding two cars of the same type. The argumentation is based on the assumption that the incremental value of a second conventional car is driven by size. Thus, controlling for car size, multi-homing should apply mostly to the combination of one electric car and one conventional car. The empirical investigation of the assumption shows that, for many years, there has been a small stable number of travelers holding two small conventional cars. While it seemed to be increasingly common to have two large conventional cars in the early 2000s, the prevalence of this owner structure has either decreased or stabilized since around 2008. Moreover, it has become more common to own one large and one small car. Hence, our assumption appears to be valid from 2008 (Figure D.3).[20]

[20] This is based on findings in Oslo, Bergen, Trondheim and Stavanger.

In principle, the utility from buying both car types can be found by adding together the single-homing utility functions for electric cars and conventional cars. However, we have to adjust for overlapping car characteristics that reduce the value of the secondary car. We use β to make this adjustment. If β equals zero no one buys two cars, because the second car is not assigned any value at all. On the contrary, if β equals one, the purchase decision of car type i is unaffected by whether the traveler buys car type j. β becomes lower the more overlapping car attributes, as the value of a second car hinges on its unique features. The utility from multi-homing is given by:

$$U_{ij}, x_i = v_i + \beta v_j - p_i - p_j - t|z_i - x_i| - t|z_j - x_i| + \alpha_i + \alpha_j$$

4.1.3 Market Coverage

This section is based on the utility specifications we defined in the previous section, and it covers how the efficiency of the local incentives crucially depends on whether the market is covered or not. Furthermore, it addresses the issue of combining market coverage and multi homing. We begin with a review of the market of interest in Hotelling's linear city. Then we look at the extended version with multi-purchasing.

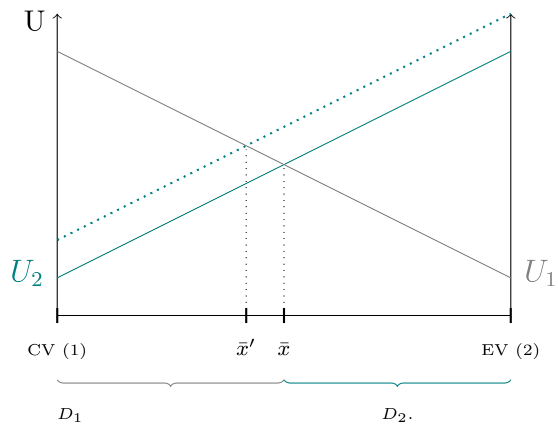


Figure 4.1.1: Single-homing and market coverage.

Figure 4.1.1 shows the original Hotelling model, which is restricted to single-purchasing and assumes market coverage. EV and CV represent the providers of electric vehicles and conventional vehicles respectively. The car providers are located one at each extreme of the Hotelling line and the car buyers are uniformly distributed along the line segment. U_1 and U_2 represents the utility from purchasing a conventional vehicle and an electric vehicle respectively. Buying the car type closest to ones preferences gives the highest utility. This is illustrated graphically in the figure, where Ui is increasing the closer to car type i a car buyer is located. The consumer at $\bar{x}$ is indifferent towards the two car types, while the consumers to the left of $\bar{x}$ prefer conventional cars and the consumers to the right of $\bar{x}$ prefer electric cars. Hence, U_1 lay above U_2 to the left of $\bar{x}$, U_2 lay above U_1 to the right of $\bar{x}$, and U_1 equals U_2 at $\bar{x}$.

Di shows that firm i's demand is made up by the consumers who get the highest utility from purchasing car type i. Neither of the utility functions reach a level of zero utility, which indicates that all travelers get a positive utility from buying any car. Thus, everyone buys a car and market coverage is obtained.

The figure demonstrates the effect of a positive shift in U2, which symbolize that the utility of electric cars has increased. This could happen if, for instance, new electric vehicle incentives were introduced or the old ones became more advantageous. One can see that the indifference point moves from $\bar{x}$ to $\bar{x}'$. Some of those who slightly preferred conventional cars before, change their minds now that the incentives for electric cars are improved. Consequently, there is a shift in the demand from conventional cars to electric cars. If the positive shift was initiated by increased incentives for electric vehicles, and the objective was to reduce demand for conventional cars, the policy is successful.[21]

Given the existence of travelers using public transport instead of cars, the car market will be uncovered. Relaxing the assumption of market coverage yields the following figure:

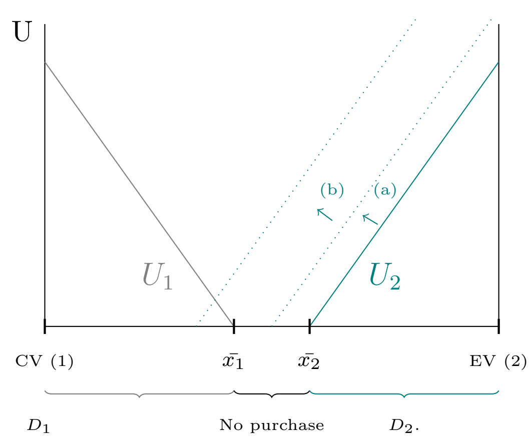


Figure 4.1.2: Single-homing without market coverage.

Figure 4.1.2 is a representation of the Hotelling framework with single-homing, but without market coverage. In contrast to what we saw in figure 4.1.1, Ui does not span from one endpoint of the line to the other. In this model, U_i intersects with the horizontal line at $\bar{x}_i$, which is the location of the traveler that is indifferent

[21]The providers of electric cars capture some of the incentive's value by increasing the price. The reduced demand for conventional cars cause a price reduction, partly reversed by the strategic price increase as a response to the price increase for electric cars. This will moderate the incentive'effect on car quantities.

between buying car type i and retaining from this purchase. The travelers who are located between car provider i and $\bar{x}_i$ get a positive utility from buying car type i. On the contrary, the travelers between $\bar{x}_i$ and car provider j would not experience any utility from car type i at all. Thus, no one to the left of $\bar{x}_1$ would buy an electric car. Likewise, a traveler to the right of $\bar{x}_2$ would never buy a conventional car. In addition, there are some travelers located in the gap between $\bar{x}_1$ and $\bar{x}_2$. These travelers do not get any utility from either of the car types and they rather use public transport. Despite both car types being offered, the car market is uncovered because of the travelers preferring public transport.

If the government increases the incentives for electric cars, a positive shift in U_2 occurs, as illustrated at point (a). The result is that some of those who previously travelled by public transport decide to get a car, and the overall car population increases. The incentives do not affect the demand for conventional cars until the market is covered, as the shift at point (b) demonstrates. As long as the car market is uncovered, which we are quite confident that it is, the incentives will not be efficient.[22]

Allowing for multi-homing, we return to the linear city with market coverage:

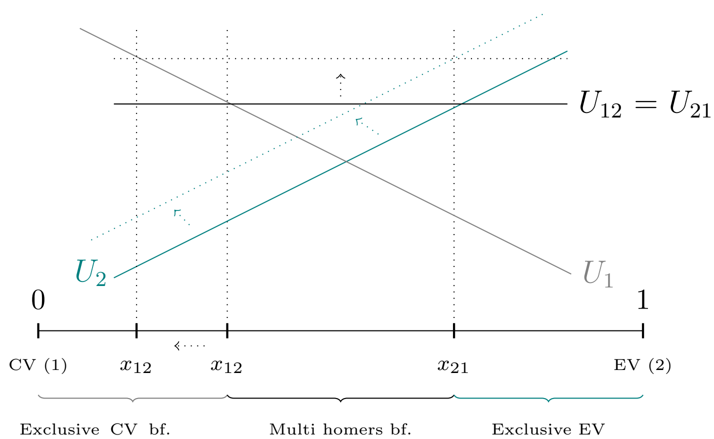


Figure 4.1.3: Multi-homing with market coverage.

[22]The more responsive the car prices are, the less efficient will the incentive be, as changed demand is met with price adjustments rather than altered quantities.

Figure 4.1.3 displays a multi-homing model with market coverage. U_1 and U_2 still represent the utility from buying a conventional car and an electric car respectively. The new utility function, U_{12}, represents the utility a traveler would get from joint purchase of one conventional car and one electric car. While U_1 and U_2 are increasing in conformity between traveler preferences and car characteristics, U_{12} is a horizontal line. This is because a relocation on the Hotelling line makes preferences get further away from car type i, but equivalently closer to car type j. Hence, for someone holding both car types, the total distance from this traveler's preferences to the two car types will be constant for any given location on the line. Multi-homing only makes sense if the utility of joint purchase is greater than the utility from just buying one conventional car or one electric car. Graphically, multi-homing occurs when U_{12} lay above both U_1 and U_2. By looking at the figure, one can see that this is the situation for the consumers located between x_{12} and x_{21}. As in figure 3.2.2, x_{ij} represents the consumer that is indifferent between buying just car type i and both car types. The consumers located between x_{ij} and car type i prefer to exclusively buy car type i, while the consumers located between x_{ij} and x_{ji} prefer the joint purchase option. Hence, the multi homers are located towards the middle of the Hotelling line. Intuitively, this makes sense; A traveler that is located closer to the middle has less extreme preferences and higher valuation of a second car.

Increased incentives for electric cars would cause a positive shift in both of the utility functions that include electric cars. The two utility functions, U_2 and U_{12}, change by the same amount, leaving the intersect between them unchanged. In words, the increased incentives cause no change in the exclusive demand for electric cars. The travelers with strongest preferences for electric cars do not change their purchase behaviour, and still make up electric cars' exclusive demand. Because the utility of electric cars has improved relative to the utility of conventional cars, U_{12} shift upwards, and the intersect between U_{12} and U_1 moves to the left. Intuitively, this means that there are more travelers who buy an electric car in addition to their primary conventional car. Increased incentives thus cause increased secondary demand for electric cars. To sum up, the existence of multi-homing travelers imply that the new demand for electric cars is in addition to, rather than instead of, conventional cars.

Now it is time to evaluate the setting with multi-homing and an uncovered market. Recall the location of those who do not buy a car at all when the market is uncovered. This is where we run into trouble, as they are located in the middle just like the multi-homers. Combining the two concepts produces a contradiction where those who buy no car also buy two cars. In the following section we will show that is possible to treat the car market as uncovered while allowing for multi-homing. This is where the definitions of both a car market and a transport market turn out to be convenient. In an novel way we combine the theory of multi-homing in the linear city, theory of market coverage and the circular approach.

4.2 The Model Setup

Before deriving the model, we briefly sum up the market specifications and assumptions. The market of interest is restricted to electric cars and conventional cars. Given the existence of public transport users, the car market is not covered. The transport market includes the most common means of everyday transportation, and consists of passenger cars and public transport. We find it plausible that most people make sure to show up for work and school every day, even if they depend on transportation. Thus, those in the market for transportation have most likely access to either cars or public transport and we can assume market coverage. Moreover, we suppose that car providers define public transport as a real contender in the market and that prices are the strategic decision variables. Regarding consumers and preferences, we assume that the travelers range requirements, environmental concerns and need for time and flexibility determines which mean of transportation they favor. Finally, we allow joint purchase of one electric car and one conventional car.

We find the Salop circle most appropriate to represent the entire market. First, the circular city's structure is convenient when we have three firms that do not fit on the same Hotelling line. For instance, given our preference specifications, conventional cars can not be placed at the same spot as electric cars or public transport, and neither in-between them. However, if we utilize a circular approach we can differentiate over more than one dimension so that all three means of transportation fit in. Second, the linear city complicates the competitive relation between two firms that is separated by a third firm. Because we assume that electric cars, conventional cars and public transport all compete against one another, the circular city seems more suitable. Finally, we can get around the trade-off between multi-homing and a uncovered car market.

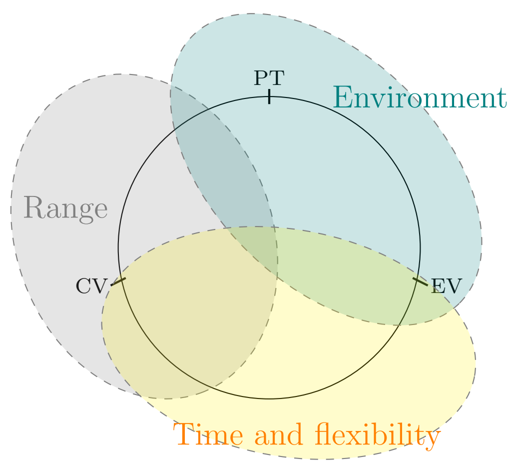


Figure 4.2.1: Traveler preferences.

The travelers who are unwilling to sacrifice superior range for the environments sake, and who value highly their time and flexibility, prefer conventional cars. Those who place greater emphasize on the environment than the cars' range, but refuse to compromise on traveling time and flexibility, choose electric cars. The remaining travelers conclude that the environment matters more than range, they are less dependent on traveling as fast and flexible as possible, and they prefer public transport.

Given that travelers perceive public transport as a substitute to cars, and that electric cars, conventional cars and public transport represent the preference extremes, we can distribute the three vehicle categories symmetrically on the Salop circle. Accordingly, we can still analyze the strategic relations and equilibriums using the standard procedures. Adding multi-purchasing to the model does not cause any particular problems. The elegant part of the setup is revealed when taking market coverage into account. When looking at the car market as a fraction of the covered transport market that is included in the model, we get an opportunity to deal with the car market as uncovered.

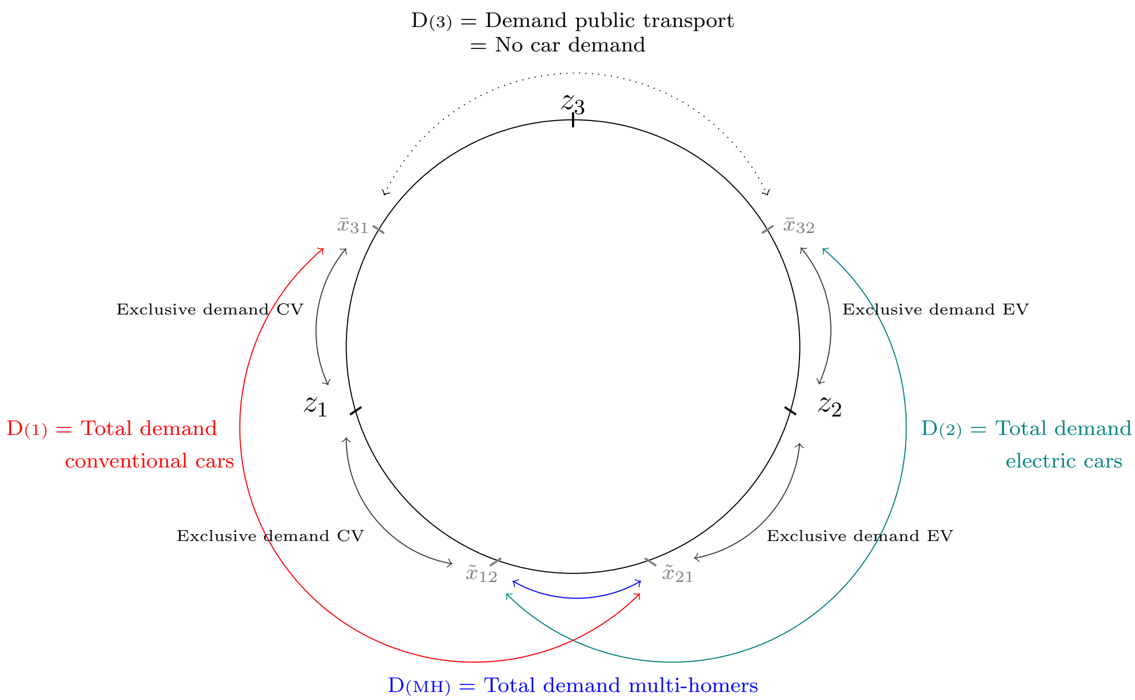


Figure 4.2.2: Our circular model with multi-homing and an uncovered car market.

Figure 4.2.2 shows the model we have derived: A circular multi-homing model with an uncovered car market. The locations of conventional vehicles, electric vehicles and public transport are represented by z_1, z_2 and z_3 respectively, while the consumers are uniformly distributed on the circle boundary.[23] The utility functions

[23]We still use the normalized setup, which implies that the circle perimeter equals 1.

of single-homers are given by:

$$U_1, x_{ij} = v_1 - p_1 - t|z_1 - x_{ij}|$$

$$U_2, x_{ij} = v_2 - p_2 - t|z_2 - x_{ij}| + \alpha$$

$$U_3, x_{ij} = v_3 - p_3 - t|z_3 - x_{ij}|$$

The utility functions of multi-homers are given by:

$$U_{12}, x_{ij} = v_1 + \beta v_2 - p_1 - p_2 - t|z_1 - x_{ij}| - t|z_2 - x_{ij}| + \alpha$$

$$U_{21}, x_{ij} = v_2 + \beta v_1 - p_2 - p_1 - t|z_2 - x_{ij}| - t|z_1 - x_{ij}| + \alpha$$

4.2.1 Demand

Car type i has two contenders, namely public transport and car type j.[24] In its competition against public transport, car type i fight over exclusive, demand from single-homers. The traveler that is indifferent between public, transport and car type i is located at $\bar{x_{3i}}$. Hence, the travelers who choose car type i instead of public transport are located in the interval from x_{3i} to z_i, while the travelers between z_3 and $\bar{x_{3i}}$ prefer public transport. In the car market, car type i competes with car type j over travelers making a choice between buying just one car and joint purchase. The traveler that is indifferent between these two options is located at x_{ij}. Hence, the exclusive demand in the car market for car type i is made up by the travelers located between z_i and x_{ij}. Likewise, x_{ji} separates the exclusive demand for car type j from the joint demand for both car types. The multi-homers are thus located between x_{ij}

[24]For car type i, $i = 1, 2$ and for mean of transportation i, $i = 1, 2, 3$.

and x_{ji}. The total demand for car type i, D_i, is presented below:

$$D_i = \underbrace{|x_{3i} - z_i|}_{\substack{\text{exclusive demand from} \\ \text{competition with} \\ \text{public transport}}} + \underbrace{|z_i - x_{ij}|}_{\substack{\text{exclusive demand from} \\ \text{competition with} \\ \text{car type } j}} + \underbrace{|x_{ji} - x_{ij}|}_{\substack{\text{overlapping demand} \\ \text{from multi-homers}}}$$

D_1 and D_2 are the demand functions for conventional cars and electric cars respectively, and they are thus given by:

$$D_1 = \bar{x}_{31} - \tilde{x}_{21}$$

$$D_2 = \tilde{x}_{12} - \bar{x}_{32}$$

Public transport is only exposed to single-homers, and its demand function reflects the exclusive demand from competition against the cars:

$$D_3 = \tilde{x}_{32} - \bar{x}_{31}$$

Evidently, the interval defining the demand function for a given mean of transportation is found simply by subtracting the location of the indifferent traveler on its right side from the location of the indifferent traveler on its left side. This is a convenient feature of the uniform distribution of travelers and the normalized set up. To obtain more informative demand functions, we identify the indifferent travelers and insert the equations into the demand functions above.

The traveler that is indifferent between public transport and conventional cars is located at $\bar{x}_{31}$, where $U_1 = U_3$.

$$\bar{x}_{31} = \frac{(z_1 + z_3)}{2} + \frac{(v_1 - v_3 - p_1 + p_3)}{2t}$$

The traveler that is indifferent between public transport and electric cars is located at $\bar{x}_{32}$, where $U_2 = U_3$.

$$\bar{x}_{32} = \frac{(z_2 + z_3)}{2} + \frac{(v_3 - v_2 - p_3 + p_2 - \alpha)}{2t}$$

The traveler at $\tilde{x}_{12}$ is indifferent between a conventional car and both a conventional car and an electric car, and is located where $U_1 = U_{12}$.

$$\tilde{x}_{12} = z_2 + \frac{\beta v_2 - p_2 + \alpha}{t}$$

The traveler at $\tilde{x}_{21}$ is indifferent between an electric car and both an electric car and a conventional car, and is located where $U_2 = U_{21}$.

$$\tilde{x}_{21} = z_1 - \frac{\beta v_1 - p_1}{t}$$

If an x-value increases it involves a clockwise movement on the circle.[25] When inserting the equations for the indifferent travelers into the demand functions, we get:

$$D_1 = \frac{1}{6} + \frac{(1 + 2\beta)v_1 - v_3 - 3p_1 + p_3}{2t}$$

$$D_2 = \frac{1}{6} + \frac{(1 + 2\beta)v_2 - v_3 - 3p_2 + p_3 + \alpha}{2t}$$

$$D_3 = \frac{1}{3} + \frac{2v_3 - v_1 - v_2 - 2p_3 + p_1 + p_2 - \alpha}{2t}$$

Car type i's demand function is independent of car type j's parameters. However, it is influenced by the parameters of public transport. The demand function for public transport got a different structure, because it depends on the parameters of both car types. Factors improving the competitive edge of public transport will therefore affect the demand for cars, and vice versa.

Proposition 1 *Single-homing makes the demand for car type i dependent on the parameters of public transport and visa verca.*

[25] Whenever $\bar{x}_{32}$ is increasing or $\bar{x}_{31}$ is decreasing, the number of travelers that use public transport increases. If $\tilde{x}_{12}$ increases or $\tilde{x}_{21}$ decreases, a greater amount of people get themselves a second car.

If the demand for public transport is high, that would correspond to lower demand for cars, because the only way for public transport to capture new travelers is by business stealing. While multi-homing allows for traveler sharing, single-homing implies competition over all travelers, which makes competition tougher in the latter context. Among the means of transportation, public transport is the only one exposed exclusively to single-homers, which makes demand for public transport the most vulnerable. Circumstances that improves the relative advantage of cars could potentially harm public transport severely. This could happen if, for instance, cars came in better quality, became cheaper or got more aligned with travelers preferences. Moreover, electric cars would be relatively more beneficial if the incentives for electric cars increased. The demand for electric cars would then increase at the expense of public transport.

Proposition 2 *Multi-homing eliminates the effects of car type i's characteristics on car type j's demand.*

Car type i competes against public transport in a single-homing context and car type j in a multi-homing context. Although the demand for cars is threatened by business stealing from public transport, softer competition within the car market makes the overall demand for cars less sensitive than the demand for public transport. Travelers in the car market purchase the car they associate with the highest utility, and a second car if its incremental value is high enough. Since the demand for a second car depends on the attributes of that car, and not those of the primary car, the demand function for j is independent of the parameters of i. Improved incentives for electric cars increase the demand for this car type, but not at the expense of the demand for conventional cars.

4.2.2 Strategic Interaction

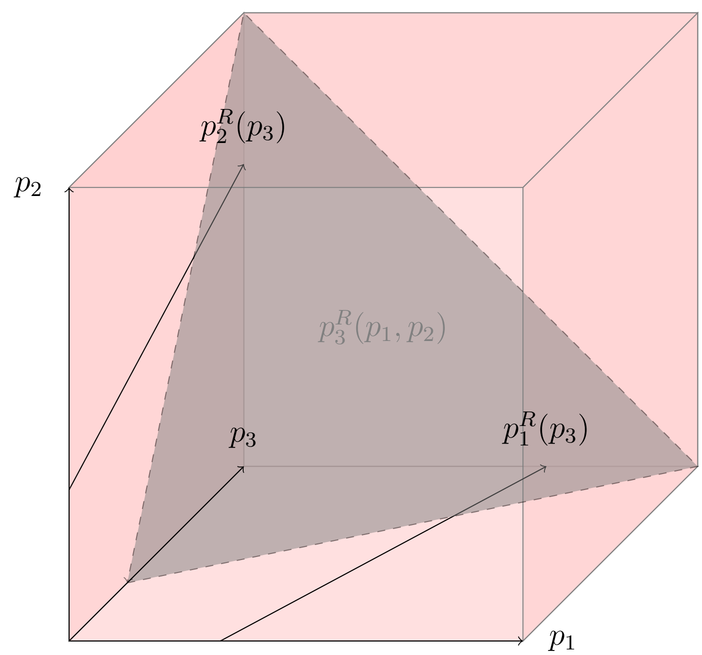
To conduct a decent competitive analysis we need to understand how the market participants respond to the actions of one another. We assume that prices are the most flexible parameters and thus the most likely to be adjusted in the short run.

An attempt to change willingness to pay, marginal costs or quantities, on the other hand, often requires costly investments or contract renegotiations. Given these considerations, price stands out as the most reasonable strategic decision variable. To find the reaction functions of the prices, we differentiate each profit function with respect to its strategic decision variable:

$$p_1^R(p_3) = \frac{t}{18} + \frac{(1+2\beta)v_1 - v_3 + p_3 + 3c_1}{6}$$

$$p_2^R(p_3) = \frac{t}{18} + \frac{(1+2\beta)v_2 - v_3 + p_3 + 3c_2 + \alpha}{6}$$

$$p_3^R(p_1, p_2) = \frac{t}{6} + \frac{2k_3 - v_1 - v_2 + p_1 + p_2 + 2c_3 - \alpha}{4}$$



Proposition 3 *Multi-homing causes strategic independence between the prices for electric cars and conventional cars. Single-homing causes strategic complementarity between the prices for car type i and public transport.*

The peculiarity of multi-purchasing, independence between the strategic decision variables, is present within the car market. A price reorientation for car type i simply adjusts the secondary demand for this car type leaving the demand, and likewise the price, for car type j unchanged. When public transport is added to the equation, the expected relation from single-purchasing emerges and reveals the strategic complementarity between prices for cars and public transport. Increased prices for public transport boost the demand for cars, as more travelers rather drive a car when cars become relatively cheaper. Because the demand for cars increases, it is optimal to increase car prices as well. The most complex reaction function accompany public transport, whose demand depends on both the price for electric cars and the price for conventional cars. Public transport's reaction function is thus a plane that spans two price dimensions.

Proposition 4 *Increased incentives for electric cars lead to higher p_2, has contradictory and net reducing effects on p_3 and do not directly affect p_2.*

Enhanced incentives for electric cars cause increased demand and higher prices for electric cars. The price increase partly shifts demand onto public transport, and the strategic reaction from the public transport sector would be to charge a higher price for public transport as well. However, the strategic effect of the incentives on p_3 is counteracted by the dominating direct effect. When additional travelers prefer to drive electric cars, the demand for public transport falls and the optimal action would be a price reduction for public transport. The demand for conventional cars is unaffected by increased incentives for electric cars and p_1 should not be changed.

4.2.3 Equilibrium Prices

$$p_1^* = \frac{12t + (17 + 46\beta)v_1 - 12v_3 - (5 - 2\beta)v_2 + 69c_1 + 3c_2 + 12c_3 - 5\alpha}{132}$$

$$p_2^* = \frac{12t + (17 + 46\beta)v_2 - 12v_3 - (5 - 2\beta)v_1 + 69c_2 + 3c_1 + 12c_3 + 17\alpha}{132}$$

$$p_3^* = \frac{28t + 60v_3 - (30 - 12\beta)v_1 - (30 - 12\beta)v_2 + 72c_3 + 18c_1 + 18c_2 - 30\alpha}{132}$$

Proposition 5 *In equilibrium, the prices of the two car types depend on the parameters of public transport, but also on each other's.*

Albeit the equilibrium price for car type i does not depend on the parameters of car type j in the pure multi-homing model, it certainly does in our partial multi-homing model. A change in the parameters of car type j alters the demand and price for public transport. Moreover, the alteration of public transport's parmeters induces changes in the demand and price of car type i. Hence, the parameters of car type j indirectly affect the demand for car type i. Thus, the equilibrium price for any mean of transportation is dependent on the parameters of all its contenders.

The price for car type i is decreasing in the travelers willingness to pay for car type j, but to what extent depends on the valuation of a second car. If $\beta = 0$, the second car has no incremental value and no one purchases two cars. Increased willingness to pay for car type j then leads to increased demand for car type j and an equivalent decrease in the demand for car type i. To recover its demand, car type i has to reduce its price. For $\beta > 0$, there exist travelers who prefer joint purchase. Increased demand for car type j then comes in addition to the demand for car type i. Because multi-homing partly absorbs the effect on the demand for car type i, the downward pressure on p_1^* is lower.

The price of car type i is increasing in its marginal cost. If c_i increases, the profit margin decreases and it becomes less imperative to provide car type i. Thus, the price will be set higher. Moreover, the price for car type i is increasing in c_j. This happens because the price for mean of transportation j is increasing in c_j, and prices are strategic complements.[26]

[26] The price for car type i increase when the price for mean of transportation j increase

If preferences become more heterogeneous, the price for car type i increases. Greater heterogeneity implies that a traveler with initial preferences for car type i gets more extreme preferences. Thus, the traveler dislikes to travel by mean of transportation j even more than before, and his demand becomes less price sensitive. On one hand, the providers of cars and public transport can charge higher prices without loosing travelers to their competitors. On the other hand, greater heterogeneity is a barrier to multi-homing as it scales down the number of travelers who find joint purchase worthwhile. While prices are increasing in heterogeneity in a pure singe-homing framework, they are unaffected by heterogeneity in a pure multi-homing framework. Thus, the overall effect of more heterogeneous preferences depends on the model specifications. Our approach is somewhere in between single-homing and multi-homing, and our model therefore predicts a modest price increase.

Proposition 6 *Enhanced incentives for electric cars increase ${p_2}^*$, reduce ${p_3}^*$ and slightly reduce ${p_1}^*$.*

Increased incentives for electric cars improve the utility that travelers get from buying this car type. The direct effect implies that demand shifts from public transport onto electric cars. When the demand for electric cars increase, the price for electric cars is set higher. Because of the complementary relation, a raise in ${p_2}^*$ leads to a strategic increase in ${p_3}^*$. Furthermore, the reduced demand for public transport causes a decrease in ${p_3}^*$. In turn, this induces strategic decreases in ${p_1}^*$ and ${p_2}^*$. In addition to the direct effects, there are indirect effects. The price decrease makes public transport behave aggressively towards conventional cars. Demand shifts from conventional cars to public transport, and ${p_1}^*$ decreases in order to retrieve demand. The strategic effect of this price drop is that public transport lower its price even further. In contrast, the price increase of electric cars has no impact on the demand for conventional cars. Because of multi-homing travelers, factors that affect the competitiveness of electric cars alter the secondary demand for electric cars rather than adjusting the demand for conventional cars. In total, ${p_3}^*$ is dominated by the direct price reducing effect, which is counteracted by the direct strategic effect and reinforced by the indirect strategic effect. ${p_2}^*$ is dominated by the price increasing direct effect, although the effect is reduced by the direct strategic effect. Finally, there are two forces putting downward pressure on ${p_1}^*$, the indirect effect and the direct strategic effect.

Proposition 7 *Multi-homing relax the price competition between the two car types. Public transport is exclusively exposed to single-homers, which makes the price of public transport the most responsive.*

An interesting result is that the price of public transport is more reactive to the increased incentives than the price of electric cars. Likewise, the price of public transport is more sensitive to changes in preference heterogeneity, willingness to pay and marginal costs. The reason is that public transport is exposed to though price competition from both electric cars and conventional cars. The car types, on the contrary, compete fiercely against public transport, but the multi-homing segment softens the price competition between the car types.

4.2.4 Equilibrium Demand

$$D_1^* = \frac{18t + (25.5 + 69\beta)v_1 - 18v_0 - (7.5 - 3\beta)v_2 - 94.5c_1 + 18c_0 + 4.5c_2 - 7.5\alpha}{132t}$$

$$D_2^* = \frac{18t + (25.5 + 69\beta)v_2 - 18v_0 - (7.5 - 3\beta)v_1 - 94.5c_2 + 18c_0 + 4.5c_1 + 25.5\alpha}{132t}$$

$$D_3^* = \frac{28t + 60v_0 - (30 - 12\beta)v_1 - (30 - 12\beta)v_2 + 60c_0 + 18c_1 + 18c_2 - 30\alpha}{132t}$$

Proposition 8 *In equilibrium, the demand for a given mean of transportation depends on the parameters of all its competitors.*

In the same manner as the equilibrium prices, the equilibrium demand for mean of transportation i is dependent on the parameters of all its competitors. The demand for mean of transportation i is increasing in the willingness to pay for mean of transportation i and decreasing in the willingness to pay for mean of transportation j. The demand is less sensitive to changes in the willingness to pay for mean of transportation j when the valuation of a second car, β, is high. The reason is that multi-homing would be more likely and business stealing scaled down.

The equilibrium demand is decreasing in c_i. Higher marginal costs decrease profit margins, $(p_i - c_i)$, and makes it less imperative to produce high quantities. Hence, it is optimal for mean of transportation i to raise its price and increase the profit margin at the expense of the sales volume. As a consequence, mean of transportation j become relatively cheaper, and the demand for j increases with a subsequent increase in p_j.

The effect of stronger preference heterogeneity on the demand for mean of transportation i depends on the initial competitive position. For instance, assume that mean of transportation i has some relative advantages that attract travelers who based on preferences alone would choose otherwise. Increased preference heterogeneity makes the demand less elastic, and additional efforts would be required to capture these travelers. Thus, demand for mean of transportation i decrease. Oppositely, more extreme preferences have positive effects on the demand for the less competitive mean of transportation j. When the demand becomes less elastic, mean of transportation j can charge a higher price with lower risk of loosing demand to mean of transportation i. On one hand, increased preference heterogeneity makes it possible to charge higher prices from the travelers, whose demand is less elastic. On the other hand, it becomes more costly to attract travelers from the rivals. In addition, more extreme preferences makes multi-homing less attractive and reduces joint demand.

Proposition 9 *Enhanced incentives for electric cars cause increased demand for electric cars, reduced demand for public transport, and a small reduction in demand for conventional cars.*

Greater incentives for electric cars increase the utility of buying them, and when electric cars become relatively more beneficial, the demand increase. A direct consequence is that the demand for public transport decreases with a subsequent price reduction. Although multi-homing eliminates the direct effect on the demand for conventional cars, the price reduction of public transport attracts some travellers from conventional cars. Thus, the demand for conventional cars decreases slightly. Whether it is optimal for electric cars to exploit the increased demand primarily by higher prices or greater quantities depends on preference heterogeneity.

Proposition 10 *Assume weak preference heterogeneity. High price elasticity of demand. Incentives for electric cars stimulate multi-homing and new demand for cars. Multi-homing limits the demand reduction for conventional cars, and the incentives are inefficient.*

For weak preference heterogeneity, preferences are less extreme and the travelers are more persuadable. Willingness to pay, prices and incentives for electric cars then matter relatively more compared to the underlying preferences. As a result, the threshold for joint purchase is lower and business stealing more feasible. Hence, the electric car providers can more effortlessly capture travelers that consider public transport and increase demand from travelers who also purchase conventional cars. However, less preference loyalty also implies that suppliers of electric cars cannot increase their prices without loosing substantial demand. Therefore, electric cars capitalize on sales volumes rather than higher profit margins for weak preference heterogeneity.[27] Because the new demand for electric cars mainly represents former users of public transport and multi-homers, increased incentives first and foremost expand the overall car population. The public transport sector experience the greatest loss of travelers, although the downward pressure on its price attracts some travelers from conventional cars.

Proposition 11 *Assume strong preference heterogeneity. Low price elasticity of*

[27] We assume that the offered quantities are quite rigid, and that the car providers thus are forced to adjust prices more than the optimal strategy suggest. This would not help shifting demand from conventional cars onto electric cars, and the conclusion of inefficiency still holds.

demand. The incentives for electric cars are not efficient. Their effects on the demand for the car types is insufficient.

Strong preference heterogeneity implies more extreme preferences and less elastic traveler demand. Thus, the demand for electric cars is less reactive to increased incentives for electric cars than it was for weak preference heterogeneity. First, travelers with underlying preferences for public transport are more reluctant to convert to cars. Second, there are fewer travelers who find multi-homing worthwhile. A characteristic of stronger preference heterogeneity is that demand decreases less for a certain price increase. Hence, when greater incentives increase the utility of buying an electric car, the providers of electric cars can price the additional utility higher. Consequently, increased incentives for electric cars affect prices more than demand. Although there exist travelers who would convert to electric cars, the effect of the incentives are to a great extent captured by higher prices. Thus, increased incentives benefit the providers of electric cars rather than shifting demand from conventional cars to electric cars. Neither in this case do the incentives efficiently obtain the policy objective.

Proposition 12 *When multi-homing occurs, the incentives for electric cars are inefficient.*

The incentives increase the demand for electric cars in addition to the demand for conventional cars and at the expense of the demand for public transport. If demand is price elastic, the incentives induce multi-homing and shift demand from public transport to electric cars. The small shift of demand from conventional cars to public transport is not sufficient to neutralize the growth in the car population, and the incentives are not efficient. If the demand is price inelastic, the prices absorb the effects of the incentives and make the car quantities less responsive. Hence, neither in this case do the incentives shift demand from conventional cars to electric cars, which implies that they are not efficient.

4.2.5 Discussion of Locations

We have assumed a symmetrical distribution of the means of transportation on the Salop circle, supposing that each mean of transportation represents a preference extreme. However, we have not analyzed whether the incentives for electric cars would induce new locations. Given the nature of the means of transportation, it would be more feasible for car type i to imitate car type j than it would be for car type i and public transport to imitate each other. Thus we concentrate this discussion around the differentiation strategies of the car types.

The emergence of hybrid cars indicates that the conventional car producers may find it optimal to differentiate less. Nevertheless, since the hybrid cars only benefit from national purchase incentives, we do not expect the local subsidies to increase demand for this car type and make it more imperative to produce hybrid cars.

The incentives for electric cars have two opposing effects on the differentiation strategy of electric cars. On one hand, the incentives increase the demand for electric cars and make it more attractive to invest in factors that increase the willingness to pay or reduce marginal costs.[28] Such investment could imply less differentiation.[29] On the other hand, the incentives might contribute to divergence. The purpose of the subsidies is to encourage people to purchase electric cars by compensating them for inconvenient features such as range limitations. The subsidies increase the demand for electric cars without imposing any costs on the car producers. If electric cars become sufficiently similar to conventional cars, the subsidies will probably be removed, which, ceteris paribus, reduce the willingness to pay for electric cars. To conclude, if the profitability of reaching more travelers through less differentiation exceeds the loss of lost subsidies, or providers of electric cars fear that the incentives will be phased out anyway, then electric cars might become more alike conventional cars. The development of battery capacity, quick charging ect. do however take time, and there is no immediate change of locations. Thus the model seems to be valid at

[28]The intuition is that many units would be exposed to the increased profit margins.
[29]For instance improved range.

least in the short run.

4.2.6 Implications of Unresponsive Public Transport Prices

As mentioned earlier, the prices of public transport services are not necessarily profit maximizing. In addition to market forces, also regulations and subsidies influence the price setting. Consequently, the prices of public transport might be less responsive than the model predicts. In this section we provide a brief discussion of how unresponsive public transport prices would affect the model's predictions.

Regardless of public transport prices, enhanced incentives for electric cars increase the demand for electric cars. As a result, the demand for public transport decrease. A profit maximizing market actor would then reduce its price to retrieve some of the demand. If the prices also serve other purposes, they might not be reduced to regain demand. In that case, the demand and prices for electric cars would be higher than the model predicts.

In our model, public transport responds with a price reduction to the increased demand for electric cars, and the reaction indirectly causes reduced demand for conventional cars. However, when the price for public transport is insensitive to shifts in demand, the indirect effect on conventional cars no longer occurs. Unresponsive public transport prices then implies that the incentives for electric cars do not affect the demand and price for conventional cars, at least less than our model predicts.

5 Empirical Analysis

In this chapter we present past research on the incentives for electric cars, as well as presenting our own empirical contribution. Based on the six most populous municipalities in Norway, we conduct a fixed effects analysis to assess the general impact of the road toll incentive. We carry out three case studies to investigate the effect of ferry subsidies, exemptions from road toll and congestion charge.

5.1 Fixed Effects Analysis of Road Toll Payments

Among the local direct subsidies, exemption from road toll payments has the greatest effect on sales of electric vehicles (Figenbaum & Kolbenstvedt, 2016). Yet, no previous research has analysed to what extent the incentive contributes to multi-homing as far as we know. In this chapter we conduct a fixed effects analysis of the effects of road toll payments on the car population and different ownership categories. The sample we study consists of the six most populous municipalities in Norway and includes data from 2008 until the end of 2015. First, we introduce the fixed effects method, the development in the vehicle fleet and the road toll variable. Further, we present the regression specifications and our analysis.

5.1.1 Fixed Effects Method

Fixed effects regression is a method to assess the net effects of the explanatory variables by controlling for time and entity invariant characteristics. The method is appropriate when the objective is to analyse the impact of a variable that is changing over time and the observations belong to a panel data set.[30] When using FE one assumes that each entity has its own time-invariant characteristics that are correlated with the explanatory variables of interest. Since the time-invariant characteristics may bias the coefficients of the explanatory variables, they need to be controlled for.

[30] Panel data implies that the data set contains observations of different entities, in this case municipalities, across time.

5.1.2 Vehicle Fleet Development

Table 5.1.1: Summary statistics: Passenger vehicles for 2008-2015 over municipalities.

Muncipality	Mean	Std.Dev.	Max	Min
Oslo	364033.1	4703.443	372408	357763
Bergen	245057.9	11142.13	262867	229925
Trondheim	135407.5	8646.013	146823	122577
Stavanger	77701.13	6122.484	85139	69094
Bærum	88674.38	10806.1	102515	74091
Kristiansand	46657.63	2927.682	50524	42256
Total	159588.6	112617.6	372408	42256

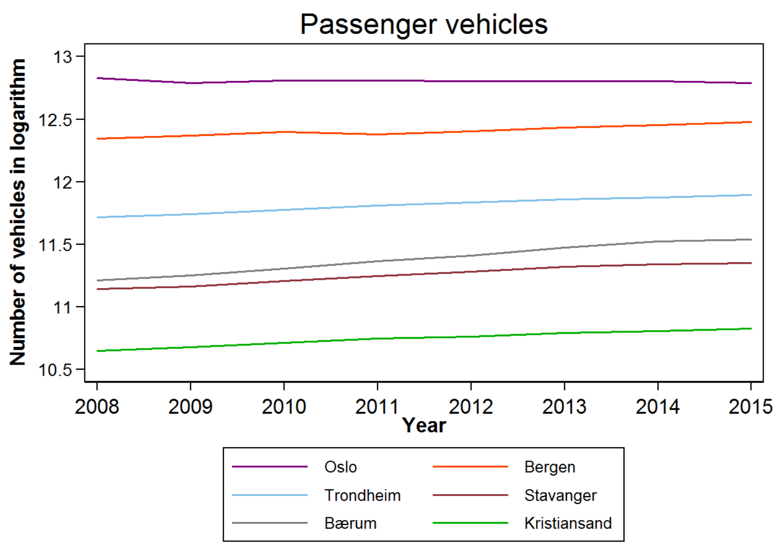


Figure 5.1.1: Total number of electric vehicles over municipalities.

Figure 5.1.1, shows that the vehicle fleet has increased steadily since 2008. Only Oslo shows indications of a decrease, although the municipality still has the highest level of cars. To identify how the composition of the vehicle fleet has developed, we take a look at the population of electric cars.

Table 5.1.2: Summary statistics: Electric vehicles for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	3384	4460.34	12515	220
Bergen	2795	4128.649	11576	165
Trondheim	1161.75	1582.618	4389	54
Stavanger	687.625	971.7682	2704	30
Bærum	1199.375	1457.45	4276	169
Kristiansand	526.375	752.4271	2112	23
Total	1625.688	2756.474	12515	23

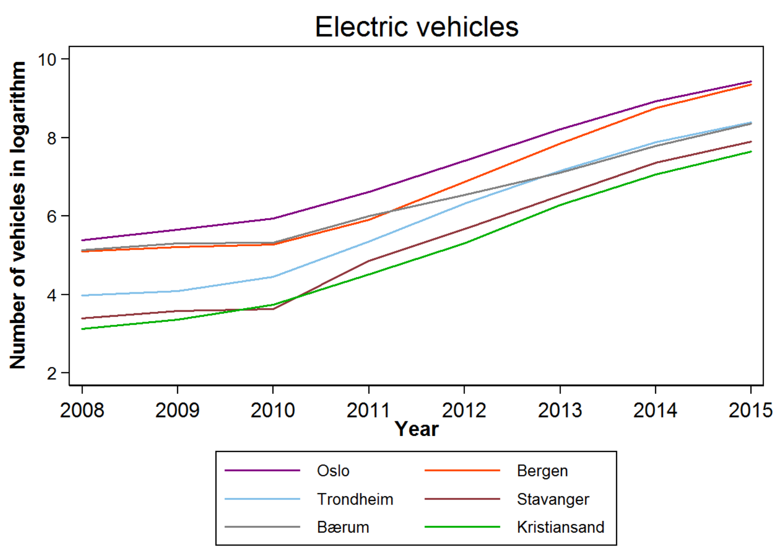


Figure 5.1.2: Total number of electric vehicles over municipalities.

Figure 5.1.2 illustrates that the number of electric vehicles increased slightly from 2008 to 2010. Around 2010 the curves of the electric car populations have kinks and then continue with higher growth rates. On average, there are most electric cars in

Oslo and Bergen. In Trondheim and Bærum the numbers are almost half the size, and the numbers are lowest in Stavanger and Kristiansand.

5.1.3 Road Toll Fees

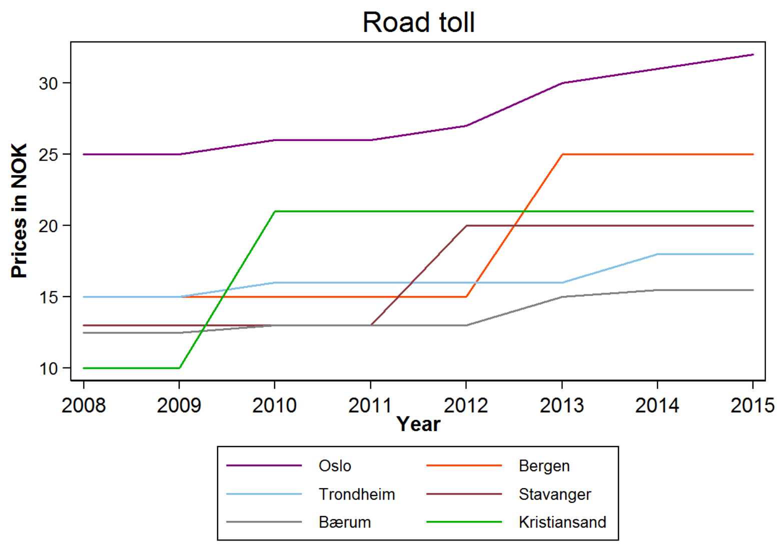


Figure 5.1.3: Road toll prices over municipalities.

The purpose of road toll payments is to achieve faster development of the road infrastructure. Furthermore, road toll might be applied to other areas, for instance, as a tool to strengthen public transport in urban areas. The road toll prices thus depend on a given municipality's scope of road projects and transport politics among other influential factors. Since road toll payments serve local purposes, the price setting is entrusted local authorities. This is why the figure shows that the road toll price in one municipality may differ from the road toll price in another. Figure 5.1.3 shows the development of road toll prices in the municipalities we included in our sample. Obviously, the road toll prices have evolved differently across the municipalities. Oslo displays the highest price level during the entire period, Bærum has the lowest average price, and Bergen is exposed to the greatest volatility. Although the prices across entities might be on different levels, they have increasing trends in common.

Hence, the road toll price variable is changing over time and between entities. The fact that we have panel data and that we are interested in a dynamic variable make FE seem appropriate.

5.1.4 The Regression Model

$$lnY_{mt} = \alpha + \beta_1 R_{mt} + \beta_1 X1_{mt} + \cdots + \beta_k Xk_{mt} + \lambda_2 M_2 + \cdots + \lambda_6 M_6 + \delta_2 T_2 + \cdots + \delta_6 T_6$$

Where Y represents the car population variables and the ownership variables that we want to explain.[31]. R_{mt} represents the road toll price in municipality m in year t, and β_1 is the road toll coefficient. λ_2 to λ_6 are dummies that control for observed and unobserved time invariant characteristics of the municipalities. For instance, we do expect that road toll prices are correlated with some geographical factors. Because it is challenging to build infrastructure in areas with uneven terrain or densely build-up areas, projects will be more expensive in municipalities with such characteristics, and if the projects are financed by road toll we believe that the prices will be set higher. If the time invariant characteristics are not controlled for, the regression could be biased. δ_2 to δ_6 are time dummies that control for entity invariant characteristics. In other words, we control for unexpected variation or special events that may affect Y. Examples of such events, that are common for all the municipalities, could be range improvements, changes in the national incentives for electric cars, or new car models.

Moreover, we included the following $X1$ to Xk control variables that we found relevant:

[31] Y is log-transformed because the absolute values differs quite much from one municipality to another, which could lead to one particular municipality driving the results.

Table 5.1.3: Summary statistics: Toll stations for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	22	0	22	22
Bergen	14	0	14	14
Trondheim	10	9.319718	24	0
Stavanger	3	0	3	3
Bærum	7	0	7	7
Kristiansand	5	0	5	5
Total	10.16667	7.366784	24	0

We assume that road toll prices are correlated with the number of toll stations. If there are more toll stations, the road toll payments are probably collected more frequently and the price at each station can be set lower.[32]

Table 5.1.4: Summary statistics: Population for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	605179.9	30078.83	647676	560484
Bergen	261945.3	9586.412	275112	247746
Trondheim	175113.1	6896.327	184960	165191
Stavanger	126327.5	4415.263	132102	119586
Bærum	113972.5	4443.694	120685	108144
Kristiansand	82983.13	2907.804	87446	78919
Total	227586.9	180560.7	647676	78919

It seems reasonable to assume that a larger population implies increased demand for cars. The population size could be correlated with road toll prices for at least two reasons. First, when the population in a municipality grows, the need for more extensive infrastructure increase. If new projects are financed by road toll payments,

[32]Except for in Trondheim, toll stations do not vary at all and we did not observe any substantial differences by including this variable.

the road toll price might increases. Second, a larger population may, on the contrary, decrease road toll prices. When a greater number of people contributes to the road toll payments, the price per passage could be set lower. It is therefore unclear whether the population size in total causes the effect of road toll to be under- or overestimated.

Table 5.1.5: Summary statistics: Education level for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	43.575	2.898645	48.4	40.3
Bergen	36.125	2.355995	40	33.3
Trondheim	37.9	2.55231	41.9	34.7
Stavanger	37.5375	2.766089	41.7	34.1
Bærum	46.9875	2.298719	50.8	44.4
Kristiansand	31.6125	2.003167	34.9	29.3
Total	38.95625	5.590985	50.8	29.3

The variable for education shows the share of inhabitants over 16 years old with higher education. Surveys show that people with more education have a greater tendency to buy electric cars than people without high education (Figenbaum & Kolbenstvedt, 2016). We suspect that education may be correlated with road toll prices if decision makers perceive high education and high income as synonyms. When the inhabitants have high education and high purchasing power, the threshold for imposing road financing on the inhabitants could be lower. On the other hand, more educated people often live the city centers because they work nearby and can afford urban house prices. In cities with sufficient public transport services, the need for cars is less evident. The assumption of positive correlation between education and road toll price do not hold if a high share of more educated people implies that there are fewer cars, and moreover, that high income individuals are less exposed to road toll.

Table 5.1.6: Summary statistics: Unemployment for 2008-2015 over municipalities.

Municipality	Mean	Std.Dev.	Max	Min
Oslo	3.1625	.4274091	3.6	2.2
Bergen	2.3375	.3997767	3	1.7
Trondheim	2.55	.3070598	3	2.2
Stavanger	2.1	.9942693	4.4	1.1
Bærum	1.825	.3991061	2.2	.9
Kristiansand	3.0125	.5743008	3.8	1.8
Total	2.497917	.7171129	4.4	.9

While one might expect unemployment and education to be negatively correlated, data from SSB challenge this assumption and shows that unemployment increased most among highly educated people in 2014.[33] Hence, we included both variables. The economic uncertainty and lack of income make it plausible that demand for cars decreases in unemployment. It is not obvious that unemployment are correlated with road toll prices, but we can think of a couple of reasons to why it could be possible. Unemployment sends signals about the business cycle to the decision makers. If unemployment increases, it is an indication of low conjuncture. On one hand, this might prevent increased road toll prices to avoid imposing additional costs on the inhabitants. On the other hand, the government might initiate infrastructure projects when the conjuncture is low to stimulate the economic activity. This could increase the road toll prices.

5.1.5 Analysis of The Car Population

In this section we analyze how road toll affect the car population. The result from the regression model we specified in the previous section is presented below.

[33] The low oil price did, for instance, force firms in the petroleum industry to lay off many highly educated people in Rogaland.

Table 5.1.7: Regressions of number of cars with fixed municipalities, fixed years and control for other variables.

	(1) Total	(2) Total EV	(3) Total CV
Fixed time effects	✓	✓	✓
Fixed entity effects	✓	✓	✓
Control variables	✓	✓	✓
Road toll	-0.00584**	0.0390**	-0.00587**
	(0.00248)	(0.0153)	(0.00249)
R^2	0.999	0.991	0.999

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The regression results show that the total number of electric vehicles significantly increase when the road toll prices increase. More specifically, when the road toll price increase by 1 Norwegian Krone, the regression model estimates that the number of electric cars increases by 3.90% in that municipality. In Oslo, for instance, that would correspond to 488 electric cars in 2015.

We can calculate how many conventional cars that must be replaced to compensate for an increase of 488 electric cars. The CO2-emissions related to car production were estimated to 85 CO2 g/km for electric cars and 43 CO2 g/km for conventional cars. Furthermore, the lifetime of a car is assumed to be 150 000 km (Hawkins et al., 2013). According to Figenbaum and Kolbenstvedt (2016) electric cars is driven 15 500 km per year, while conventional cars are driven 500 km less. In years, the lifetimes of electric cars and conventional cars are then 9.67 years and 10 years respectively. Thus, electric cars are replaced slightly more frequently than conventional cars, which must be accounted for in the calculations. From the data set we find that the average CO2-emissions in the use phase are 0 g/km for electric cars, 119 g/km for cars using petrol fuel, 132 g/km for cars using diesel fuel and 87 g/km for hybrid cars. Weighing the CO2-emissions of conventional cars based on market shares gives an average of 120.6 g/km. To offset the pollution from the production of the electric cars, the number of conventional cars has to decrease by at least 268.[34] The road toll coefficient for the number of conventional cars suggests that 1 NOK increase in road toll prices on average cause 0.586% reduction of conventional cars in Oslo. That would correspond to 2025 cars in 2015. If the number of conventional cars actually do decrease by 268 and the number of electric cars increases by 488, a net increase of 220 electric cars would make the environment equally well off. The road toll coefficient for the total number of cars suggests 0.583% reduction, which equals 2087 cars.

We can do the same calculation for a future point in time when the electric vehicle fleet has exceeded 1.5 millions. Using the Co2-estimates and car features of Völler et al. (2014), we find that 488 more electric cars requires 494 fewer conventional cars to offset the CO2-emissions.[35] Thus, the incentive is less efficient the more electric cars there are. Many factors can, however, improve the outcome of the calculation. Battery manufacturers may find more climate friendly ways to produce batteries, which would reduce the CO2-emissions from the production phase of electric cars. Longer lifetimes of electric cars would reduce the average annual CO2-emissions, as the production pollutions are spread out over a longer period of time. Furthermore, Norway and other European countries may invest in higher capacity of renewable energy sources, reducing the fossil energy compensation of electricity used by electric cars.

To sum up, if a municipality government increases its road toll prices, the regression suggest that the number of electric cars increases and that the number of

[34] CO2 emissons and market shares are based on 2015 numbers. See Appendix chapter E.2.
[35] Assuming that the conventional car mix of diesel, petrol and hybrid cars remain the same.

conventional cars decreases. Hence, in the short run, the regression model do reject the hypothesis that the road toll incentive leads to an increased overall car population.[36]

5.1.6 Analysis of Owner Structures

Table 5.1.8: Summary statistics: Owners with one electric vehicle for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	475.625	451.8505	1241	93
Bergen	363.625	407.3033	1112	53
Trondheim	174.125	185.5405	502	23
Stavanger	92.375	98.68121	259	11
Bærum	142.875	126.5221	335	25
Kristiansand	63.5	71.16179	189	4
Total	218.6875	296.2697	1241	4

[36] On a 10% significance level.

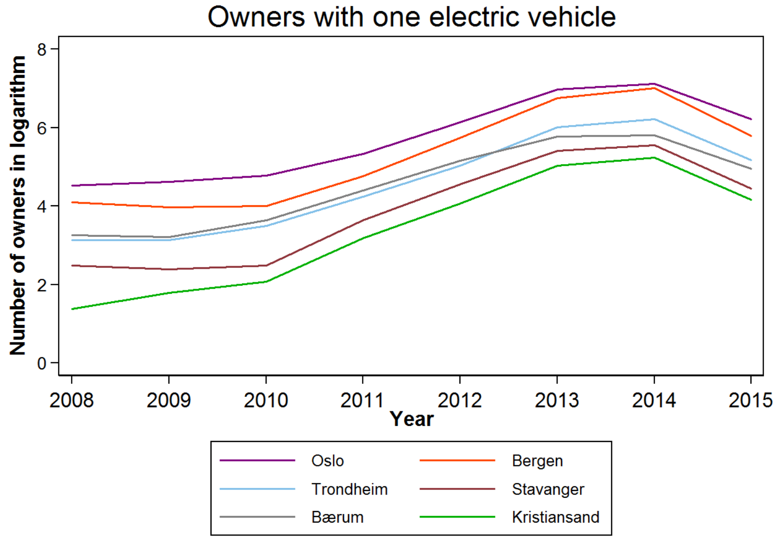


Figure 5.1.4: Owners with one electric vehicle over municipalities in logarithm.

The growth rates for the numbers of owners with one electric car were highest from 2010 until 2013. The growth levels off during 2013, and from 2014 the number of owners with one electric car decreases. However, from the previous section we know that the total amount of electric cars increases in 2014, which implies that the number of multi-homers must increase.

Table 5.1.9: Summary statistics: Owners with one conventional car for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	187950.9	25614.48	221960	147493
Bergen	136148.5	4844.642	143279	128720
Trondheim	76042.75	2735.08	79938	71535
Stavanger	42357.13	1869.189	44937	39137
Bærum	31495.75	872.8102	32663	30255
Kristiansand	25440.13	866.1756	26668	24103
Total	83239.19	296.2697	1241	4

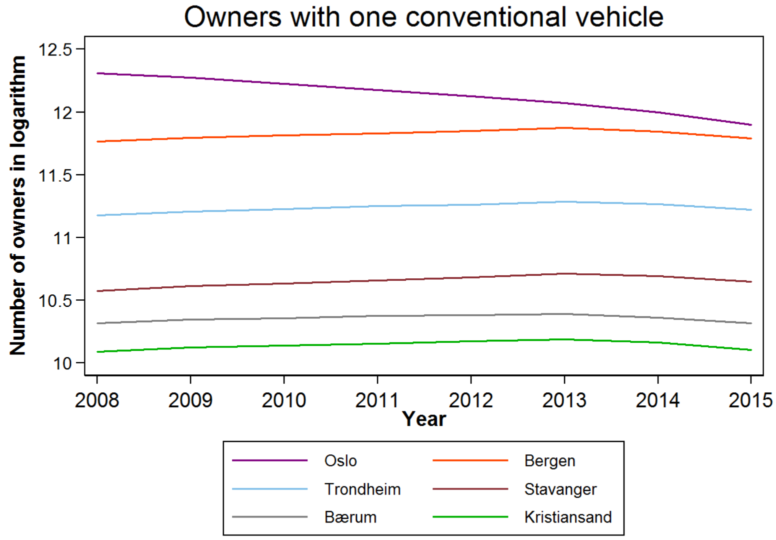


Figure 5.1.5: Owners with one conventional car vehicle over municipalities in logarithm.

In Oslo, the number of owners with one conventional car decreases the entire period. In the other municipalities, the numbers are more stable, but is possible to spot a weak growth from 2008 until 2013 with a subsequent decrease until 2015.

Table 5.1.10: Summary statistics: Owners with one conventional and one electric vehicle for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	839	1084.773	2985	63
Bergen	1009.625	1464.606	4037	68
Trondheim	414.375	564.394	1531	12
Stavanger	240.5	331.9858	909	6
Bærum	335.375	401.3886	1101	27
Kristiansand	186.625	269.3601	744	8
Total	504.25	831.3748	4037	6

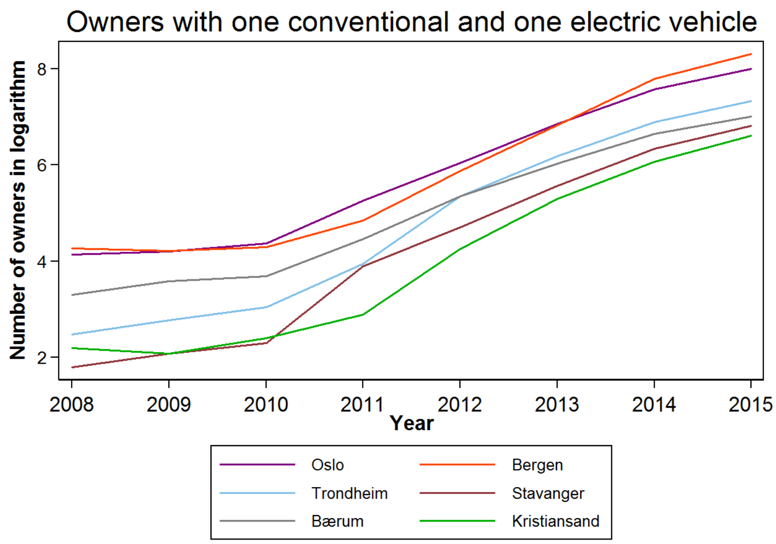


Figure 5.1.6: Owners with one conventional and one electric vehicle over municipalities in logarithm.

While the number of multi-homers with one conventional car and one electric increased just a little from 2008 to 2010, the growth rates increased around 2010 and have remained high since. The number of multi-homers in Bergen surpasses the number in Oslo around 2013, which is interesting considering that Bergen is a smaller municipality.

Table 5.1.11: Summary statistics: Owners with one/two conventional and one electric vehicle for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	995.625	1136.055	3057	105
Bergen	1163.875	1521.51	4094	95
Trondheim	497.5	601.9578	1589	25
Stavanger	282.875	351.9105	928	12
Bærum	402	425.0381	1141	45
Kristiansand	222.625	284.2117	761	13
Total	594.0833	882.5534	4094	12

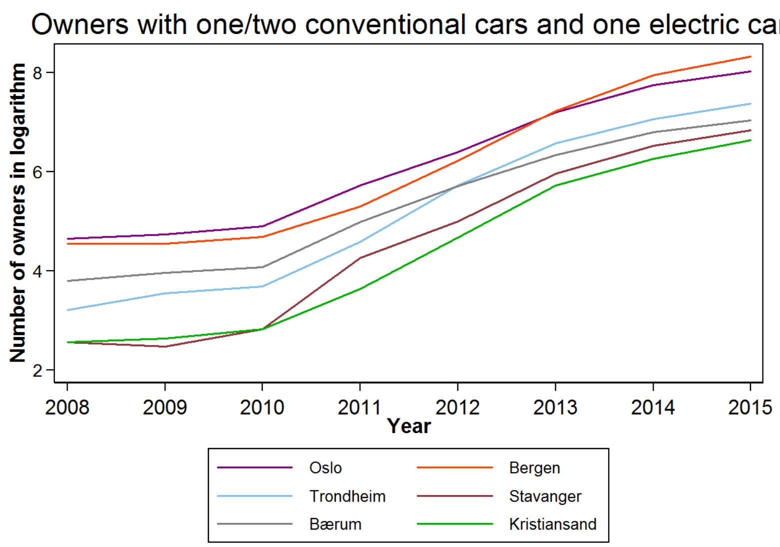


Figure 5.1.7: Owners with one/two conventional and one electric vehicle over municipalities in logarithm.

Figure 5.1.7 shows the number of multi-homers with one electric car and one or two conventional cars. The figure look pretty much like the figure 5.1.6 and by comparing the summary statistics we see that there exist people with three cars or more.

Table 5.1.12: Summary statistics: Owners with two conventional vehicles for 2008-2015 over municipalities.

Municipality	**Mean**	**Std.Dev.**	**Max**	**Min**
Oslo	33953.75	3685.828	38354	27218
Bergen	36829.38	2210.483	39336	33686
Trondheim	20516.5	1073.804	21919	18902
Stavanger	11436.88	823.387	12513	10246
Bærum	8621.875	424.5766	9143	8075
Kristiansand	7100.625	330.8102	7452	6667
Total	19743.17	12134.05	39336	6667

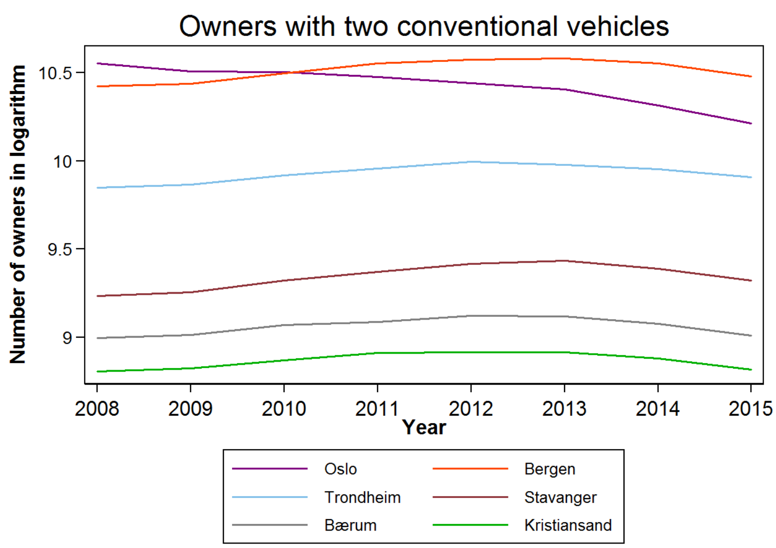


Figure 5.1.8: Owners with two conventional vehicles over municipalities in logarithm.

While it seems to be less and less common to have two conventional cars in Oslo, this trend only accounts for the other municipalities from around 2013, and to a lesser extent. In total, the figures and summary statistics show that the last couple of years the number of multi-homers with both car types has increased, while the number of owners with exclusively conventional cars has decreased.

Table 5.1.13: Regressions of ownership with fixed municipalities, fixed years and control for other variables.

	(1) OneEV	(2) OneCV	(3) CV+EV	(4) MCV+1EV	(5) 2CV
Fixed time effects	✓	✓	✓	✓	✓
Fixed entity effects	✓	✓	✓	✓	✓
Control variables	✓	✓	✓	✓	✓
Road toll	0.0324***	-0.00342	-0.00179	0.00827	-0.00256
	(0.0116)	(0.00205)	(0.0178)	(0.0141)	(0.00203)
R^2	0.992	0.999	0.988	0.991	0.999

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In accordance with our theoretical model, the regressions of car owners suggest that higher road toll prices increase the number of single-homers with one electric car by 3.24%. The coefficient for the number of multi-homers with one electric car and one conventional car shows 0.179% decrease, but if we look at the extended segment of owners with one or two conventional cars and one electric car, the number of multi-homers seems to increase by 0.827%. Since the highest percentage also applies to the largest owner group, the coefficients suggest that the number of multi-homers will increase, although insignificance bring uncertainty to the effects. The coefficients for conventional car owners suggest that there will be fewer owners of one and two conventional cars, although the coefficient for owners of two conventional cars is insignificant. However, we do not know whether the majority replace one conventional car with an electric car or if they buy an electric car in addition. Our model supports the latter explanation, but the ambiguous multi-homing coefficients and the significant increase in one EV might as well illustrate the first explanation. Neither do we know whether the new electric car owners are former users of public transport, which our model claims, or if they are people who replaced their conventional car with an electric car. Even though the percentage change is lower for owners of one conventional car than for owners of one electric car and owners of both car types, the absolute change is probably much higher for owners of one conventional car because of the huge size of this owner category.

If we consider Oslo once more, the percentage changes imply that there will be 25 more multi-homers with one electric car and one or two conventional cars. In addition, there will be 16 new single-homing electric cars owners. Reversing the calculations from the previous section, we find that in order to justify the environmental effect of 41 electric cars, 23 conventional car owners must substitute one conventional car for an electric one. According to the face value of the coefficients, there will on average be 504 fewer car owners with one conventional car and 70 fewer owners of two conventional cars. Hence, it seems like the reduction of conventional cars is sufficient, although some of these people keep their conventional cars and buy supplementary electric cars. According to Minken (2005), increased road toll prices shift demand from conventional cars to public transport, which would be in line with our models predictions. Nevertheless, we can not empirically investigate what happens in the public transport sector with our data set. The reduction of conventional cars should be sufficient to reduce CO2-emissions, at least in the short run. In the future based example from the previous section, we saw that a given increase of electric cars requires an almost equivalent decrease of conventional cars. Thus, unless battery production becomes more climate friendly or the capacity of renewable energy sources increase, just a few multi-homers may cause negative environmental effects when the electric vehicle fleet exceeds 1.5 million cars.

5.2 Case Analysis

5.2.1 Econometric Method

To analyse specific cases of local incentives we use a difference-in-differences (DiD) method. The aim is to identify the causal effect of policy interventions on various vehicle and ownership structures. We will use the setup to measure the causal effect of ferry fares, toll stations and congestion charge. The setup, in its simplest form, requires one treatment, one control group and two periods; before and after the intervention (Angrist & Pischke, 2009). In an ideal research situation we would be able to observe the counterfactual outcome of the treatment group. However, considering it is unobservable, we will introduce control groups with similar attributes as the treatment groups and we assume that they have equal trends in the absence of any treatments. As a result of the policy intervention the setup assumes deviation from the common trend, as illustrated in figure 5.2.1. Hence, the difference between the treatment group and the counterfactual treatment group is the causal effect we are interested in. We will utilize this method to compare cities or local areas where a policy change occurs with similar cities or local areas where there is no change.

As mentioned, the strict parallel trend assumption for DiD has to hold. This is a strong assumption, as there are various policy interventions that have taken place at different times and places that might affect the outcome variables of interest. The common pre-treatment trend can be investigated by looking at historical data, while other factors that might affect the outcome variables for either of the groups must be investigated.

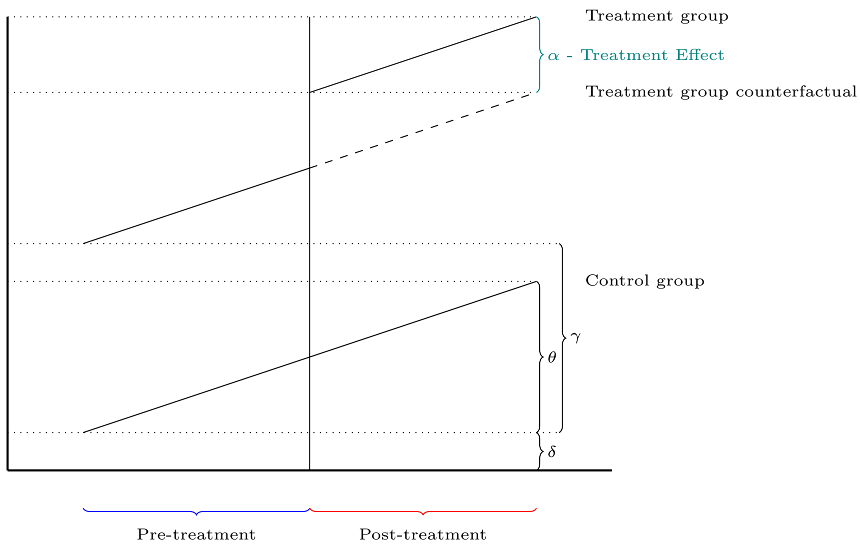


Figure 5.2.1: Difference-in-Differences.

In particular, we estimate:

$$lnY_{ict} = \delta + \gamma A_s + \theta Post_t + \alpha(A_s Post_t) + \epsilon_{ist} \tag{1}$$

Where lnY is the outcome variable, which is related to different ownership structures and vehicle types. By looking at three locations with different vehicle fleet sizes the most interesting interpretations stem from percentage changes over absolute changes. We therefore utilize an approximation by log transforming the outcome variables. The average pre-treatment effect in the control group is represented by δ. The indicator A_s is a dummy that switches on if the area is treated and γ is the average pre-treatment effect in treatment group relative to the control group, implying that if we add δ to γ we get the average pre-treatment effect for the treated area, as illustrated in figure 5.2.1. Similarly, $Post_t$ is a dummy for post treatment periods and θ is the average post-treatment effect for the control group. Moreover, given that the strict parallel trend assumption is satisfied, adding θ to δ and γ will give the average outcome for the counterfactual treatment group after the intervention. The interaction term $A_s Post_t$ denotes the treated city and the control group after the intervention. The average treatment effect we are interested in is the difference between the average outcome for the counterfactual treatment group and the treatment group, and is denoted with α.

5.2.2 Case 1: Ferry Fares in Fosen

When the government decided to give electric vehicles free admission to national road ferries in 2009, several county municipalities began to practice this payment exemption on county road ferries as well. Since then, the number of electric vehicles on the ferries has escalated. The costs these free riders impose on the ferry companies has made some county municipalities get second thoughts about the policy. A supporting argument is that conventional cars do not have higher emissions than electric cars on the ferries, as the engines are switched off. Sør-Trøndelag county municipality abolished the ferry payment exemption on the first of June 2014, similarly Rogaland county municipality introduced a reduced fare for electric cars in June 2016. Given that the free ferry admission encouraged people to buy electric cars, one would expect diminishing growth in the sales and people selling their electric cars when the subsidies were removed.

Fosen is a peninsula in Trøndelag, and the place of residence for several people commuting to Trondheim. The commuters located close to the mainland travel most easily by car or public transport, and those who live at the south-west part can access a coastal express to Trondheim. For our purpose, however, the most interesting commuters are the residents on the south-east part of Fosen. From here, the ferry takes you to Trondheim three times faster than driving on the mainland.[37] Thus, most commuters in this area use the ferry. Similarly, from Ryfylke in Rogaland a great proportion of the workforce commutes to Stavanger. The ferry is the fastest and thus the most common mean of transportation.

In the following, we present a case study of the free ferry incentives based on a DiD analysis of Ryfylket and Fosen. First, we check whether the two districts are

[37] According to Google maps it takes approximately three hours to drive from Rørvik Ferry Quay to Trondheim and one hour with a combination of ferry and driving.

appropriate candidates for the DiD model. We then proceed with regressions and interpretations of the results. When we conduct our analysis we consider the time interval that begins one year before the policy intervention and ends one year after.

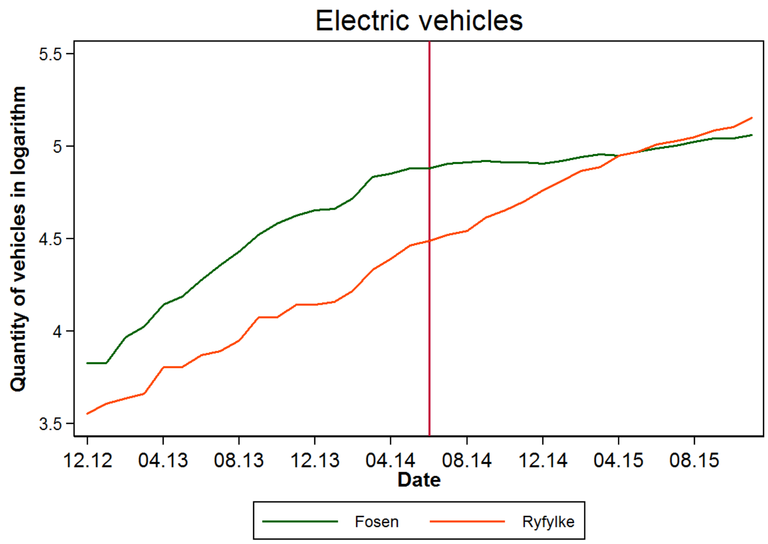


Figure 5.2.2: Total number of electric vehicles in Fosen & Ryfylke in logarithm.

From 2009, when the decision of free ferry admission for electric vehicles was made, the populations of electric cars share increasing and parallel trends in Ryfylket and Fosen. Moreover, the trends separate in June 2014, when Sør-Trøndelag Municipality withdrew the incentive for the ferry between Fosen and Trondheim. Just before the withdrawal, we see a small decrease in the growth rate of electric vehicles in Fosen, this is probably because the policy change became public knowledge in late April 2014. The immediate growth reduction is most likely due to travelers who were considering to buy an electric car but decided not to do so when the ferry fare increased the user cost of eletric vehicles. In addition, a lagged reduction in the growth probably occurs as the owners of electric cars who wants to sell their car have had enough time to sell them. While the number of electric cars in Ryfylke has grown steadily the entire period, Fosen has experienced a diminishing growth since the incentive were removed. As a result, Ryfylke is surpassing Fosen in total electric vehicles one year after the withdrawal of free ferry admission.

Table 5.2.1: Estimates from regressions of passenger car types in logarithm.

	(1) Total cars	(2) Total EVs	(3) Total CVs
Dummy Fosen	-0.21***	0.48***	-0.22***
	(0.0032)	(0.054)	(0.0029)
Post treatment	0.018***	0.30***	0.015***
	(0.0032)	(0.054)	(0.0029)
Treatment effect Fosen	-0.0040	-0.16*	-0.0033
	(0.0045)	(0.076)	(0.0042)
Intercept	8.79***	4.29***	8.78***
	(0.0023)	(0.038)	(0.0021)
N	24	24	24
R^2	0.998	0.882	0.998

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The regression estimates show that the total number of electric vehicles in Fosen were reduced with approximately 16% as a result of the policy implication. This implies a reduction of eight electric vehicles. In November 2014, the last period included in the analysis, there were 136 electric vehicles in Fosen and 5267 conventional vehicles, which implies that their market shares were 2.5% and 97.5% respectively. The treatment coefficient for the total number of vehicles indicates a negative, but insignificant effect.

Table 5.2.2: Estimates from regressions of owner structures in logarithm.

	(1) CV	(2) EV	(3) CV+EV	(4) 2CV	(5) 1or2CV+1EV
Dummy Fosen	-0.27***	0.72***	0.47***	-0.20***	0.24***
	(0.0019)	(0.065)	(0.047)	(0.0093)	(0.046)
Post treatment	0.0059**	0.36***	0.31***	0.041***	0.25***
	(0.0019)	(0.065)	(0.047)	(0.0093)	(0.046)
Treatment effect Fosen	-0.0081**	-0.23*	-0.21**	0.015	-0.12
	(0.0027)	(0.092)	(0.067)	(0.013)	(0.065)
Intercept	8.36***	3.19***	3.49***	6.78***	3.86***
	(0.0014)	(0.046)	(0.033)	(0.0066)	(0.032)
N	24	24	24	24	24
R^2	0.999	0.913	0.894	0.978	0.777

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The withdrawal of the ferry incentives has a negative and statistically significant effect on both single- and multi-homers holding electric cars. Our estimates show a 23% reduction of owners with only one electric vehicle and 21% reduction in the number of multi-homers, which is equivalent to a reduction of three single-homers and six multi-homers. These effects are in accordance with figures F.4 and 5.2.3, which show that the quantity of single- and multi-homers flattens out after the intervention in Fosen. Intuitively, the immediate policy implication is lowest for owners already possessing a electric vehicle and highest for those considering to acquire one. The reason is that one can more effortlessly change a purchase decision than one can sell a car. Surprisingly, the number of single-homers holding one conventional vehicle also experiences a statistically significant decrease, although the effect is below 1% and economically insignificant. The significance could be a result of the parallel trend assumption not being satisfied for this group of owners. Figure F.6 shows that trends for the treatment and control group are diverging before the intervention. Moreover, the curves for owners holding one conventional vehicle shows no kink, implying that single-homers who give up their electric vehicle do not seem to substitute it for a conventional car. The coefficient for the number of owners holding two conventional vehicles indicates an increased amount of this owner type, but the result is insignificant. Even though the effect is statistically insignificant, the graph shows a positive effect (figure F.7), this might be a result of potential multi-homers choosing two conventional vehicles instead of one of each type due the removal of the ferry incentives.

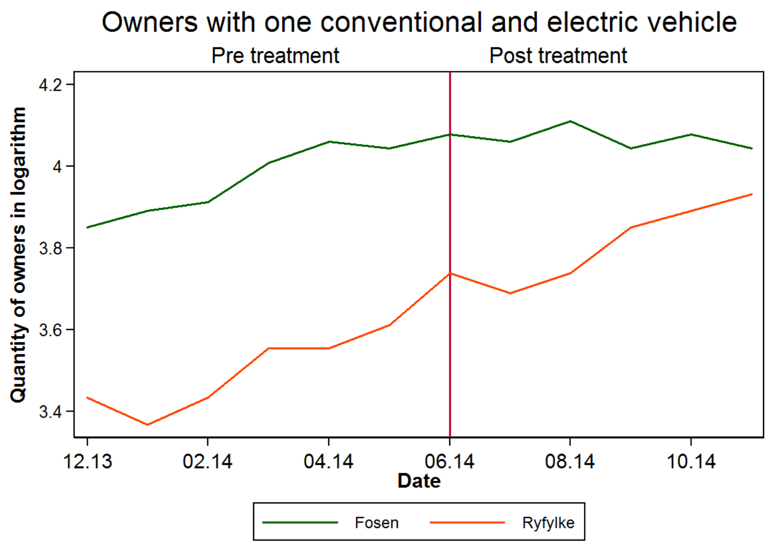


Figure 5.2.3: Owners with one conventional and one electric vehicle in Fosen & Ryfylke in logarithm.

5.2.3 Case 2: Road Toll Payments on Askøy

The circumstances in our second case resembles the situation in case 1, where commuters were connected to their workplaces through ferries. There are, however, three main differences. Firstly, in this case we consider commuters who have to cross a bridge rather than taking a Ferry. More specifically, we look at Sotra and Askøy, two islands with bridges connecting them to Bergen. Secondly, we look at a situation where one of the islands, Askøy, introduced toll stations and thus provided an indirect incentive for electric cars, but affecting conventional cars more directly. Toll stations are usually introduced to finance road projects. Askøypakken, which includes seven road projects and improved public transport services on Askøy, is a good example of such road toll financing. Compared with the Fosen case we expect to see the opposite effects of what we saw in the first case. We also expect stronger effects on variables related to conventional vehicles, as road toll directly makes these cars more expensice to drive. Finally, while the announcement and the introduction of the policy change in Fosen happened almost simultaneously, inhabitants of Askøy anticipated the toll stations before the introduction and had time to adapt to the change.

Because travelers from the two islands are exposed to the same conditions once they have crossed their respective bridges, only island-specific factors distinguish the Askøy-Bergen journey from the Sotra-Bergen journey. We expect that both islands share similar attributes and are exposed to identical effects of other interventions that take place in Bergen, which in turn satisfy the DiD parallel trend assumption and make Sotra a suitable control group. We thus assume that any divergence in trend is caused by the intervention in Askøy.

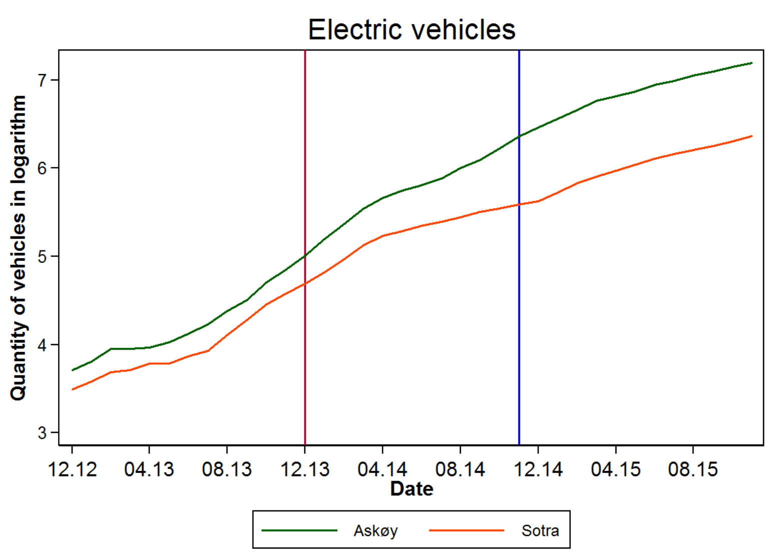


Figure 5.2.4: Total number of electric vehicles in Askøy & Sotra in logarithm.

Before the toll stations on Askøy were operative, travelers from Sotra and Askøy were exposed only to common road toll payments in Bergen. Figure 5.2.4 confirm the expected parallel trends, which last until end of 2013, when the Norwegian Parliament approved the introduction of toll stations on Askøy. Because electric vehicles have been exempted from such payments since 1997, road toll reduce the user costs of electric cars relative to conventional cars, and encourage travelers to buy the electric type. After the announcement, the number of electric vehicles grew faster on Askøy relative to on Sotra. We expect that some people prepared for the change, and shifted their car park on beforehand. Thus, we assume that the increased growth in Askøy is due to the announcement, and we use the announcement date to define the occurrence of the treatment. We find it appropriate to include 12 months before and after the announcement in the analysis.[38]

Table 5.2.3: Estimates from regressions of passenger car types in logarithm.

	(1) All vehicles	(2) Total EVs	(3) Total CVs
Dummy Askøy	0.12***	0.25	0.12***
	(0.0047)	(0.14)	(0.0036)
Post treatment	0.032***	1.31***	0.019***
	(0.0047)	(0.14)	(0.0036)
Treatment effect Askøy	-0.0063	0.25	-0.015**
	(0.0066)	(0.20)	(0.0052)
Intercept	9.28***	3.94***	9.27***
	(0.0033)	(0.10)	(0.0026)
N	48	48	48
R^2	0.970	0.828	0.979

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Even though the graphical illustration (G.2) shows an increase in the total number of electric vehicles due to the announcement, our regression result indicates that

[38] The toll stations were operational 11 months after the announcement.

the increase is statistically insignificant.[39] Figure G.3 shows that the total number of conventional vehicles grew steadily in Sotra, while Askøy experienced a drop after the announcement, this is reflected in our estimation where we see a significant reduction on 1.5%, which is equivalent to a reduction of 33 conventional vehicles. In November 2014 there were in total 12 579 vehicles in Askøy, more specifically, 577 electric cars and 12 002 conventional cars. The maket shares for electric and convetnional cars were 4.6% and 95.4% respectively.

Table 5.2.4: Estimates from regressions of private vehicle types and multi-homers in logarithm.

	(1)	(2)	(3)	(4)	(5)
	CV	EV	CV+EV	2CV	1or2CV+1EV
Dummy Askøy	0.16^{***}	0.43^{**}	-0.070	0.081^{***}	0.11
	(0.0024)	(0.14)	(0.17)	(0.0074)	(0.16)
Post treatment	0.016^{***}	1.36^{***}	1.20^{***}	-0.0021	1.27^{***}
	(0.0024)	(0.14)	(0.17)	(0.0074)	(0.16)
Treatment effect Askøy	-0.0099^{**}	0.12	0.53^{*}	-0.024^{*}	0.35
	(0.0034)	(0.20)	(0.24)	(0.010)	(0.23)
Intercept	8.81^{***}	3.01^{***}	3.26^{***}	7.33^{***}	3.39^{***}
	(0.0017)	(0.098)	(0.12)	(0.0052)	(0.11)
N	48	48	48	48	48
R^2	0.994	0.842	0.786	0.809	0.795

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In line with the theoretical prediction, the regression results indicate that the number of owners with one electric car increases as a response to the announcements of road toll-incentives. However, we do not have strong evidence of this increase, as the coefficient is insignificant. Further, our regression estimates show that there is a statistically significant reduction of owners holding one conventional car on about

[39] Increasing the post-period to the maximum length given our data-set also gives insignificant results.

1%, equivalent to a reduction of 156 conventional vehicles.[40] The 53% increase in the number of multi-homers with one car of each type indicates that the reality reflects the theoretical prediction. Although it is statistically significant, the multi-homer coefficient requires cautionary interpretation considering that the trends were not parallel before the treatment and there is no kink afterwards (figure 5.2.5). In addition, the volatility related to multi-homers from Sotra makes the DiD method inappropriate for this group of owners. The number of owners holding two conventional vehicles decrease by 2.4% as a result of the policy implication, equivalent to reduction of 38 owners. The finding is supported by figure G.5.

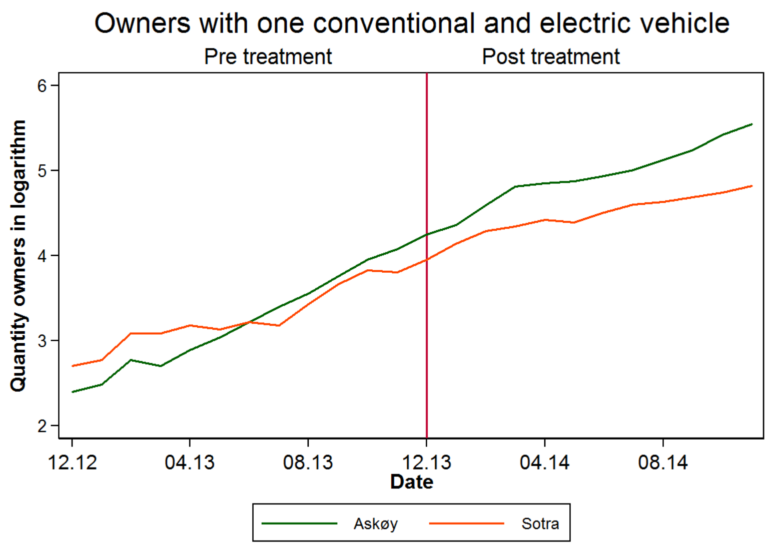


Figure 5.2.5: Owners with one conventional and electric vehicle in Askøy & Sotra in logarithm.

5.2.4 Case 3: Congestion Charge in Kristiansand

Introduction of congestion charge has been a hot political topic in Oslo lately, and it has already been established in Trondheim (2010), Kristiansand (2013) and Bergen

[40] Increasing the post-period to the maximum length given our data-set gives a negative effect of 2.4%. This could be interpreted as long term effects whereas the change in behaviour caused by introduction of the toll stations are included in much greater extent.

(2016). All these cities have under certain weather conditions experienced poor air quality during the winter, whereas extraordinary increases in congestion charge prices have been regarded as a solution under these circumstances. The purpose of the congestion charge is to improve the air quality by increasing the efficiency of the vehicle flow during rush hours. The payment encourages owners of conventional cars to drive outside rush hours, use public transport or buy electric cars instead. Electric vehicles contribute to better air quality through two sources. Firstly, electric vehicles do not pollute. Secondly, electric vehicles ease the congestion by their access to public transport lanes. The possibility to reduce queue and create a smoother car flow do, however, require available public transport lanes. In our third case, we will take a closer look at how introduction of congestion charge affect Kristiansand. We will use Stavanger as control group since this municipality only charges flat toll rates.

Stavanger and Kristiansand are, respectively, the fourth and fifth largest cities in Norway in terms of population size, and they share many similarities. Both cities work as cruxes for surrounding municipalities and are monocentric. We therefore expect similarities in settlement, driving pattern and organization of public transportation. Even though the population sizes are different, we assume similar population growth.

Kristiansand has five toll stations covering vehicles travelling to the city, which had flat toll rates before the introduction of congestion charge in mid November 2013.[41] Similar to the drivers on Askøy, the car owners in Kristiansand had some time to adapt to the policy, as the decision was made by the city council in June 2013. The congestion charge incentive shares many similarities with the toll road incentive, but there is one main difference. While the introduction of toll stations on Askøy affected all travelers more or less in the same way, the congestion charge can be avoided by adjusting the driving behavior. Workers with flexitime can, for

[41] Commuters driving on weekdays between 06:30 and 09:00 in the morning and between 14:30 and 17:00 in the afternoon, paid 7 NOK more compared to the general flat toll rate outside the rush hours.

instance, attend the office earlier or later. As mentioned, some traveler segments will find it hard to avoid the congestion charge, and certain traveler groups will probably be more encouraged to purchase electric vehicles than others. For instance, families with younger children could be more affected by the policy as they may not have the same flexibility to drive outside the rush hours as other population groups. According to a report by Figenbaum and Kolbenstvedt (2016) that include sociodemographic factors over vehicle type owners, states that while PHEV and ICEV owners share many similarities, there are greater differences between ICE and BEV owners.[42] On average, BEV owners have longer distances to work and live in larger households with more and younger children. Among BEV owners, the share of more educated people and workers are greater than among ICE owners. Since the congestion charge can be avoided, we expect greater effects from introduction of toll stations than from implementing congestion charge.[43]

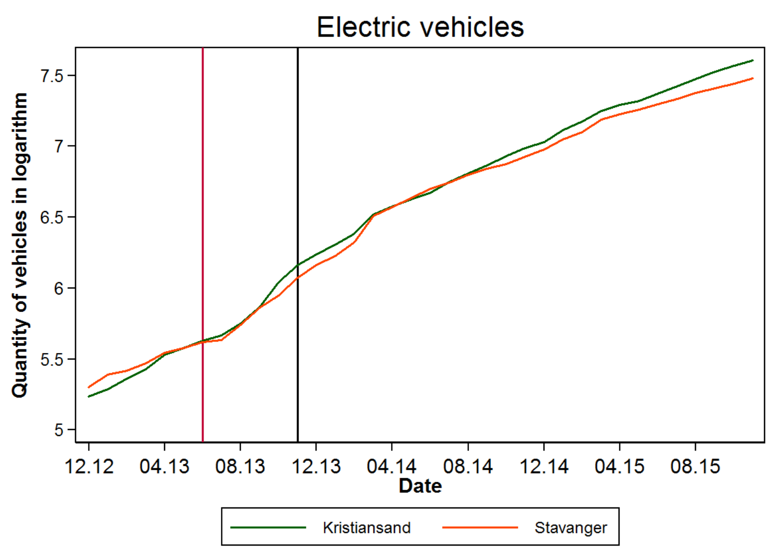


Figure 5.2.6: Total number of electric vehicles in Kristiansand & Stavanger in logarithm.

[42]The reports use the abbreviation BEV for electric vehicles, ICEV for internal combustion engine vehicles and PHEV for plug in hybrid electric vehicles.

[43]For a sufficiently high congestion charge price relative to the flat toll rate, one might expect that congestion charge has the greatest impact.

Figure 5.2.6 shows that inhabitants of Kristiansand almost possess the exact same number of electric vehicles as inhabitants of Stavanger. However, after the announcement, the trend lines diverge, most likely due to the announcement and implementation of congestion charge. We therefore modify the setup slightly by excluding observations within the time frame between the announcement and the introduction and look at the effect six months before the announcement and six months after the introduction of the congestion charge.[44]

Table 5.2.5: Estimates from regressions of private vehicle types in logarithm.

	(1) All vehicles	(2) Total EVs	(3) Total CVs
Dummy Kristiansand	-0.29***	-0.048	-0.29***
	(0.0026)	(0.088)	(0.0019)
Post treatment	0.028***	0.86***	0.022***
	(0.0026)	(0.088)	(0.0019)
Treatment effect Kristiansand	-0.0069*	0.10	-0.0098**
	(0.0032)	(0.12)	(0.0028)
Intercept	10.9***	5.45***	10.9***
	(0.0022)	(0.062)	(0.0014)
N	24	24	24
R^2	0.999	0.915	1.000

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The total number of electric vehicles gives an indication of a positive effect due to the intervention. However, by the end of the post-period, both cites had almost the exact same quantity of electric vehicles. Moreover, there are no obvious parallel trends before treatment takes place (figure H.2), and the DiD approach will be inappropriate to estimate the total number of electric vehicles. Furthermore, our analysis shows that the total number of conventional vehicles have a statistically significant negative treatment effect, but the economical significance is rather low as the decrease is below 1%, which is equivalent to a reduction of 370 conventional ve-

[44] November 2013 will be the first post-period, even though the introduction took place 18th.

hicles. The negative treatment effect on conventional vehicles outweigh the positive effect on electric vehicles, causing a significant negative effect for private vehicles in Kristiansand due to the introduction of the congestion charge. The vehicles market shares in February 2014 were 1.4% for electric cars and 98.6% for conventional cars.

Table 5.2.6: Estimates from regressions of private vehicle types and multi-homers in logarithm.

	(1) CV	(2) EV	(3) CV+EV	(4) 2CV	(5) 1or2CV+1EV
Dummy Kristiansand	-0.27***	-0.22*	0.088	-0.28***	0.087
	(0.0020)	(0.092)	(0.090)	(0.0058)	(0.086)
Post treatment	0.030***	0.83***	0.91***	-0.0084	0.94***
	(0.0020)	(0.092)	(0.090)	(0.0058)	(0.086)
Treatment effect Kristiansand	-0.018***	0.15	0.18	0.0030	0.12
	(0.0028)	(0.13)	(0.13)	(0.0082)	(0.12)
Intercept	10.5***	4.74***	4.29***	8.75***	4.53***
	(0.0014)	(0.065)	(0.064)	(0.0041)	(0.061)
N	24	24	24	24	24
R^2	0.999	0.908	0.928	0.996	0.932

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Our estimation shows that the number owners holding one conventional vehicle decrease by 1.8% as a result of the policy intervention. The reduction might be caused by diverging pre-parallel trends between Kristiansand and Stavanger, making the DiD method inappropriate for this group of owners (figure H.6). The same seems to apply for multi-homers with both car types according to figure 5.2.7. While the number of multi-homers grows steadily in Kristiansand the entire period, there is greater volatility in Stavanger, and the results are thus not as reliable as we would like. The trends for owners of one electric vehicle, on the other hand, satisfy the parallel pre-trend assumption (figure H.4), but the positive effect is statistically insignificant. There could be several explanations to why the results are insignificant. As mentioned, compared with the previous case, congestion charge can much easier be avoided without. Another explanation could be related to the introduction of

Tesla Model S into the Norwegian market in August 2013. According to Figenbaum and Kolbenstvedt (2016), in comparison with other electric vehicle owners, Tesla owners more often single-home. The range and size of a Tesla make it resemble a conventional vehicle and the model launch of Tesla can be regarded as a technology improvement in our model.[45] The DiD-method assume that the introduction have equal effects on the treatment and the control group. Our data collection reveals that the level of educations is higher in Stavanger, which has a positive effect on number of owners holding electric vehicle (Figenbaum & Kolbenstvedt, 2016), and probably makes the effect of the introduction of Tesla Model S higher in Stavanger. Education is most likely correlated with income, and higher income in Stavanger would reinforce the effect. Figure H.4 supports this argument, considering that we only observe a kink for Stavanger after the introduction of Tesla S. Nonetheless, our coefficients will in this regard only be underestimated and the insignificance do not alter the validity of our analysis.

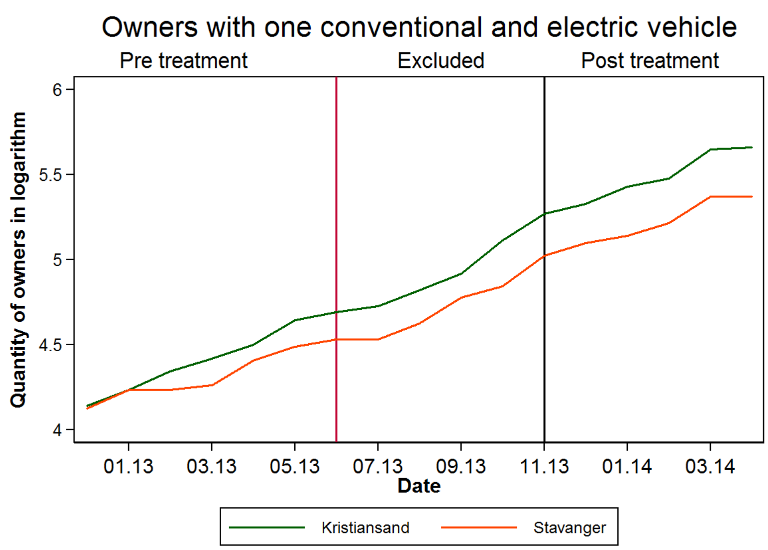


Figure 5.2.7: Owners with one conventional and electric vehicle in Kristiansand & Stavanger in logarithm.

[45] Other cities also show similar trends. In this thesis we have focused on local incentives, and will therefore leave quality improvements for further research.

5.3 Heteroskedasticity

The presence of heteroskedasticity will, according to Wooldridge (2013), imply that OLS is no longer the best linear unbiased estimator. As a consequence, statistical inference is weakened, and there is a higher risk of incorrect conclusions of statistical significance or vice verca. Figure 5.3.1 shows that the variance is not constant, which is an indicator of heteroskedasticity. Conducting a Breush-Pagan test support this claim. Running a regression with robust standard errors improve the old-fashioned standard errors that assume homoskedasticity (Angrist & Pischke, 2009). However, this would only give higher precision in cases where the statistical inference is unequal to our initial estimation, which implies that the conclusions we drew most likely are correct even if heteroskedasticity occurs.

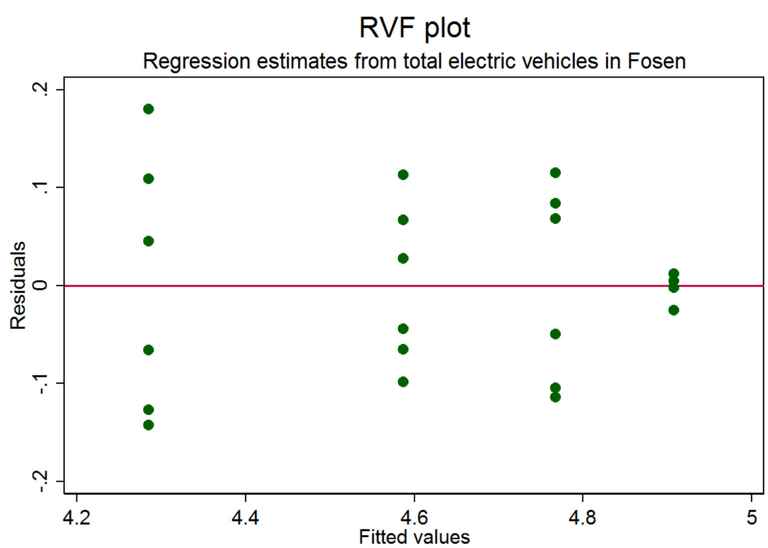


Figure 5.3.1: RVF plot of regression estimates from total electric vehicles in Fosen.

5.4 Weaknesses of the Analysis

A price examination would improve the analysis of the strategic interactions and provide more robust results. This would require access to historical price information of all car types and public transport services.[46] In addition, official car prices are not necessarily representative. Rather than giving a discount on the purchase price, car dealers compete on car equipment prices and the final price the car buyers pay is not officially reported. The price analysis is left out for further research.

Because hybrid cars are partly driven by petrol or diesel fuel, and do not benefit from the local incentives for electric cars, we have treated them as conventional cars in our analysis. On average, hybrid cars drive in E-mode 55% of the time (Figenbaum & Kolbenstvedt, 2016), and thus produce fewer emissions than conventional cars. In addition, among hybrid car owners it is more common to single-home than it is among owners of electric cars (Figenbaum & Kolbenstvedt, 2016). If the hybrid cars replace joint purchases of one electric car and one conventional car, they might be the most climate friendly solution. Not only would they reduce the number of cars produced, but they also pollute less compared to multi-homers driving their conventional car more than 45% of the time. A complete analysis of the incentives environmental effects would therefore identify whether the incentives increase multihoming at the expense of single-homers with hybrid cars.

Due to other factors or incentives affecting the outcome variables of interest, the applied time frames restrict our analysis to short term effects. Consequently, our estimates for multi-homers might be overestimated considering that some would acquire a new vehicle before selling the one they already possess. On the other hand, the effects on owners with one or more cars of same type might also be lagged if people want sell the car they already got before purchasing different type. Introduction of toll stations or congestion charge is often accompanied by changes in public transportation provision, implying that change of behavior could also be caused by improved public transport services.[47] As a result, our coefficients might be overestimated, however, we assume that this effect is small, considering that owning cars usually serve more purposes than only commuting back and forth from work. Fur-

[46] We were not able to obtain this during the period of our thesis

[47] Askøypakken is a such example.

thermore, longer time frames would probably produce more statistically significant estimates, but also make it harder to pinpoint the causality as mentioned.

5.4.1 Serial Correlation

Utilizing a difference-in-differences approach often relies on time series data that is not independent of past and future observations. Such correlation can lead to overestimation of t-values and significance levels, which in turn can lead to false rejections of the null hypothesis (Bertrand, Duflo, & Mullainathan, 2004). There are three factors to consider when serial correlation occurs, the length of the time series, serial correlation of the most commonly used dependent variables and correcting procedures. In this paper, we have used the same dependent variables on different data, depending on the case we are interested in. The time series length of case 2, is longer compared with case 1 and case 3, making the probability of overestimated t-values higher.

Bertrand et al. (2004) suggest several solutions to overcome serial correlation in difference-in-differences applications. Given large number of groups, robust block bootstrap can be used to compute consistent standard errors. Another method, that require fewer groups, eliminates the time series dimension by collapsing data into pre- and post-periods. The drawback is that it takes away statistical power, and increase the likelihood of accepting a false null hypothesis. Both methods require several treatment groups, while our cases only consider one group as we could not find other suitable candidates. We have also considered collapsing the data over postal number, but this would require more data power and time resources than we have to our disposition.

6 Discussion

In this chapter we return to our research question with the intention of bringing together the empirical findings with the theoretical model we have derived. The purpose of this thesis is to assess the effect of local subsidies on multi-homing, which is important to understand how efficiently the incentives obtain their objectives. Even though the market share of electric vehicles in Norway has increased steadily the last years and was 17.1% in 2015, it will take a long time before the entire vehicle fleet consists of low-emission vehicles if the subsidies leads to multi-homing. The second part of this chapter discuss the generalisability and causality of our findings.

6.1 Combining the Theoretical Model With the Empirical Results

Our theoretical model predicts that increased incentives for electric vehicles make it more imperative to buy an electric car in addition to a conventional car. Under such circumstances, our model suggest that the number of multi-homers will increase. Furthermore, our framework predicts that enhanced incentives shift demand from public transport onto electric cars. When the demand for public transport decreases the profit maximizing solution would be to reduce the price of the service, although we admit that the public transport prices are not necessarily profit maximizing and might be unresponsive. However, if public transport reduce its price, the indirect effect is that conventional cars become less competitive and demand shifts from conventional cars to public transport. In the case with inflexible public transport prices, the demand for conventional cars is unaffected by the incentives for electric vehicles. Because the objective of the incentives is to replace conventional vehicles by low-emission vehicles, the model with responsive public transport prices is more careful not to assume that the incentives are inefficient. Based on the model, we expect the net effects of enhanced incentives for electric cars to increase multi-homing, increase single-homing of electric cars and have low or no effect on the demand for conventional cars. Consequently, we expect an increased car population and that the incentives do not meet the policy objective.[48]

The empirical findings partially concur with the theoretical model's predictions. In the table below we consider increased incentives for electric vehicles and present the predictions of our model along with the empirical indications.[49]

Table 6.1.1: Comparison of the theoretical model's predictions and the empirical findings related to increased incentives for electric cars.

	(1) Model expectations	(2) FE Road toll	(3) DiD Road toll	(4) DiD Congestion charge	(5) DiD Ferry fares
One EV	↑	↑	↑	↑	↑
One CV	↓	↓	↓	↓ ⋄	↑ ⋄
EV + CV	↑	↑	↑ ⋄	↑ ⋄	↑
Total EV	↑	↑	↑	↑ ⋄	↑
Total CV	(↓)	↓	↓	↓	↑
Total	↑	↓	↓	↓	↑

The model expectation of total CV is in parenthesis to signal that the reduction is either low or absent.
⋄: Indicates absence of pre-treatment parallel trends, making DiD analysis inappropriate.

In line with our model, the regression estimates show that the number of single- and multi-homers with electric cars increases in enhanced incentives for electric cars. Accordingly, the theoretical and empirical models agree that the total number of electric vehicles will increase. The red arrows highlight differences between the theo-

[48]Removal of incentives for electric vehicles would cause opposite effects.

[49]In order to make all cases comparable, we reverse the findings for the case with removed ferry incentives such that we get the results for increased incentives. We assume that introduction of free ferry admission will give similar opposite effects as the observed withdrawal.

retical model and the empirical results, and the deviating results seems to be related to the incentives effects on conventional cars. The theoretical model only predicts a reduction of conventional cars if the public transport prices are responsive to the demand shifting caused by the electric vehicle incentives. However, the reduction would be small and, moreover, we suspect that the public transport prices do not respond or affect the demand for electric cars at all. The empirical results, on the other hand, suggest that road toll and congestion charges significantly reduce the number of owners with one conventional car. Given the owner category sizes, the percentage changes would imply that the reduced number of conventional car owners offset the increased number of single- and multi-homing owners with one electric cars such that the overall car population decrease.

Hence, the empirical results indicate that the theoretical model is overestimating the incentives demand increasing effect on electric cars or underestimating the demand reducing effect on conventional cars. The model deviations is probably related to people having heterogeneous preferences and utility functions. If the model overestimates how much the incentives increase the demand for electric cars, it is an indication of people being more reluctant to buy electric cars in the real world. Peoples' preferences for conventional cars or public transport could be stronger than expected and the incremental valuation of a second car might be lower than anticipated. If the model underestimates the incentives reduction of demand for conventional cars, it could be a sign of conventional car owners having weaker preferences than expected. Furthermore, it signals that the car buyers behavior is heterogeneous and can not be the modelled exactly. We do, for instance, believe that some people substitute their conventional for an electric car, a bicycle or walking shoes, due to the incentives, although our theoretical model do not take into account such behaviour.

Interestingly, the ferry incentive produces results that are quite different from road toll and congestion charge incentives. First, the differences demonstrate sensitivity to the model assumptions. If ferry fares become cheaper for electric cars, the regression shows an increased number of conventional car owners, which is a bit strange and likely a bi-product of not parallel pre-trends.[50] Second, it emphasizes an important difference in the incentives nature. While reduced ferry fares is a direct subsidy that applies solely to electric cars, increased road toll and congestion charge affect conventional cars directly and subsidise electric cars indirectly. In contrast to our theoretical model, the empirical results also capture the direct effect on conventional cars, which could explain why increased road toll and congestion charge cause such great reductions of conventional cars.[51] The effect of policies that subsidise electric cars without affecting conventional cars could therefore be less efficient, which would be supported by the empirical findings for ferry fares and the theoretical model. To test this hypothesis, it would be interesting to investigate the effects of access to public transport lanes, charging stations and free parking. Unfortunately, we must leave this for further research due to time-constraints.

By combining the theoretical predictions, empirical findings and past research we find that the incentives contribute to multi-homing. Whether multi-homing cause the incentives'to be inefficient depends on the incentives nature and the considered time horizon. The electric vehicle incentives that are indirect consequences of policies that directly reduce the demand for electric cars, such as road toll and congestion charge, appear to be efficient in achieving their objectives. They reduce the overall vehicle fleet, as well as replacing conventional cars with electric cars.

It is more ambiguous whether incentives that affect electric vehicles directly, but do not have a direct impact on conventional cars, are efficient. Such incentives are ferry fares, bus lane access, free parking and quick or subsidised charging stations. They seem to increase single- and multi-homing of electric cars, while the reduction of conventional cars is much less evident. In the short run their contribution to multi-homing do not seem to outweigh the positive effects on the environment. The CO2-equivalent calculation shows that a net increase of electric cars could be

[50] As mentioned, in order to make all cases comparable, we reverse the findings for the case with removed ferry incentives.

[51] Increased road toll and congestion charge make conventional cars more expensive to use and the demand decrease.

compatible with a more climate friendly vehicle fleet. The explanation is that a larger car population with a sufficient share of electric cars can pollute less than a smaller vehicle fleet with a higher share of conventional cars. In the long run, the efficiency depends on whether the electricity consumption of the electric cars, either directly or indirectly, contributes to increased production of fossil energy. When the electric vehicle fleet exceeds 1.5 million cars, the incentives is only efficient if the power plants have greater renewable energy capacity or if multi-homing is prohibited.

Finally, the incentives may stimulate the technical development of electric cars, such that electric cars in the future can outperform conventional cars. Hence, the incentives may help phasing out high-emission vehicles in the long run regardless of whether they contribute to multi-homing in the short run. The technological aspect has not been the prime focus in this thesis and is, as mentioned, left out for further research.

6.2 Generalisation and Causality

Since road toll and congestion charge affect the demand for conventional cars regardless of their effects as incentives, we do not assess the net incentive effect. The causal relationships between the incentive and the outcome variables are thus challenged. However, the road toll incentive can not exist without road toll's other attributes and we therefore find it relevant to consider the gross effect of road toll.[52]

Because of restricted computer capacity we found it necessary to extract a sample of municipalities and years for the fixed effects analysis. We do not include the years before 2008, when electric vehicles were sold to a very limited extent. Moreover, we only include the six most populous municipalities in Norway.[53] We are aware that car ownership may respond differently to road toll prices in the sample municipalities than in other areas. Because cold temperatures reduce electric cars's range and make

[52] The same applies to congestion charge.

[53] Oslo, Bergen, Trondheim, Stavanger, Bærum and Kristiansand.

charging slower, we expect that the effect of road toll is lower in municipalities with extremely cold winters, like Karasjok, Røros and Tynset. Moreover, range challenges are more difficult to overcome in areas with long distances. As more than 50% of Norway's municipalities cover greater areas than the largest municipality within our sample, the average effect of road toll is probably lower across the whole population than for our sample. Although our sample is not representative for the entire Norwegian population, it is still interesting. First, the sample includes about 30% of the Norwegians, and by uncovering causal effects we can predict the behavior of a big share of the population. Second, we believe that our results can be extrapolated to other municipalities. Such municipalities would be characterized by areas that are about 500 km^2 or smaller and without the coldest winters. Finally, we pinpoint the effects in areas where it is most likely that such incentives will be introduced. For road toll to be a relevant financial income source, a certain car flow would be required, which makes it most relevant to look at municipalities with a certain number of inhabitants.

The DiD method applied in our cases, is a great tool to reveal the causal effect of policy changes giving it high degree of internal validity. However, if the intervention had happened somewhere else, we would expect different estimation results. Hypothetically, if the removal of the ferry incentives had happened in Ryfylke rather than Fosen, different alternative routes, public transportation service and time of travel would give different effects. Hence, the cases do not have strong external validity. However, the aim of the cases was to supplement the findings from the fixed effects model and take a closer look how the intervention concretely affects intervened areas.

7 Conclusion

The purpose of the research was to identify to what extent incentives for electric cars contribute to multi-homing. This is important to understand how effective the incentives are in achieving the policy objective, as this channel is not well understood. In this chapter we present our contributions, main findings and recommendations.

Our first contribution is a theoretical model intended for the transportation market, derived from Hotelling's linear city and Salop's circular city. According to our model, increased local incentives for electric cars lead to a greater number of single- and multi-homers with an electric car. The existence of people buying more than one car type softens the competition between electric and conventional vehicles such that the incentives have no direct effect on the demand for conventional cars. Whether it could exist an indirect effect depends on the responsiveness of prices for public transport. In theory, public transport prices would be reduced because of demand shifting from public transport to conventional cars. However, we have provided arguments for why the prices might not be adjusted. In either case, the indirect effect of the incentives on the demand for conventional cars would at most be modest. Hence, the model predicts that the incentives mainly increase the overall vehicle fleet rather than replacing conventional cars by electric ones, which implies that the incentives are inefficient. In order to test our model we have conducted empirical research on the car market. In particular, we have carried out a fixed effect analysis to assess the effect of the road toll incentive, and we have used a difference-in-differences setup to investigate the effects of exemptions from road toll, congestion charge and ferry fares.

The empirical results show that all of the evaluated incentives encourage people to buy multiple cars. However, the results indicate that multi-homing not categorically cause the incentives to be inefficient. Also the characteristics of a particular incentive and the considered time horizon must be taken into account. The regressions estimate that higher road toll prices and congestion charge indirectly subsidise electric vehicles, which increase the number of single-and multi-homers with an electric car. The results also suggest that, in addition to the indirect subsidy effects, these payments have direct effects reducing the demand for conventional cars. Moreover, the direct effects outweigh the effects that increase the demand for electric cars such that the overall car population decreases. Introducing a ferry incentive, on the other hand, do not directly affect the demand for conventional cars. Thus, the incentive primarily increase the demand for electric cars and expand the vehicle fleet.

Since road toll and congestion charge contribute to replacing conventional cars with electric cars and also reduce the car population, we recommend that these incentives are withheld. It is more unclear whether the incentives without a direct impact on conventional cars should be continued, as they seem to increase the overall number of cars in Norway. CO2-equivalent calculation shows that these incentives may be efficient in the short run even if they enlarge the vehicle fleet. The requirement is that each new electric car replace at least 0.623 conventional cars, which leaves room for some multi-homing. However, as the number of electric vehicles increases it becomes more challenging to replace the electricity the vehicles consumes with renewable energy. Given the current renewable power generation capacity, one conventional car must be replaced per new electric car when the electric car population exceeds 1.5 millions. Thus, in the long run, these incentives will only be efficient if the power plants have greater renewable energy capacity or if multi-homing of both car types do not occur. This could be the case if technology improvements make electric vehicles superior in the future. Finally, we emphasize that the electric vehicle incentives evidently contribute to multi-homing, and we recommend that decision makers use frameworks that consider such purchase behavior.

Technical Appendix

To conduct our analysis we got access to five excel files that contained the Motor Vehicle registry obtained from Norwegian Public Roads Administration. One file carried information about every vehicle that has been type approved in Norway. Using stata, we merged this file with another file containing technical information regarding the cars, before appending a file with the individually approved vehicles.[54] Finally, we merged the file including all approved vehicles with a file containing detailed historical information over license numbers.[55] The resulting data file included the cars registration history, such as first time registration, notifications of sale, change of ownership, deregistration and wrecking, as well as technical details. We used information about fuel type to identify electric cars, length to distinguish between large and small cars and postal numbers to separate municipalities and districts. A challenging next step was to turn our data set into a usable panel data set with monthly observations for each license-number and unique ownership periods for any combination of car and owner that had existed.[56] For the fixed effects and difference-in-differences analyses we aggregated the individual observations over postalnumbers to obtain municipality- and district-entities. From SSB (Statistics Norway) we collected data for level of education, unemployment and public transport, and historical road toll prices and number of toll stations were collected from AutoPASS.

[54]This file already contained technical information about the vehicles.

[55]The car history file has missing values for wrecked cars and owners that are passed away.

[56]This task proved to be challenging due to lack of consistency over registrations.

Appendices

Parameters

t : Preference heterogeneity.

z_i: Location of mean of transportation i.

pi = Price for mean of transportation i.

vi = Gross willingness to pay for mean of transportation i.

β = Factor for adjusting the value of the car for being secondary.

αi = Local subsidies for electric cars.

$\tilde{x}_{ij}$ = Location of traveler that is indifferent towards i and the bundle i and j.

$\bar{x}_{ij}$ = Location of traveler that is indifferent towards i and j.

U_i = Utility of mean of transport i.

U_{ij} = Joint utility of mean of transport i and j.

... where i= 1,2,3 and j = 1,2

The general utility functions are derived directly from these parameters.

$U_i, x_{ij} = v_i - p_i - t|z_i - x_{ij}| + \alpha_i$

$U_{ij}, x_{ij} = v_i + \beta v_j - p_i - p_j - t|z_i - x_{ij}| - t|z_j - xij| + \alpha_i + \alpha_j$

A Derivation of Traveler Demand

A.1 Indifferent Consumers

$\tilde{x}_{12}$ represents the traveler that is indifferent between purchasing a conventional car and both a conventional car and a electric car. $\tilde{x}_{12}$ is located on the circle where $U_1 = U_{12}$.

$$U_1 = v_1 - p_1 - t(z_1 - \tilde{x}_{12})$$

$$U_{12} = v_1 + \beta v_2 - p_1 - p_2 - t(z_1 - \tilde{x}_{12}) - t(\tilde{x}_{12} - z_2) + \alpha$$

$$U_1 = U_{12} \text{ then gives :}$$

$$v_1 - p_1 - t(z_1 - \tilde{x}_{12}) = v_1 + \beta v_2 - p_1 - p_2 - t(z_1 - \tilde{x}_{12}) - t(\tilde{x}_{12} - z_2) + \alpha$$

$$\tilde{x}_{12} = z_2 + \frac{\beta v_2 - p_2 + \alpha}{t} \tag{1}$$

Symmetrically, $\tilde{x}_{21}$ represents the traveler that is indifferent between purchasing a electric car and both an electric car and a conventional car.

$$U_2 = v_2 - p_2 - t(\tilde{x}_{21} - z_2) + \alpha$$

$$U_{21} = v_2 + \beta v_1 - p_2 - p_1 - t(\tilde{x}_{21} - z_2) - t(z_1 - \tilde{x}_{21}) + \alpha$$

$$U_2 = U_{21} \text{ then gives :}$$

$$v_2 - p_2 - t(\tilde{x}_{21} - z_2) + \alpha = v_2 + \beta v_1 - p_2 - p_1 - t(\tilde{x}_{21} - z_2) - t(z_1 - \tilde{x}_{21}) + \alpha$$

$$\tilde{x}_{21} = z_1 - \frac{\beta v_1 - p_1}{t} \quad (2)$$

$\bar{x}_{23}$ shows the traveler that is indifferent between electric cars and public transport.

$$U_2 = v_2 - p_2 - t(z_2 - \bar{x}_{32}) + \alpha$$

$$U_3 = v_3 - p_3 - t(\bar{x}_{32} - z_3)$$

$$U_2 = U_3 \text{ then gives :}$$

$$v_2 - p_2 - t(z_2 - \bar{x}_{32}) + \alpha = v_3 - p_3 - t(\bar{x}_{32} - z_3)$$

$$\bar{x}_{32} = \frac{(z_2 + z_3)}{2} + \frac{(v_3 - v_2 - p_3 + p_2 - \alpha)}{2t} \quad (3)$$

The traveler who is indifferent between conventional cars and public transport is located at $\bar{x}_{13}$, and is found by replicating the above procedure.

$$U_1 = v_1 - p_1 - t(\tilde{x}_{31} - z_1)$$

$$U_3 = v_3 - p_3 - t(z_3 - \bar{x}_{32})$$

$$U_1 = U_3 \text{ then gives :}$$

$$v_1 - p_1 - t(\tilde{x}_{31} - z_1) = v_3 - p_3 - t(z_3 - \bar{x}_{32})$$

$$\bar{x}_{31} = \frac{(z_1 + z_3)}{2} + \frac{(v_3 - v_1 - p_3 + p_1)}{2t} \tag{4}$$

A.2 Demand

The demand for a mean of transportation equals the interval ranging from the indifferent traveler on it's left side to the indifferent traveler on it's right side. The normalized circle perimeter, normalized density of travelers and uniform distribution of travelers do facilitate the derivation of the demand functions. We can simply subtract the intervals right endpoints from the intervals left endpoints.

Demand for conventional cars:

$$D_1 = \bar{x}_{31} - \tilde{x}_{21}$$

$$= \frac{z_3 + z_1}{2} + \frac{v_1 - v_3 - p_1 + p_3}{2t} - \left(z_1 - \frac{\beta v_1 + p_1}{t} \right)$$

$$= \frac{z_3 - z_1}{2} + \frac{(1 + 2\beta)v_1 - v_3 - 3 - 3p_1 + p_3}{2t}$$

$$D_1 = \frac{1}{6} + \frac{(1 + 2\beta)v_1 - v_3 - 3p_1 + p_3}{2t} \tag{5}$$

Demand for electric cars:[57]

$$D_2 = \tilde{x}_{12} - \bar{x}_{32}$$

$$= z_2 + \frac{\beta k_2 - p_2 + \alpha}{t} - \left(\frac{z_2 + z_3}{2} + \frac{v_3 - v_2 - p_3 + p_2 - \alpha}{2t} \right)$$

$$= \frac{z_2 - z_3}{2} + \frac{(1 + 2\beta) v_2 - v_3 - 3p_2 + p_3 + \alpha}{2t}$$

$$D_2 = \frac{1}{6} + \frac{(1 + 2\beta) v_2 - v_3 - 3p_2 + p_3 + \alpha}{2t} \tag{6}$$

Demand for public transport and the size of the uncovered car market:

$$D_3 = \bar{x}_{32} - \bar{x}_{31}$$

$$= \frac{z_3 + z_2}{2} + \frac{v_3 - v_2 - p_3 + p_2 - \alpha}{2t} - \left(\frac{z_1 + z_3}{2} + \frac{v_1 - v_3 - p_1 + p_3}{2t} \right)$$

$$= \frac{z_2 - z_1}{2} + \frac{2v_3 - v_1 - v_2 - 2p_3 + p_1 + p_2 - \alpha}{2t}$$

$$D_3 = \frac{1}{3} + \frac{2v_3 - v_1 - v_2 - 2p_3 + p_1 + p_2 - \alpha}{2t} \tag{7}$$

[57] The symmetrical distribution of z_i implies that $z_3 - z_1$ and $z_2 - z_3$ equals $\frac{1}{3}$ and that $z_2 - z_1 = \frac{2}{3}$.

B Strategic Interaction

B.1 Reaction Functions

Prices are the strategic decision variables in out model. To derive the reaction function of the strategic decision variables, we differentiate the profit functions with respect to prices.

Reaction function conventional cars:

$$\pi_1 = D_1 \times (p_1 - c_1)$$

$$\frac{\partial \pi_1}{\partial p_1} = \frac{\partial D_1}{\partial p_1} \times (p_1 - c_1) + D_1 = 0$$

$$-\frac{3}{2t} \times (p_1 - c_1) + \frac{z_3 - z_1}{2} + \frac{(1+2\beta)v_1 - v_3 + p_3 - 3p_1}{2t} = 0$$

$$p_1^R(p_3) = \frac{t}{18} + \frac{(1+2\beta)v_1 - v_3 + p_3 + 3c_1}{6} \tag{8}$$

Reaction function electric cars:

$$\pi_2 = D_2 \times (p_2 - c_2)$$

$$\frac{\partial \pi_2}{\partial p_2} = \frac{\partial D_2}{\partial p_2} \times (p_2 - c_2) + D_2 = 0$$

$$-\frac{3}{2t} \times (p_2 - c_2) + \frac{z_2 - z_3}{2} + \frac{(1+2\beta)v_2 - v_3 + p_3 - 3p_2 + \alpha}{2t} = 0$$

$$p_2^R(p_3) = \frac{t}{18} + \frac{(1+2\beta)v_2 - v_3 + p_3 + 3c_2 + \alpha}{6} \tag{9}$$

Reaction function public transport:

$$\pi_3 = D_3 \times (p_3 - c_3)$$

$$\frac{\partial \pi_3}{\partial p_3} = \frac{\partial D_3}{\partial p_3} \times (p_3 - c_3) + D_3 = 0$$

$$-\frac{1}{t} \times (p_3 - c_3) + \frac{z_2 - z_1}{2} + \frac{2v_3 - v_1 - v_2 + p_1 + p_2 - 2p_3 - \alpha}{2t} = 0$$

$$p_3^R(p_1, p_2) = \frac{t}{6} + \frac{2v_3 - v_1 - v_2 + p_1 + p_2 + 2c_3 - \alpha}{4} \tag{10}$$

C Equilibriums

C.1 Equilibrium Prices

First we insert equation (10) for p_3 into equations (8) and (9):

Equation 8:

$$p_1^R(p_3) = \frac{t}{18} + \frac{(1+2\beta)v_1 - v_3 + p_3 + 3c_1}{6}$$

$$= \frac{t}{18} + \frac{(1+2\beta)v_1 - v_3 + 3c_1}{6} + \frac{1}{6}\left(\frac{t}{6} + \frac{2v_3 - v_1 - v_2 + p_1 + p_2 + 2c_3 - \alpha}{4}\right)$$

$$p_1^R(p_2) = \frac{6t}{253} + \frac{(3+8\beta)v_1 - 2v_3 - v_2 + 12c_1 + 2c_3 + p_2 - \alpha}{23} \tag{11}$$

Equation 9:

$$p_2^R(p_3) = \frac{t}{18} + \frac{(1+2\beta)v_2 - v_3 + p_3 + 3c_2 + \alpha}{6}$$

$$= \frac{t}{18} + \frac{(1+2\beta)v_2 - v_3 + 3c_2 + \alpha}{6} + \frac{1}{6}\left(\frac{t}{6} + \frac{2v_3 - v_1 - v_2 + p_1 + p_2 + 2c_3 - \alpha}{4}\right)$$

$$p_2^R(p_1) = \frac{6t}{253} + \frac{(3+8\beta)v_2 - 2v_3 - v_1 + 12c_2 + 2c_3 + p_1 + 3\alpha}{23} \tag{12}$$

The equilibrium price for conventional cars is then found by inserting (12) into (11):

$$\begin{aligned} p_1^R(p_2) &= \frac{6t}{253} + \frac{(3+8\beta)v_1 - 2v_3 - v_2 + 12c_1 + 2c_3 + p_2 - \alpha}{23} \\ &= \frac{6t}{253} + \frac{(3+8\beta)v_1 - 2v_3 - v_2 + 12c_1 + 2c_3 - \alpha}{23} \\ &+ \frac{1}{23}\left(\frac{6t}{253} + \frac{(3+8\beta)v_2 - 2v_3 - v_1 + 12c_2 + 2c_3 + 3\alpha}{23}\right) \end{aligned}$$

$$p_1^* = \frac{12t + (17+46\beta)v_1 - 12v_3 - (5-2\beta)v_2 + 69c_1 + 12c_3 + 3c_2 - 5\alpha}{132} \tag{13}$$

Inserting (13) to (12) gives the equilibrium price for electric cars:

$$p_2^R(p_1^*) = \frac{6t}{253} + \frac{(3+8\beta)v_2 - 2v_3 - v_1 + 12c_2 + 2c_3 + p_1^* + 3\alpha}{23}$$

$$= \frac{6t}{253} + \frac{(3+8\beta)v_2 - 2v_3 - v_1 + 12c_2 + 2c_3 + 3\alpha}{23}$$
$$+ \frac{1}{23}\left(\frac{12t + (17+46\beta)v_1 - 12v_3 - (5-2)v_2 + 69c_1 + 12c_3 + 3c_2 - 5\alpha}{132}\right)$$

$$p_2^* = \frac{12t + (17+46\beta)v_2 - 12v_3 - (5-2\beta)v_1 + 69c_2 + 12c_3 + 3c_1 + 17\alpha}{132} \tag{14}$$

The equilibrium price for public transport is found by inserting (13) and (14) into equation (10):

$$p_3^R(p_1^*, p_2^*) = \frac{t}{6} + \frac{2v_3 - v_1 - v_2 + p_1^* + p_2^* + 2c_3 - \alpha}{4}$$

$$= \frac{t}{6} + \frac{2v_3 - v_1 - v_2 + 2c_3 - \alpha}{4}$$
$$+ \frac{1}{4}\left(\frac{12t + (17+46\beta)v_1 - 12v_3 - (5-2\beta)v_2 + 69c_1 + 12c_3 + 3c_2 - 5\alpha}{132}\right)$$
$$+ \frac{1}{4}\left(\frac{12t + (17+46\beta)v_2 - 12v_3 - (5-2\beta)v_1 + 69c_2 + 12c_3 + 3c_1 + 17\alpha}{132}\right)$$

$$p_3^* = \frac{28t + 60v_3 - (30-12\beta)v_1 - (30-12\beta)v_2 + 72c_3 + 18c_1 + 18c_2 - 30\alpha}{132} \tag{15}$$

C.2 Equilibrium Demand

To find the equilibrium demand for conventional cars we insert the equations for p_1^* and p_3^* into D_1:

$$D_1 = \frac{1}{6} + \frac{(1+2\beta)v_1 - v_3 - 3p_1 + p_3}{2t}$$

$$\begin{aligned}
&= \frac{1}{6} + \frac{(1+2\beta)v_1 - v_3}{2t} \\
&+ -\frac{3}{2t}\left(\frac{12t + (17+46\beta)v_1 - 12v_3 - (5-2\beta)v_2 + 69c_1 + 12c_3 + 3c_2 - 5\alpha}{132}\right) \\
&+ \frac{1}{2t}\left(\frac{28t + 60v_3 - (30-12\beta)v_1 - (30-12\beta)v_2 + 72c_3 + 18c_1 + 18c_2 - 30\alpha}{132}\right)
\end{aligned}$$

$$D_1^* = \frac{18t + (25.5+69\beta)v_1 - 18v_3 - (7.5-3\beta)v_2 - 94.5c_1 + 18c_3 + 4.5c_2 - 7.5\alpha}{132t} \tag{16}$$

The equilibrium demand for electric cars is found likewise, by inserting p_2^* and p_3^* into D_2:

$$D_2 = \frac{1}{6} + \frac{(1+2\beta)v_2 - v_3 - 3p_2 + p_3 + \alpha}{2t}$$

$$
\begin{aligned}
&= \frac{1}{6} + \frac{(1+2\beta)v_2 - v_3 + \alpha}{2t} \\
&- \frac{3}{2t}\left(\frac{12t + (17+46\beta)v_2 - 12v_3 - (5-2\beta)v_1 + 69c_2 + 12c_3 + 3c_1 + 17\alpha}{132}\right) \\
&+ \frac{1}{2t}\left(\frac{28t + 60v_3 - (30-12\beta)v_1 - (30-12\beta)v_2 + 72c_3 + 18c_1 + 18c_2 - 30\alpha}{132}\right)
\end{aligned}
$$

$$
D_2^* = \frac{18t + (25.5+69\beta)v_2 - 18v_3 - (7.5-3\beta)v_1 - 94.5c_2 + 18c_3 + 4.5c_1 + 25.5\alpha}{132t} \tag{17}
$$

To find the equilibrium demand for public transport we insert p_1^*, p_2^* and p_3^* into D_3:

$$
D_3 = \frac{1}{3} + \frac{2v_3 - v_1 - v_2 - 2p_3 + p_1 + p_2 - \alpha}{2t}
$$

$$
\begin{aligned}
&= \frac{1}{3} + \frac{2v_3 - v_1 - v_2 - \alpha}{2t} \\
&- \frac{2}{2t}\left(\frac{28t + 60v_3 - (30-12\beta)v_1 - (30-12\beta)v_2 + 72c_3 + 18c_1 + 18c_2 - 30\alpha}{132}\right) \\
&+ \frac{1}{2t}\left(\frac{12t + (17+46\beta)v_1 - 12v_3 - (5-2)v_2 + 69c_1 + 12c_3 + 3c_2 - 5\alpha}{132}\right) \\
&+ \frac{1}{2t}\left(\frac{12t + (17+46\beta)v_2 - 12v_3 - (5-2)v_1 + 69c_2 + 12c_3 + 3c_1 + 17\alpha}{132}\right)
\end{aligned}
$$

$$
D_3^* = \frac{28t + 60v_3 - (30-12\beta)v_1 - (30-12\beta)v_2 - 60c_3 + 18c_1 + 18c_2 - 30\alpha}{132t} \tag{18}
$$

C.3 Equilibrium Profits

Equilibrium profit for conventional cars:

$$\pi_1^* = D_1^* \times (p_1^* - c_1)$$

$$\begin{aligned}
=&\left(\frac{18t + (25.5 + 69\beta)v_1 - 18v_3 - (7.5 - 3\beta)v_2 - 94.5c_1 + 18c_3 + 4.5c_2 - 7.5\alpha}{132t}\right)\\
&\times\left(\frac{12t + (17 + 46\beta)v_1 - 12v_3 - (5 - 2\beta)v_2 + 69c_1 + 12c_3 + 3c_2 - 5\alpha}{132} - c_1\right)
\end{aligned}$$

$$\begin{aligned}
=&\frac{1}{t}\left(\frac{18t + (25.5 + 69\beta)v_1 - 18v_3 - (7.5 - 3\beta)v_2 - 94.5c_1 + 18c_3 + 4.5c_2 - 7.5\alpha}{132}\right)\\
&\times\left(\frac{18t + (25.5 + 69\beta)v_1 - 18v_3 - (7.5 - 3\beta)v_2 - 94.5c_1 + 18c_3 + 4.5c_2 - 7.5\alpha}{198}\right)
\end{aligned}$$

$$\pi_1^* = \frac{(18t + (25.5 + 69\beta)v_1 - 18v_3 - (7.5 - 3\beta)v_2 - 94.5c_1 + 18c_3 + 4.5c_2 - 7.5\alpha)^2}{26136t}$$

Equilibrium profit for electric cars:

$$\pi_2^* = D_2^* \times (p_2^* - c_2)$$

$$\begin{aligned}
=&\left(\frac{18t + (25.5 + 69\beta)v_2 - 18v_3 - (7.5 - 3\beta)v_1 - 94.5c_2 + 18c_3 + 4.5c_1 + 25.5\alpha}{132t}\right)\\
&\times\left(\frac{12t + (17 + 46\beta)v_2 - 12v_3 - (5 - 2\beta)v_1 + 69c_2 + 12c_3 + 3c_1 + 17\alpha}{132} - c_2\right)
\end{aligned}$$

$$=\frac{1}{t}\left(\frac{18t+(25.5+69\beta)v_2-18v_3-(7.5-3\beta)v_1-94.5c_2+18c_3+4.5c_1+25.5\alpha}{132t}\right)$$
$$\times\left(\frac{18t+(25.5+69\beta)v_2-18v_3-(7.5-3\beta)v_1-94.5c_2+18c_3+4.5c_1+25.5\alpha}{198}\right)$$

$$\pi_2^*=\frac{(18t+(25.5+69\beta)v_2-18v_3-(7.5-3\beta)v_1-94.5c_2+18c_3+4.5c_1+25.5\alpha)^2}{26136t}$$

Equilibrum profit for public transport:

$$\pi_3^*=D_3^*\times(p_3^*-c_3)$$

$$=\frac{1}{t}\left(\frac{28t+60v_3-(30-12\beta)v_1-(30-12\beta)v_2-60c_3+18c_1+18c_2-30\alpha}{132t}\right)$$
$$\times\left(\frac{28t+60v_3-(30-12\beta)v_1-(30-12\beta)v_2+72c_3+18c_1+18c_2-30\alpha}{132}-c_3\right)$$

$$\pi_3^*=(\frac{()28t+60v_3-(30-12\beta)v_1-(30-12\beta)v_2-60c_3+18c_1+18c_2-30\alpha)^2}{26136t}$$

D Model Assumption

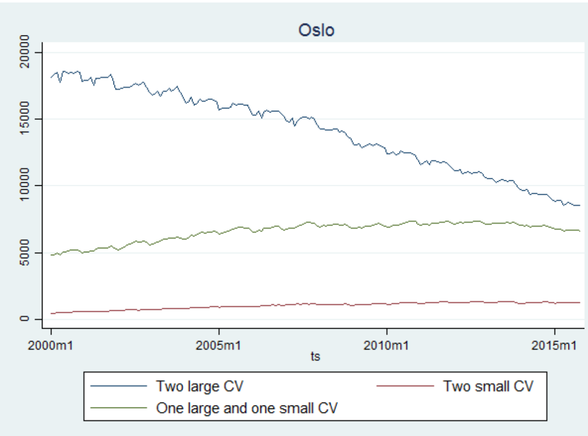


Figure D.1: Owners with two large, two small or one large and one small conventional car in Oslo.

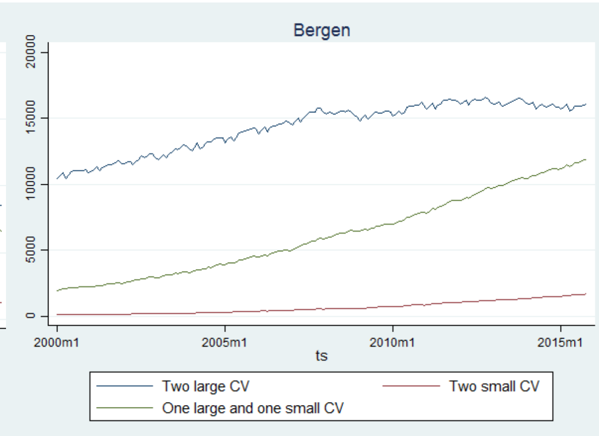


Figure D.2: Owners with two large, two small or one large and one small conventional car in Bergen.

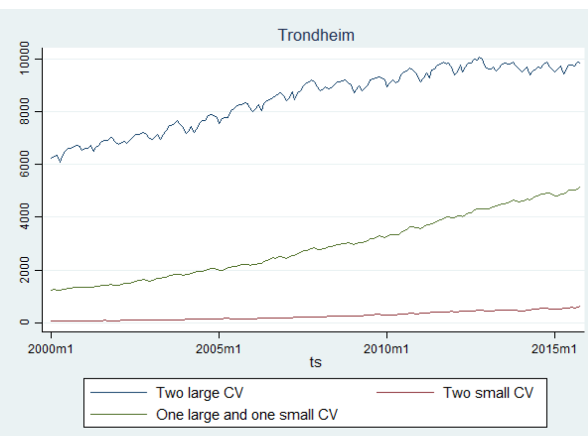


Figure D.3: Owners with two large, two small or one large and one small conventional car in Trondheim.

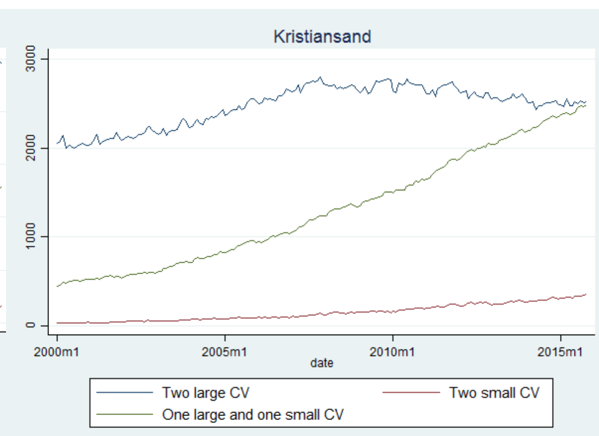


Figure D.4: Owners with two large, two small or one large and one small conventional car in Kristiansand.

E Fixed Effects Regression

We have in our fixed effect regression estimates utilized Oslo and year 2008 as base categories. Control variables includes population, unemployment, education, public transport and number of toll stations.

Table E.1: Regression of total vehicles with fixed effects for cities and years.

	(1)	(2)	(3)
	Total	Total	Total
Road toll	0.0120***	-0.00270	-0.00584**
	(0.00254)	(0.00297)	(0.00248)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.994	0.997	0.999
N	48	48	48

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.2: Regression of total electric vehicles with fixed effects for cities and years.

	(1)	(2)	(3)
	Total EV	Total EV	Total EV
Road toll	0.353***	0.0349**	0.0390**
	(0.0441)	(0.0152)	(0.0153)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.684	0.988	0.991
N	48	48	48

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.3: Regression of total conventional vehicles with fixed effects for cities and years.

	(1) Total CV	(2) Total CV	(3) Total CV
Road toll	0.00956***	-0.00286	-0.00587**
	(0.00235)	(0.00296)	(0.00249)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.995	0.997	0.999
N	48	48	48

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.4: Regression of single-homers holding one electric vehicle.

	(1) EV	(2) EV	(3) EV
Road toll	0.260***	0.0372***	0.0324**
	(0.0354)	(0.0125)	(0.0118)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.705	0.988	0.992
N	48	48	48

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.5: Regression of single-homers holding one conventional vehicle.

	(1) CV	(2) CV	(3) CV
Road toll	-0.000761	0.00112	-0.00342*
	(0.00286)	(0.00453)	(0.00205)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.993	0.994	0.999
N	48	48	48

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.6: Regression of multi-homers holding one conventional and electric vehicle.

	(1) CV+EV	(2) CV+EV	(3) CV+EV
Road toll	0.364***	-0.000328	-0.00179
	(0.0501)	(0.0189)	(0.0178)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.633	0.983	0.991
N	48	48	48

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.7: Regression of multi-homers holding one or two conventional and one electric vehicle.

	(1) 1or2CV+1EV	(2) 1or2CV+EV	(3) 1or2CV+EV
Road toll	0.336	0.0137	0.00827
	(0.0439)	(0.0153)	(0.0141)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.661	0.987	0.993
N	48	48	48

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.8: Regression of owners holding two conventional vehicles.

	(1) 2CV	(2) 2CV	(3) 2CV
Road toll	0.00250	0.00150	-0.00256
	(0.00301)	(0.00402)	(0.00203)
City dummies	Yes	Yes	Yes
Year dummies	No	Yes	Yes
Control variables	No	No	Yes
R^2	0.990	0.994	0.999
N	48	48	48

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

E.1 CO2-emission equivalents

Table E.9: 2015 market shares and CO2-emissions.

Car type	Market share	CO2 production	CO2 use
EV	17.1%	87 g/km	0 g/km short term, 73 g/km long term
ICE petrol	29.6%	43 g/km	119 g/km
ICE diesel	40.9%	43 g/km	132 g/km
ICE hybrid	12.4%	43 g/km	87.5 g/km

Weigthed CO2-emissions for use of conventional cars:

Share petrol ICE = $\frac{29.6}{40.9+29.6.+12.4} = 0.357$

Share diesel ICE = $\frac{40.9}{40.9+29.6.+12.4} = 0.4933$

Share hybrid ICE = $\frac{12.4}{40.9+29.6.+12.4} = 0.1496$

Average CO2 g/km = $(0.357 \times 119) + (0.4933 \times 132) + (0.1496 \times 87.5) = 120.6$

How many conventional cars must be replaced to maintain or reduce CO2-emissions if the number of electric cars increases by 268:

Short term:

CO2-emissions 488 electric cars:

$$87g/km \times 150\ 000km \times 488 = 6\ 368\ 400\ 000g$$

CO2-emissions per conventional car:

$$(43 + 120.6)g/km \times 150\ 000km = 24\ 540\ 000g$$

Lifetime adjusted CO2-emissions per conventional car:

$$24\ 540\ 000g \times 0.967 = 23\ 730\ 180$$

Minimum reduction of conventional cars:

$$\frac{6\ 368\ 400\ 000}{23\ 730\ 180} = 268$$

Long term:

CO2-emissions 488 electric cars:

$$(87 + 73)g/km \times 150\ 000km \times 488 = 11\ 712\ 000\ 000g$$

CO2-emissions per conventional car:

$$(43 + 120.6)g/km \times 150\ 000km = 24\ 540\ 000g$$

Lifetime adjusted CO2-emissions per conventional car:

$$24\ 540\ 000g \times 0.967 = 23\ 730\ 180$$

Minimum reduction of conventional cars:

$$\frac{11\ 712\ 000\ 000g}{23\ 730\ 180} = 494$$

F Fosen

Following postal numbers have been included in the analysis from Fosen: 7100, 7101, 7105, 7110, 7112, 7113, 7114, 7119, 7120, 7121, 7125 7126.

F.1 Figures

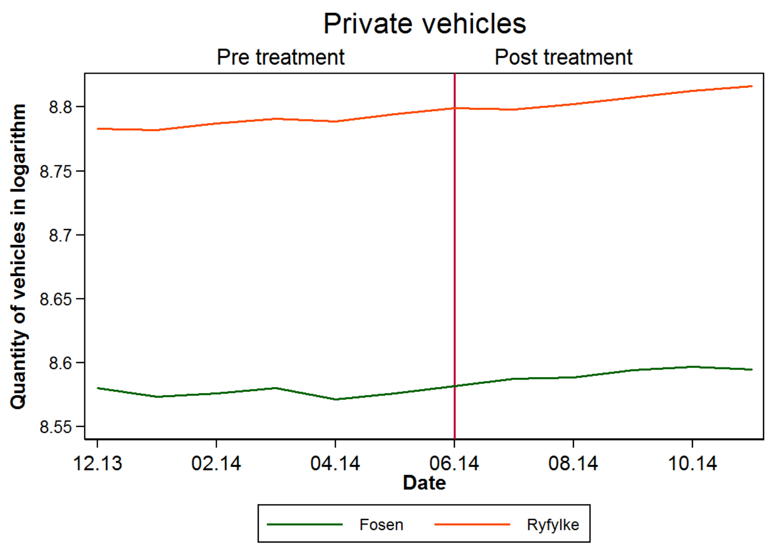


Figure F.1: Total number of vehicles in Fosen & Ryfylke in logarithm.

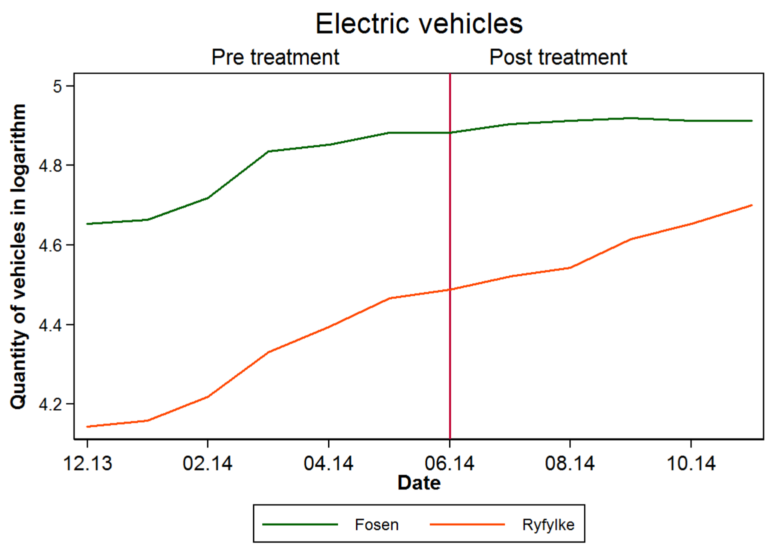


Figure F.2: Total number of electric vehicles in Fosen & Ryfylke in logarithm.

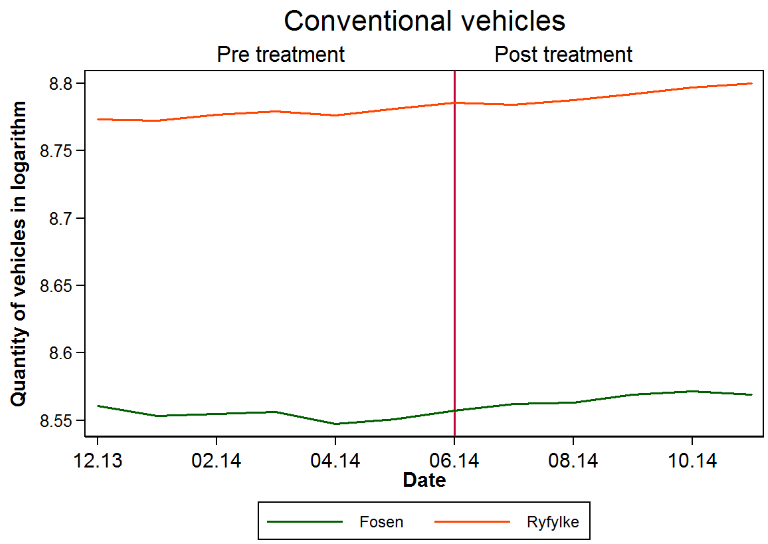


Figure F.3: Total number of conventional vehicles in Fosen & Ryfylke in logarithm.

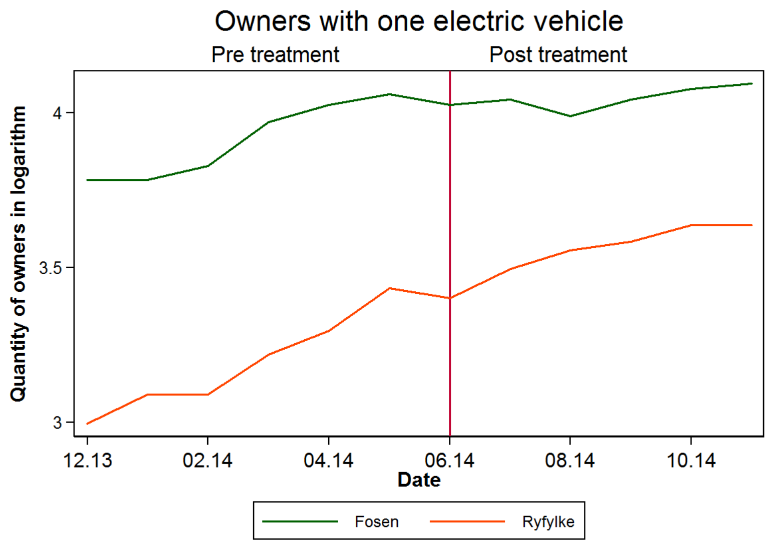


Figure F.4: Owners with one electric vehicle in Fosen & Ryfylke in logarithm.

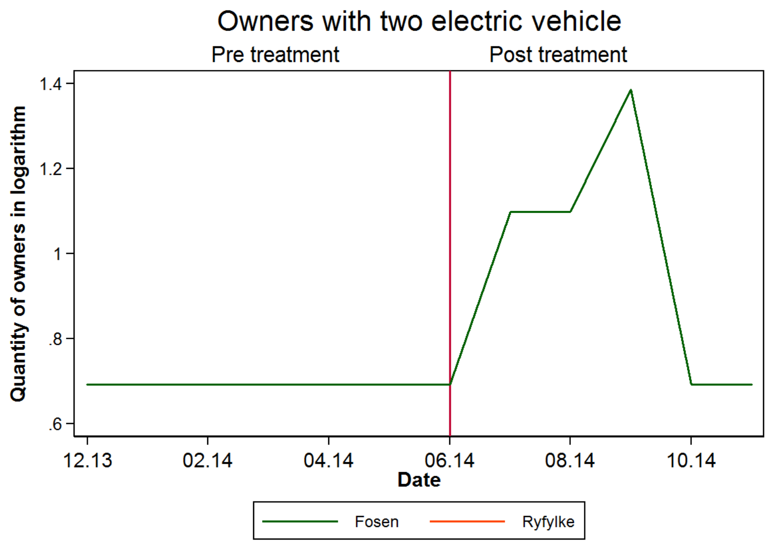


Figure F.5: Owners with two electric vehicles in Fosen & Ryfylke in logarithm.

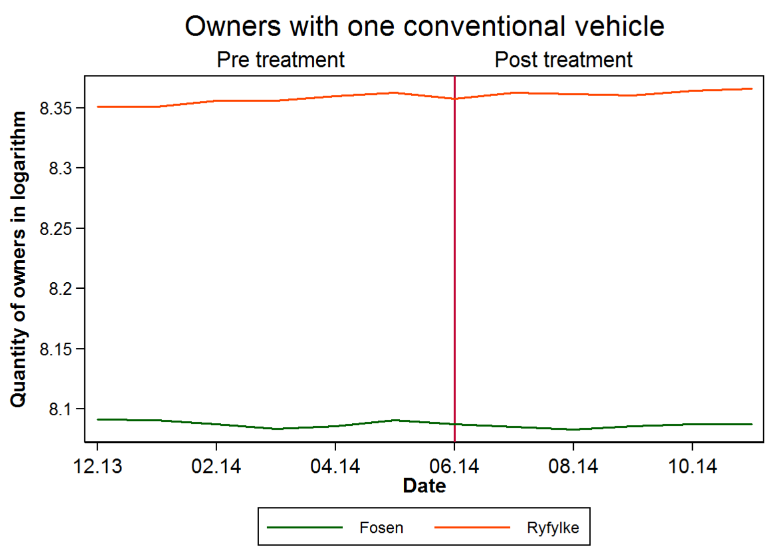


Figure F.6: Owners with one conventional vehicle in Fosen & Ryfylke in logarithm.

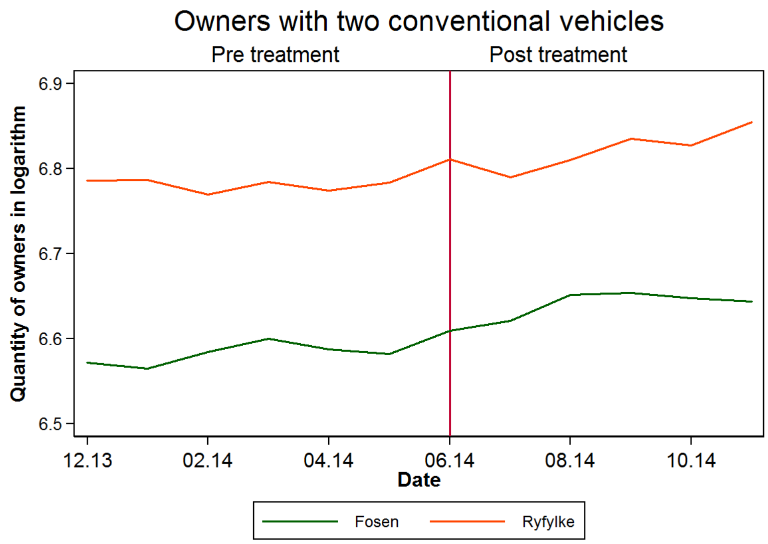


Figure F.7: Owners with two conventional vehicles in Fosen & Ryfylke in logarithm.

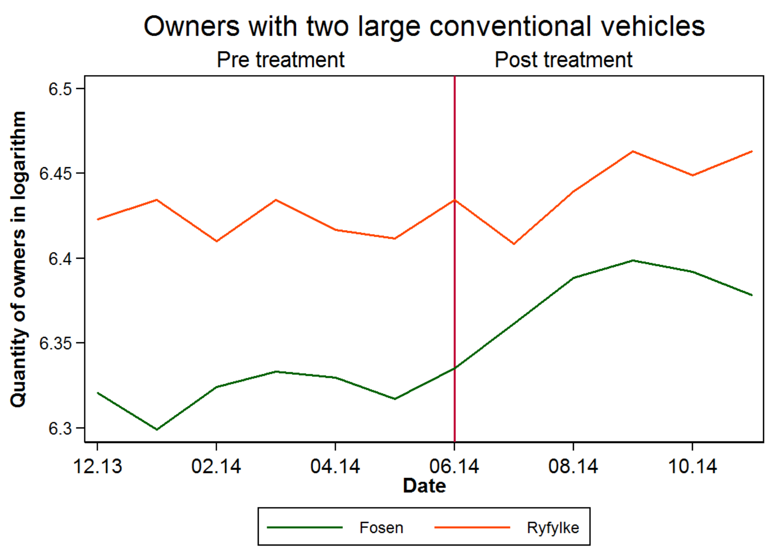


Figure F.8: Owners with two large conventional vehicles in Fosen & Ryfylke in logarithm.

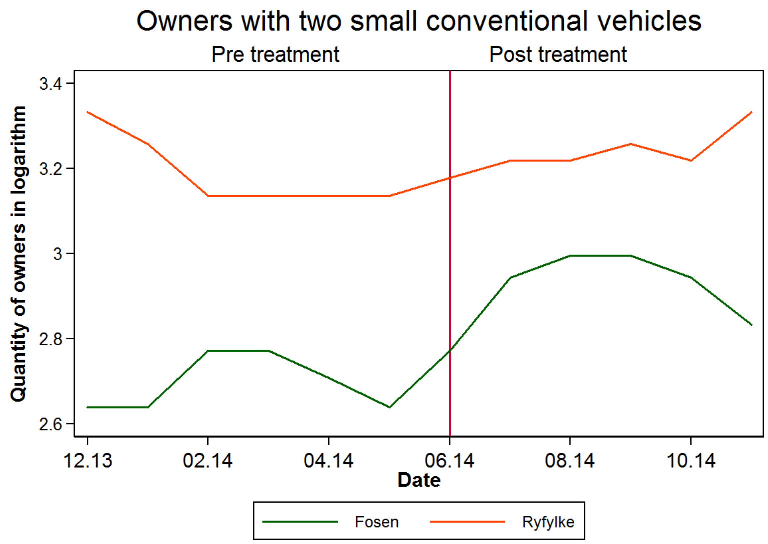


Figure F.9: Owners with two small conventional vehicle in Fosen & Ryfylke in logarithm.

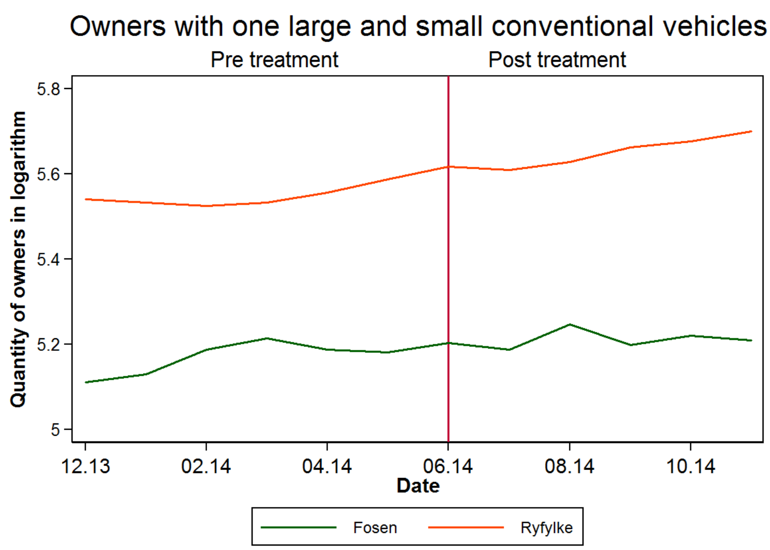


Figure F.10: Owners with one large and one small conventional vehicle in Fosen & Ryfylke in logarithm.

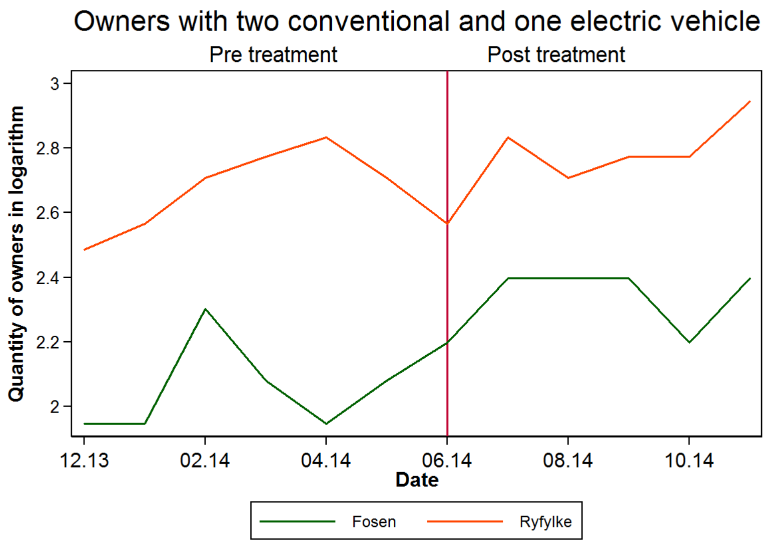


Figure F.11: Owners with two conventional and one electric vehicle in Fosen & Ryfylke in logarithm.

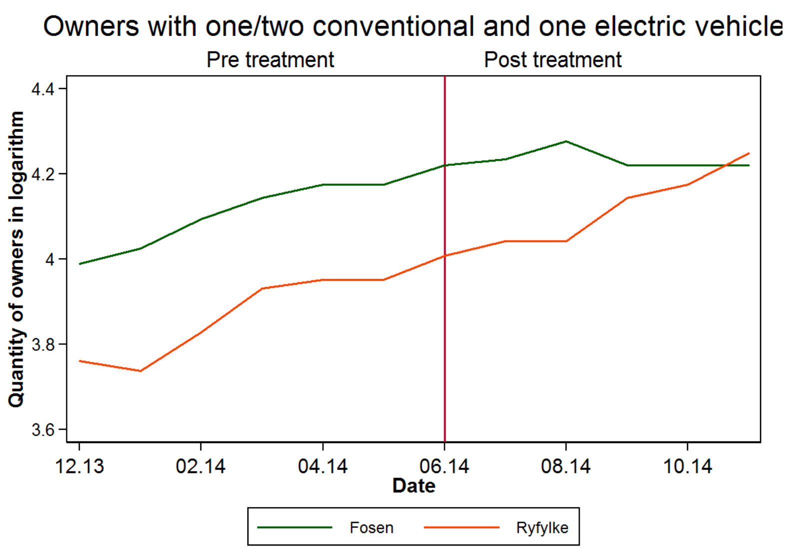


Figure F.12: Owners with one/two conventional and one electric vehicle in Fosen & Ryfylke in logarithm.

F.2 Regression Estimates

Table F.1: Estimates from regressions of private electric vehicles owners in logarithm.

	(1) EV	(2) 2EV
Dummy Fosen	0.72***	
	(0.065)	
Post treatment	0.36***	0.25
	(0.065)	(0.12)
Treatment effect Fosen	-0.23*	
	(0.092)	
Intercept	3.19***	0.69***
	(0.046)	(0.085)
N	24	12
R^2	0.913	0.304

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table F.2: Estimates from regressions of private conventional car owners.

	(1) CV	(2) 2CV	(3) 2LCV	(4) 2SCV	(5) LCV+SCV
Dummy Fosen	-0.27***	-0.20***	-0.10***	-0.49***	-0.38***
	(0.0019)	(0.0093)	(0.010)	(0.044)	(0.018)
Post treatment	0.0059**	0.041***	0.021	0.049	0.10***
	(0.0019)	(0.0093)	(0.010)	(0.044)	(0.018)
Treatment effect Fosen	-0.0081**	0.015	0.034*	0.17*	-0.061*
	(0.0027)	(0.013)	(0.014)	(0.062)	(0.025)
Intercept	8.36***	6.78***	6.42***	3.19***	5.55***
	(0.0014)	(0.0066)	(0.0072)	(0.031)	(0.013)
N	24	24	24	24	24
R^2	0.999	0.978	0.894	0.910	0.982

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table F.3: Estimates from regressions of multi-homers in logarithm.

	(1) CV+EV	(2) 2CV+1EV	(3) 1or2CV+1EV
Dummy Fosen	0.47***	-0.63***	0.24***
	(0.047)	(0.073)	(0.046)
Post treatment	0.31***	0.087	0.25***
	(0.047)	(0.073)	(0.046)
Treatment effect Fosen	-0.21**	0.19	-0.12
	(0.067)	(0.10)	(0.065)
Intercept	3.49***	2.68***	3.86***
	(0.033)	(0.051)	(0.032)
N	24	24	24
R^2	0.894	0.861	0.777

Standard errors in parentheses

G Askøy

G.1 Figures

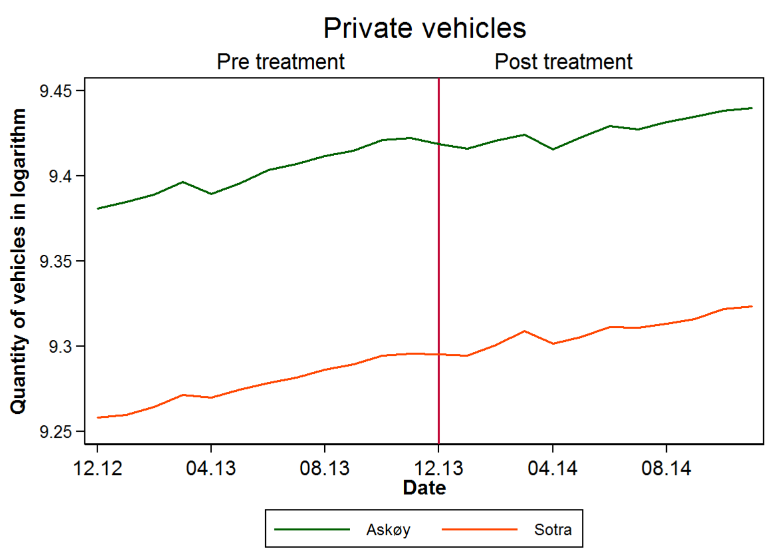


Figure G.1: Total number of vehicles in Askøy & Sotra in logarithm.

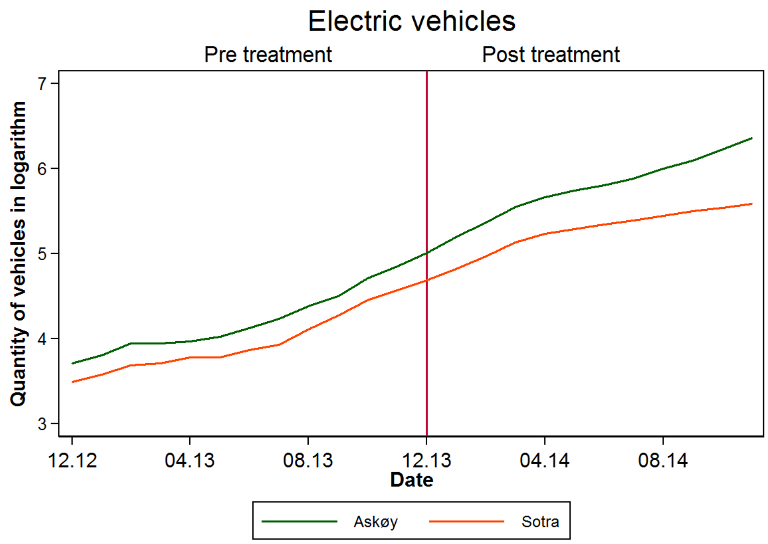


Figure G.2: Total number of electric vehicles in Askøy & Sotra in logarithm.

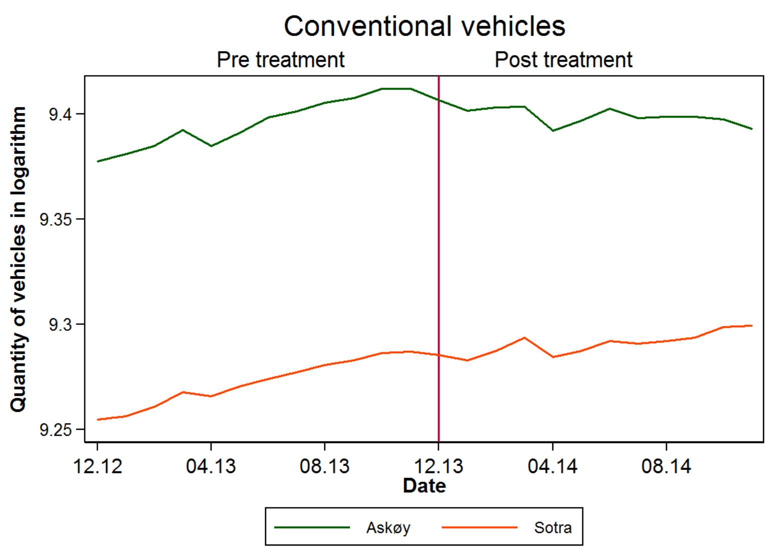


Figure G.3: Total number of conventional vehicles in Askøy & Sotra in logarithm.

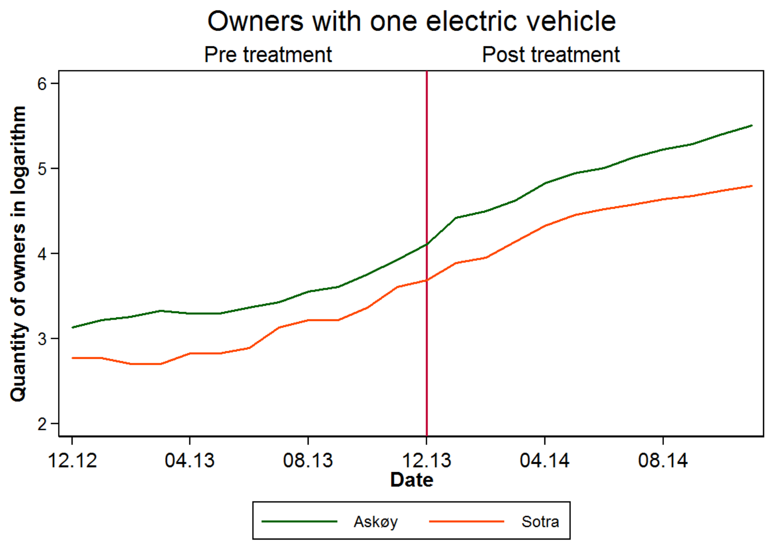


Figure G.4: Owners with one electric vehicle in Askøy & Sotra in logarithm.

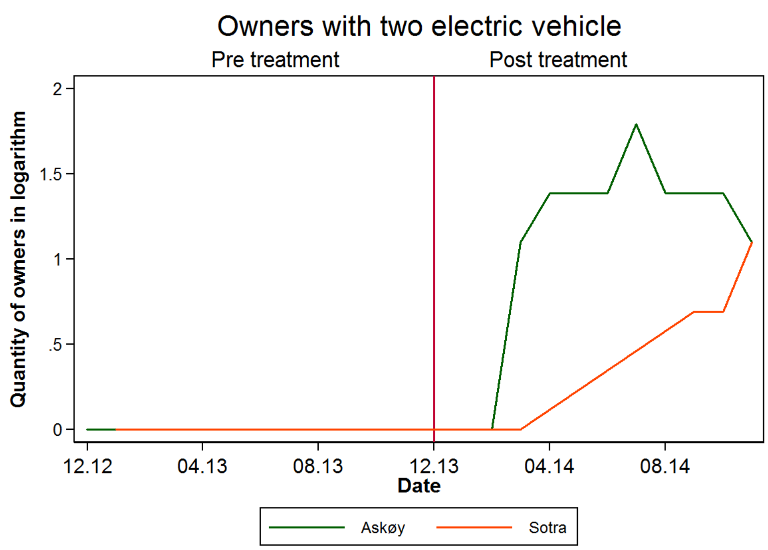


Figure G.5: Owners with two electric vehicles in Askøy & Sotra in logarithm.

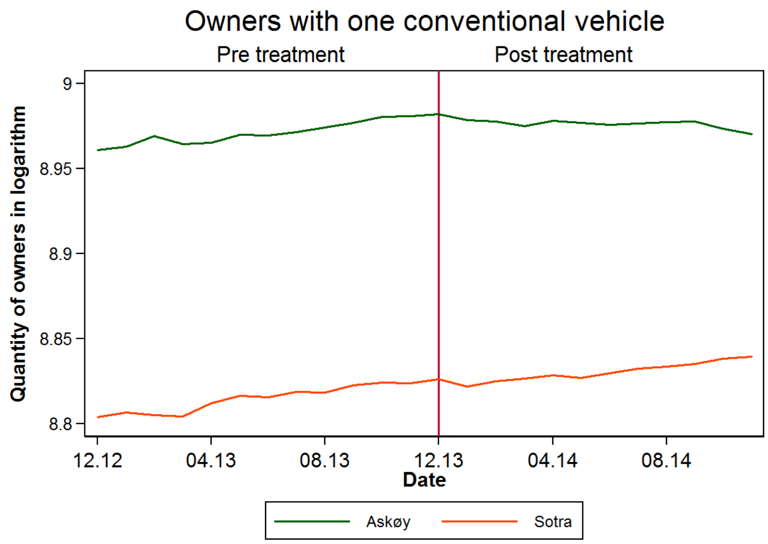


Figure G.6: Owners with one conventional vehicle in Askøy & Sotra in logarithm.

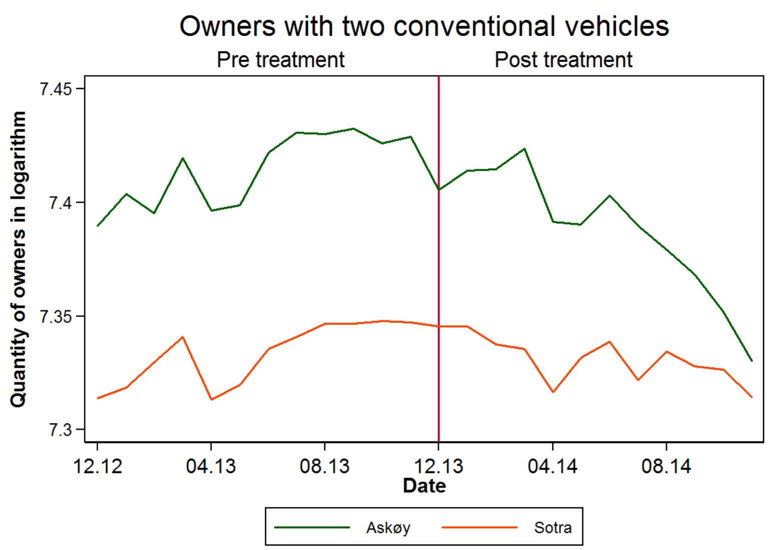


Figure G.7: Owners with two conventional vehicles in Askøy & Sotra in logarithm.

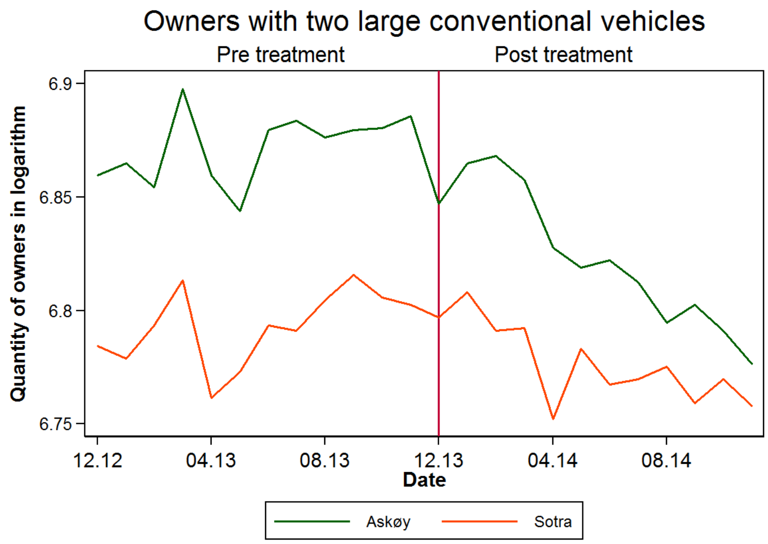


Figure G.8: Owners with two large conventional vehicles in Askøy & Sotra in logarithm.

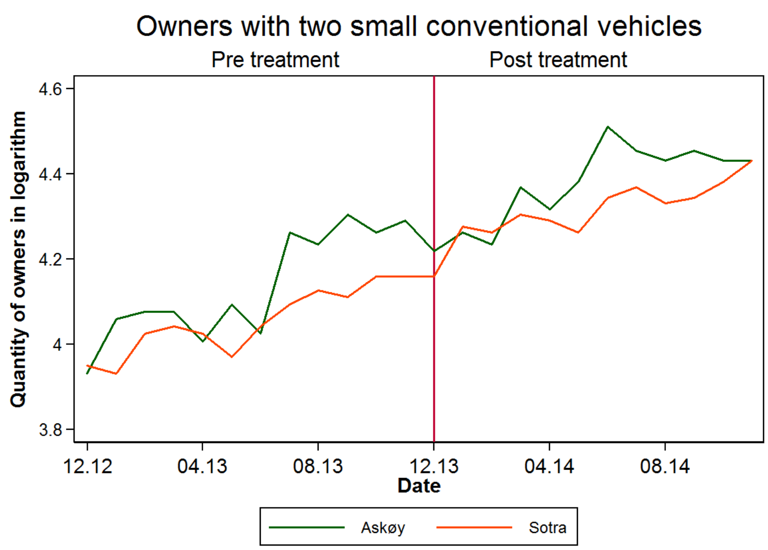


Figure G.9: Owners with two small conventional vehicle in Askøy & Sotra in logarithm.

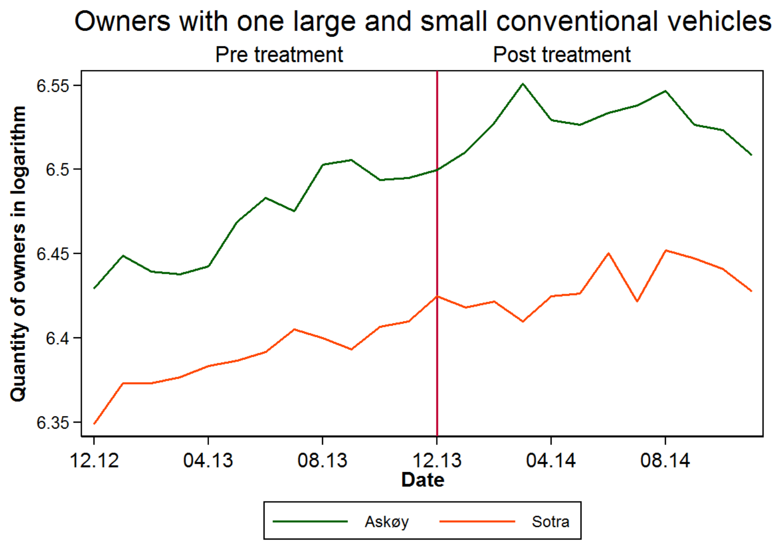


Figure G.10: Owners with one large and one small conventional vehicle in Askøy & Sotra in logarithm.

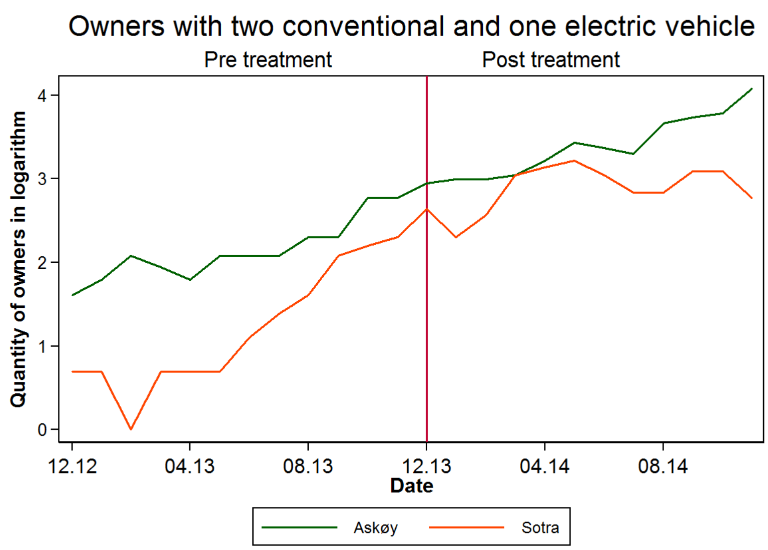


Figure G.11: Owners with two conventional and one electric vehicle in Askøy & Sotra in logarithm.

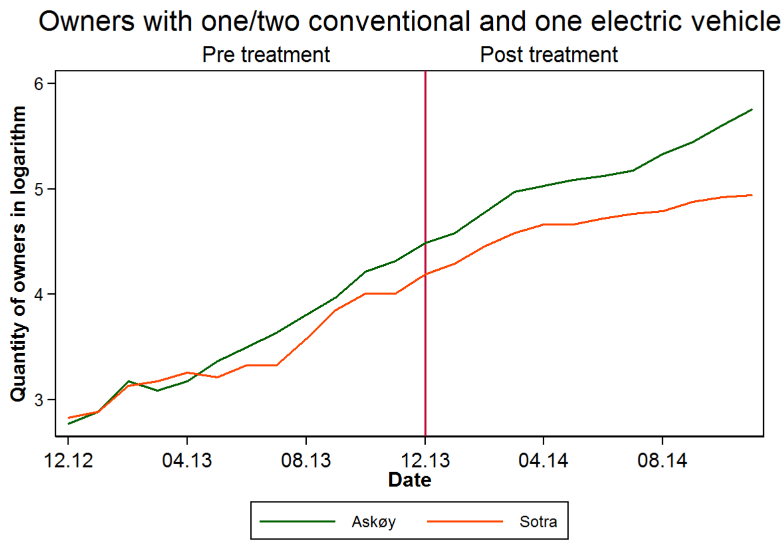


Figure G.12: Owners with two large conventional vehicles in Askøy & Sotra in logarithm.

G.2 Regression Estimates

Table G.1: Estimates from regressions of private electric vehicles owners in logarithm.

	(1) EV	(2) 2EV
Dummy Askøy	0.43**	-3.2e-16
	(0.14)	(0.21)
Post treatment	1.36***	0.50*
	(0.14)	(0.22)
Treatment effect Askøy	0.12	0.73*
	(0.20)	(0.28)
Intercept	3.01***	1.1e-16
	(0.098)	(0.15)
N	48	27
R^2	0.842	0.738

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table G.2: Estimates from regressions of private conventional car owners.

	(1) CV	(2) 2CV	(3) 2LCV	(4) 2SCV	(5) LCV+SCV
Dummy Askøy	0.16***	0.081***	0.079***	0.082*	0.081***
	(0.0024)	(0.0074)	(0.0085)	(0.039)	(0.0079)
Post treatment	0.016***	-0.0021	-0.016	0.26***	0.043***
	(0.0024)	(0.0074)	(0.0085)	(0.039)	(0.0079)
Treatment effect Askøy	-0.0099**	-0.024*	-0.032*	-0.021	0.015
	(0.0034)	(0.010)	(0.012)	(0.055)	(0.011)
Intercept	8.81***	7.33***	6.79***	4.05***	6.39***
	(0.0017)	(0.0052)	(0.0060)	(0.028)	(0.0056)
N	48	48	48	48	48
R^2	0.994	0.809	0.768	0.669	0.884

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table G.3: Estimates from regressions of multi-homers in logarithm.

	(1) CV+EV	(2) 2CV+1EV	(3) 1or2CV+1EV
Dummy Askøy	-0.070	0.96***	0.11
	(0.17)	(0.19)	(0.16)
Post treatment	1.20***	1.70***	1.27***
	(0.17)	(0.19)	(0.16)
Treatment effect Askøy	0.53*	-0.46	0.35
	(0.24)	(0.27)	(0.23)
Intercept	3.26***	1.18***	3.39***
	(0.12)	(0.14)	(0.11)
N	48	48	48
R^2	0.786	0.774	0.795

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

H Kristiansand

H.1 Figures

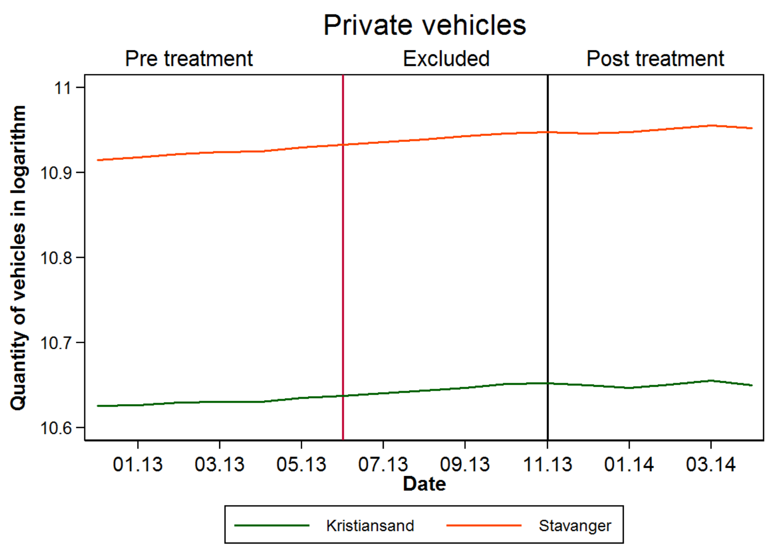


Figure H.1: Total number of vehicles in Kristiansand & Stavanger in logarithm.

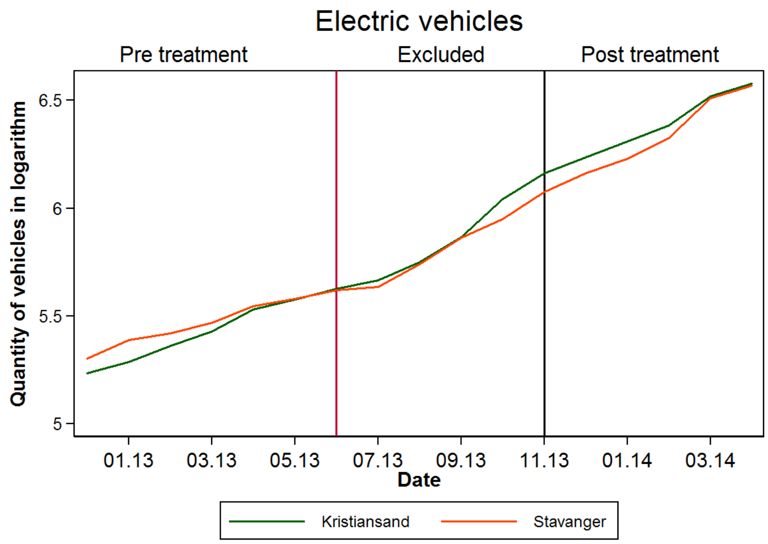


Figure H.2: Total number of electric vehicles in Kristiansand & Stavanger in logarithm.

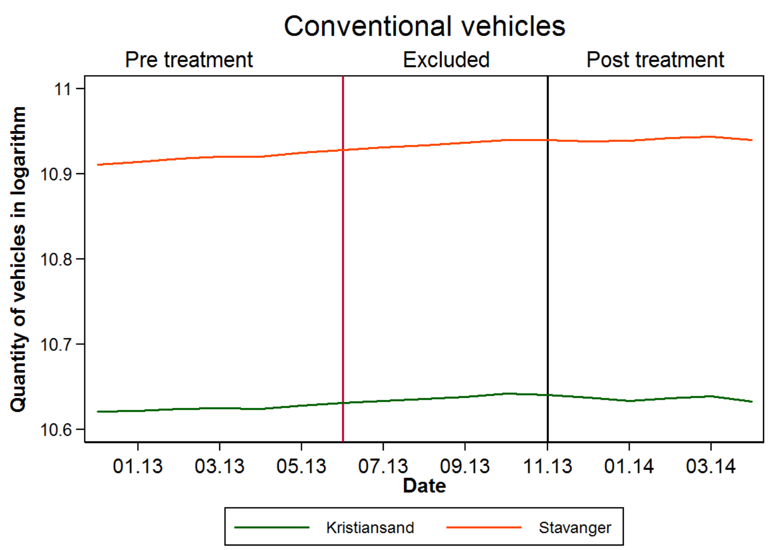


Figure H.3: Total number of conventional vehicles in Kristiansand & Stavanger in logarithm.

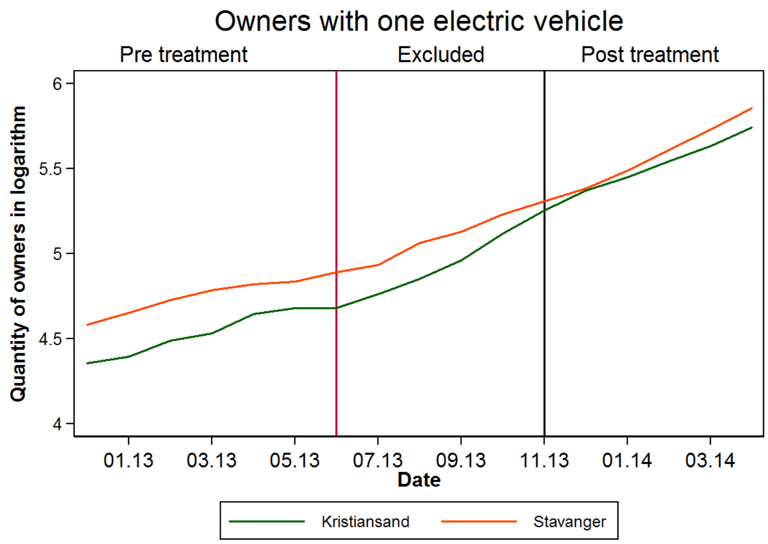


Figure H.4: Owners with one electric vehicle in Kristiansand & Stavanger in logarithm.

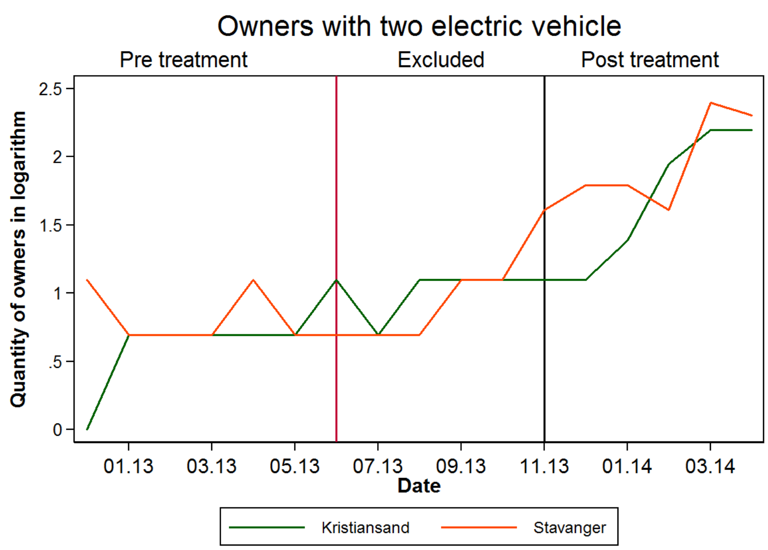


Figure H.5: Owners with two electric vehicles in Kristiansand & Stavanger in logarithm.

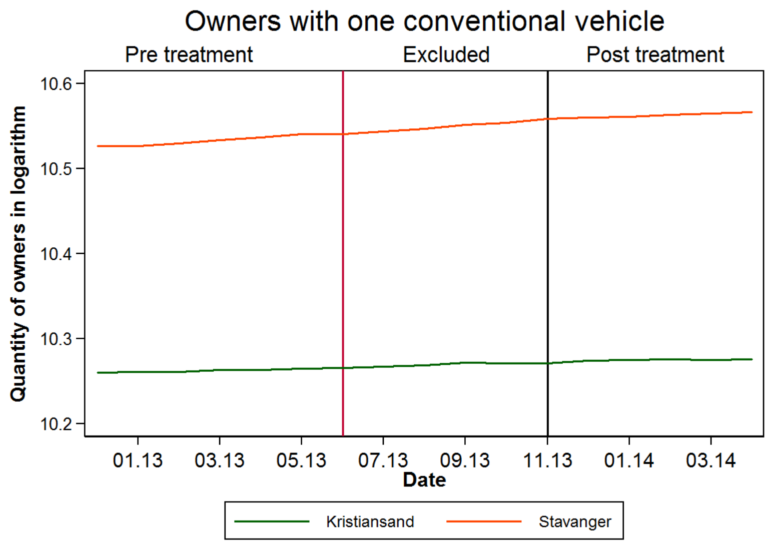


Figure H.6: Owners with one conventional vehicle in Kristiansand & Stavanger in logarithm.

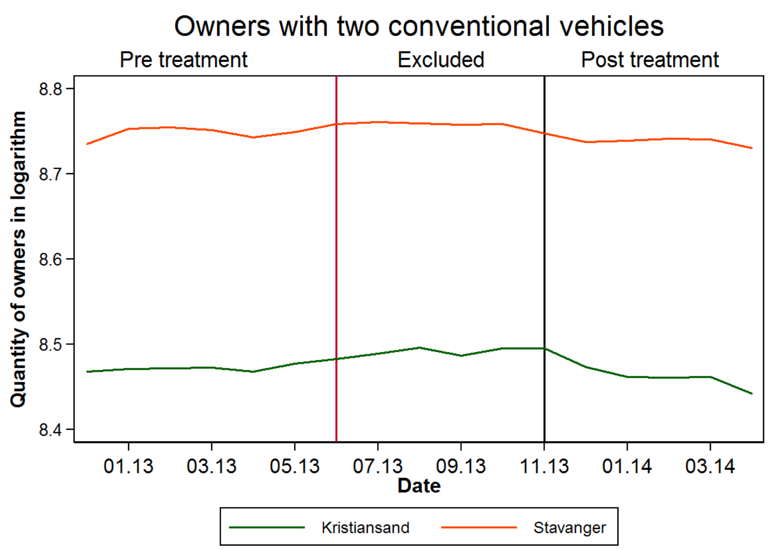


Figure H.7: Owners with two conventional vehicles in Kristiansand & Stavanger in logarithm.

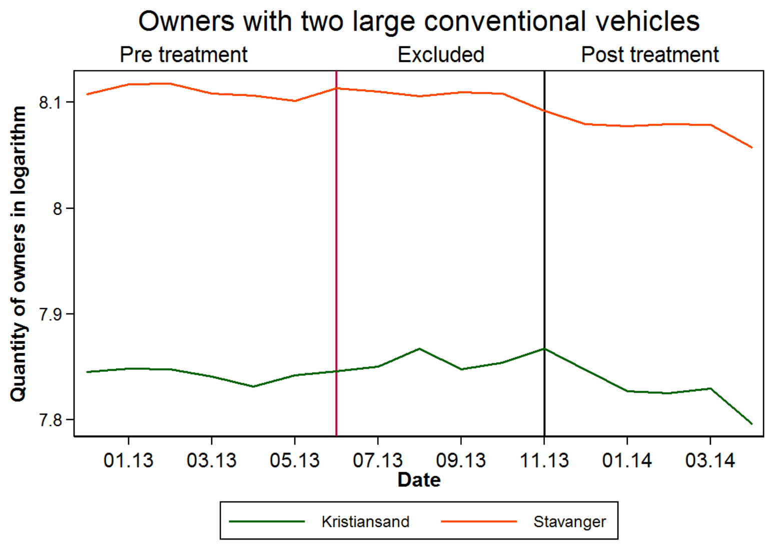


Figure H.8: Owners with two large conventional vehicles in Kristiansand & Stavanger in logarithm.

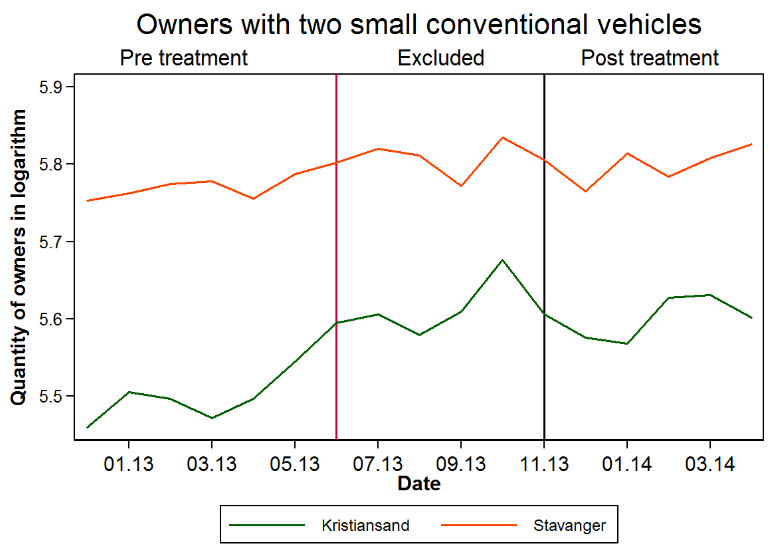


Figure H.9: Owners with two small conventional vehicle in Kristiansand & Stavanger in logarithm.

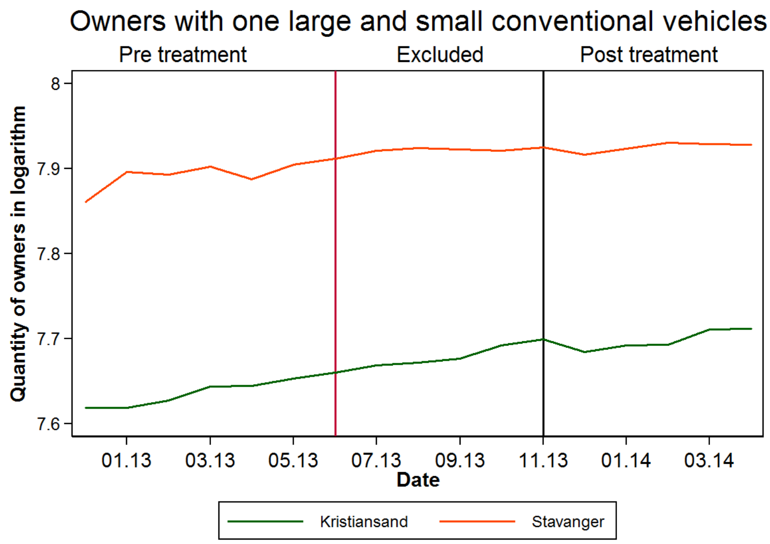


Figure H.10: Owners with one large and one small conventional vehicle in Kristiansand & Stavanger in logarithm.

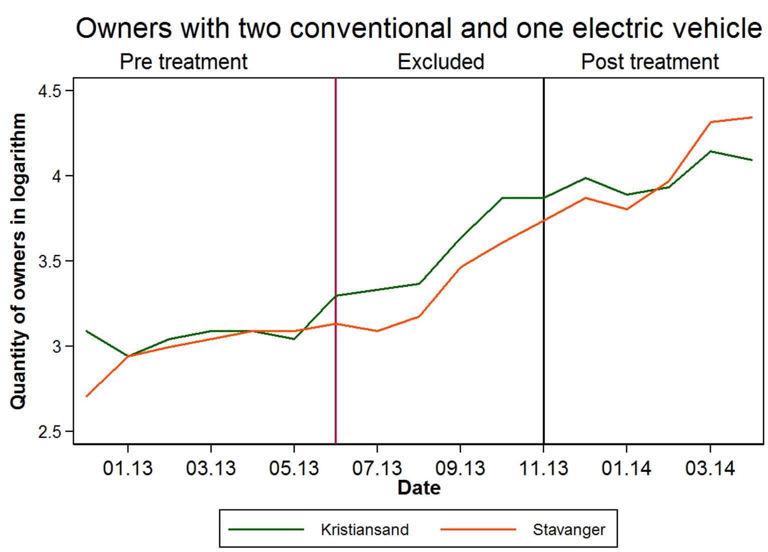


Figure H.11: Owners with two conventional and one electric vehicle in Kristiansand & Stavanger in logarithm.

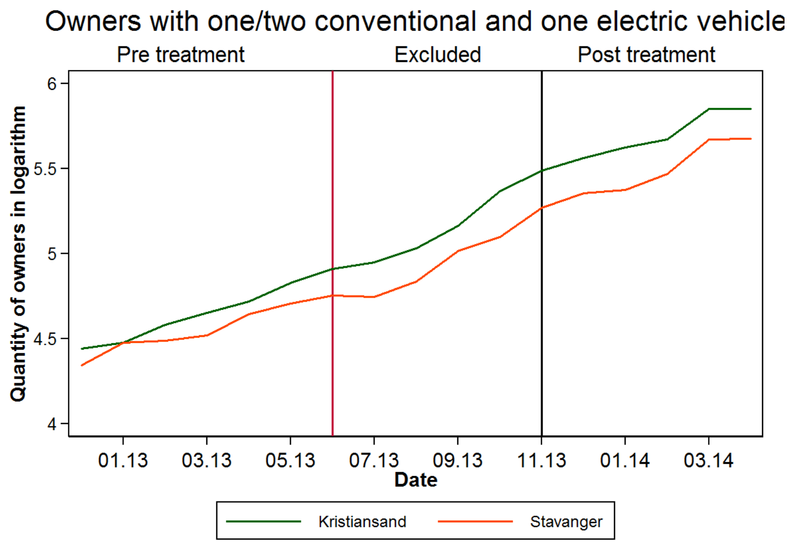


Figure H.12: Owners with two large conventional vehicles in Kristiansand & Stavanger in logarithm.

H.2 Regression Estimates

Table H.1: Estimates from regressions of private electric vehicles owners in logarithm.

	(1) EV	(2) 2EV
Dummy Kristiansand	-0.22*	-0.25
	(0.092)	(0.21)
Post treatment	0.83***	1.09***
	(0.092)	(0.21)
Treatment effect Kristiansand	0.15	-0.012
	(0.13)	(0.29)
Intercept	4.74***	0.83***
	(0.065)	(0.15)
N	24	24
R^2	0.908	0.742

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table H.2: Estimates from regressions of private conventional car owners.

	(1) CV	(2) 2CV	(3) 2LCV	(4) 2SCV	(5) LCV+SCV
Dummy Kristiansand	-0.27***	-0.28***	-0.27***	-0.27***	-0.26***
	(0.0020)	(0.0058)	(0.0081)	(0.014)	(0.0071)
Post treatment	0.030***	-0.0084	-0.032***	0.032*	0.035***
	(0.0020)	(0.0058)	(0.0081)	(0.014)	(0.0071)
Treatment effect Kristiansand	-0.018***	0.0030	0.022	0.074**	0.029**
	(0.0028)	(0.0082)	(0.011)	(0.019)	(0.010)
Intercept	10.5***	8.75***	8.11***	5.77***	7.89***
	(0.0014)	(0.0041)	(0.0057)	(0.0096)	(0.0050)
N	24	24	24	24	24
R^2	0.999	0.996	0.990	0.971	0.992

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table H.3: Estimates from regressions of multi-homers in logarithm.

	(1) CV+EV	(2) 2CV+1EV	(3) 1or2CV+1EV
Dummy Kristiansand	0.088	0.072	0.087
	(0.090)	(0.093)	(0.086)
Post treatment	0.91***	1.03***	0.94***
	(0.090)	(0.093)	(0.086)
Treatment effect Kristiansand	0.18	-0.093	0.12
	(0.13)	(0.13)	(0.12)
Intercept	4.29***	2.98***	4.53***
	(0.064)	(0.066)	(0.061)
N	24	24	24
R^2	0.928	0.917	0.932

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

References

Ambrus, A. & Reisinger, M. (2006). *Exclusive vs overlapping viewers in media markets*. Retrieved September 12, 2016, from http://nbn-resolving.de/urn/resolver.pl?urn=nbn:de:bvb:19-epub-13390-9

Anderson, S., Foros, Ø., & Kind, H. J. (2016). *Hotelling competition with multi-purchasing*. Retrieved September 12, 2016, from https://brage.bibsys.no/xmlui/handle/11250/166318

Angrist, J. D. & Pischke, J.-S. (2009). *Mostly harmless econometrics*. Princeton: Princeton University Press.

Bertrand, M., Duflo, E., & Mullainathan, S. (2004). How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics*, *119*(1), 249–275.

Cazzola, P. & Gorner, M. (2016). *Global EV Outlook 2016*. International Energy Agency. Retrieved December 16, 2016, from https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf

Economides, N. (1993). Hotelling's "main street" with more than two competitors*. *Journal of Regional Science*, *33*(3), 303–319.

Fearnley, N., Pfaffenbichler, P., Figenbaum, E., & Jellinek, R. (2015). *E-vehicle policies and incentives - assessment and recommendations*. Institute of Transport Economics. Retrieved July 12, 2016, from https://www.toi.no/getfile.php?mmfileid=41187

Figenbaum, E. & Kolbenstvedt, M. (2016). *Learning from norwegian battery electric and plug-in hybrid vehicle users*. Institute of Transport Economics. Retrieved October 8, 2016, from https://www.toi.no/getfile.php?mmfileid=43161

Gabszewicz, J. & Wauthy, X. (2003). The option of joint purchase in vertically differentiated markets. *Economic Theory*, *22*(4), 817–829.

Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H. (2013, February). Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology*, *17*(1), 53–64.

Hjorthol, R., Engebretsen, Ø., & Uteng, T. P. (2014). Den nasjonale reisevaneundersøkelsen 2013/14. Retrieved August 30, 2016, from https://www.toi.no/getfile.php?mmfileid=39511

Hotelling, H. (1929). Stability in competition. *The Economic Journal*, *39*(153), 41.

Kim, H. & Serfes, K. (2006). A location model with preference for variety. *The Journal of Industrial Economics*, *54*(4), 569–595.

Lancaster, K. (1979). *Variety, equity, and efficiency: product variety in an industrial society*. New York City: Columbia University Press. Retrieved September 12, 2016, from https://books.google.no/books?id=WTdSAQAAIAAJ

Ministry of Climate and Environment. (2007). *Norsk klimapolitikk. Meld. St. 34 (2006-2007)*. White paper, Oslo. Retrieved September 9, 2016, from https://www.regjeringen.no/no/dokumenter/Stmeld-nr-34-2006-2007-/id473411/

Ministry of Climate and Environment. (2012). *Norsk klimapolitikk. Meld. St. 21 (2011-2012)*. White paper, Oslo. Retrieved September 9, 2016, from https://www.regjeringen.no/no/dokumenter/meld-st-21-2011-2012/id679374/

Ministry of Petroleum and Energy. (2016). *Kraft til endring - Energipolitikken mot 2030. Meld. St. 25 (2015-2016)*. White paper, Oslo. Retrieved from https://www.regjeringen.no/contentassets/31249efa2ca6425cab08130b35ebb997/no/pdfs/stm201520160025000dddpdfs.pdf

Minken, H. (2005). *Road pricing, public transport and equity*. Institute of Transport Economics. Retrieved December 5, 2016, from https://www.toi.no/getfile.php?mmfileid=1780

Mussa, M. & Rosen, S. (1978). Monopoly and product quality. *Journal of Economic Theory*, *18*(2), 301–317.

Nenseth, V. & Hjorthol, R. (2007). *Sosiale trenders betydning for bilbruk*. Institute of Transport Economics. Retrieved September 20, 2016, from https://www.toi.no/getfile.php?mmfileid=5879

OECD. (n.d.). The automobile industry in and beyond the crisis. *2009*. Retrieved December 15, 2016, from /content/chapter/eco_outlook-v2009-2-3-en

Oslo Economics. (2015). *Elbilens konkurransedyktighet i norge: Rapport utarbeidet for NAF*. Oslo Economics. Retrieved August 30, 2016, from https://www.naf.no/globalassets/dokumenter/politikk/elbilenskonkurransedyktighetnorge.pdf

Sæter, E. (2016, January 5). -Ingen unnskyldninger lenger. *Dagens Næringsliv*. Retrieved November 30, 2016, from http://www.dn.no/privat/dnBil/2016/01/05/2045/Bilsalg/ingen-unnskyldninger-lenger

Salop, S. C. (1979). Monopolistic competition with outside goods. *The Bell Journal of Economics*, *10*(1), 141–156.

Tirole, J. (1988). *The theory of industrial organization*. Cambridge: The MIT Press.

Völler, S., Wolfgang, O., & Korpås, M. (2014). *Energi- og miljøpåvirkning av elbil systemanalyse med emps*. Sintef Energi. Retrieved December 1, 2016, from https://www.sintef.no/globalassets/sintef-energi/programvare/tr-a7385.pdf

Wooldridge, J. (2013). *Introduction to econometrics*. Hampshire: Cengage Learning EMEA.