



Empirical studies on Environment-Friendly Vehicles in Japan

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(日本におけるエコカーの政策についての計量分析)

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1.Introduction

Ever since the Kyoto protocol, developed countries such as the United States, Japan and several European countries started implementing policies and programs to attain the CO₂ emission targets committed in the protocol. One of the targeted sectors for these initiatives is the transportation sector. According to a 2015 study by the EPA,¹ the transportation sector in the United States accounts for 27% of all greenhouse gas emissions, second only to the electricity sector that accounts for 29%. Within the transportation sector, 60% of total emissions are due to light-duty vehicles.² In the case of Japan, according to a 2015 study by JCCCA,³ the transportation sector contributes 17% of direct CO₂ emission and 17% of indirect CO₂ emissions. The case for Japan is less severe in terms of transportation sector emissions but it is still not negligible.

The Japanese government have introduced several subsidies, tax cuts and green tax programs aimed at the passenger vehicle market. The goal of most of these policies is to encourage consumers to buy vehicles that emit less CO₂, also called environment-friendly vehicles. Some policies targeted the transport sector indirectly, such as subsidizing the initial cost of charging stations for electric vehicles. Considering the various types of policies aimed at passenger vehicles, there is no doubt that understanding the impact of such policies is important for promoting these vehicles.

In this study, we will empirically analyze policies either directly or indirectly aimed at environment-friendly vehicles in the Japanese market. Having a diversity of incentives for different levels of environment-friendly vehicles makes the Japanese automobile market a good candidate for our empirical analysis. We will cover three major topics in this paper: the effect

¹ <https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions>

² A vehicle with a weight of 3,500kg or less.

³ http://www.jccca.org/chart/chart04_04.html

of tax incentives on sales of environment-friendly vehicles; the impact of charging infrastructure on sales electric vehicles; and the relationship between catalogue fuel efficiency and real fuel efficiency.

In the Chapter 2, we will study the tax incentives that were introduced in the Japanese market in 2009 and aimed at environment-friendly vehicles. Our objective is to see how much did the tax incentives contributed to that sharp increase of the sales of environment-friendly vehicles observed after the introduction of the tax incentives. The tax incentives constitute of tax cuts and subsidies for buying an environment-friendly vehicle. We will use the sales data of the top selling 30 vehicles in Japan and regress it on variables representing the tax cuts and subsidies alongside other control variables such as car price, gasoline price and income per capita. The contribution of this chapter is twofold. First, we use many different ranges for environment-friendly vehicles. From hybrid-electric vehicles to other vehicles that are less fuel efficient but still fall under the environment-friendly vehicle category. Second, the structure of the tax incentives in Japan allows us to test direct tax cuts at the point of purchase that range from total tax exemptions to a 50% tax cut. The results show that tax cuts were the most significant contributor to the increase of sales of environment-friendly vehicles. Subsidies came second and other factors such as gasoline price weren't as significant of a determinant for the sample.

In Chapter 3, we examine the role of charging infrastructure investment in promoting the sales of electric vehicles. Electric vehicles emit less carbon dioxide than other environment-friendly vehicles, including hybrid-electric vehicles. This is conditional on the amount of CO₂ emissions that is generated from electricity production. In the case of Japan, even considering that, electric vehicle emissions are lower. There are many hurdles that must be overcome for the sales of electric vehicles to increase. One hurdle is that many consumers consider electric vehicles as new technology and they are not willing to risk buying something that has not been

tested thoroughly. Another hurdle is the driving range of an electric vehicle, which is shorter than other types of vehicles. This causes an anxiety for consumers of not being able to drive for long distances. This anxiety can be alleviated if there are enough charging stations for consumers to charge their vehicles. In 2009, the Japanese government introduced a policy that subsidized half of the cost of constructing a charging station. In this analysis, we estimate the effect of this policy on the sales of electric vehicles. We use the sales data of the Nissan leaf from 2011 and 2012 for 49 prefectures in Japan and regress it on the number of new charging stations that received the subsidy. We also use other control variables in the estimation such as gasoline price, electricity price and average driving distance for each region. The contribution of this study is twofold. First, we develop a simple theoretical model explaining the buying decision for a green consumer of an electric vehicle. Second, we use real sales data of electric vehicles to measure the effect of charging stations on the demand. The result shows that charging stations had a positive but modest effect on the sales of electric vehicles. Also, the result suggests that longer average driving distances affected sales of electric vehicles negatively. This shows that consumers in regions with longer driving distances were buying less electric vehicles, which suggests that the range anxiety effect is stronger than the fuel-cost saving and potential CO₂ abatement effect from driving an electric vehicle. We also did a simple simulation of the abatement cost and found out that the abatement cost for subsidizing charging stations is more expensive than the other measures of abatement cost. However, this is conditional on the initial quantity of electric vehicle of the sample and the cost-effectiveness could be better with a larger initial quantity of electric vehicles.

In Chapter 4, we explore the relationship between fuel efficiency and data manipulation. Policies for promoting environment-friendly vehicles define the performance based on catalogue fuel efficiency, or the fuel efficiency obtained from a lab test. According to research

done by the European Federation for Transport and Environment (T&E),⁴ a gap exists between fuel efficiencies experienced on-road by drivers and the fuel efficiencies that are obtained from lab tests. Although it is natural to see a gap due to driving behavior and other conditions, according to the study, there is a consistent pattern with this gap between real fuel efficiency and catalogue fuel efficiency that can be observed in the European countries included. The recent case of the Mitsubishi fuel efficiency manipulation suggests the possibility that automobile companies might manipulate the numbers that would simulate the on-road conditions in order to make fuel efficiency seem better in the test. The statistics from the study of T&E about the fuel efficiency gap might suggest that these manipulation incidents could be a widespread problem in Europe. This chapter aims to test whether this is true for the Japanese automobile market or not. We investigate this by empirically testing three hypotheses. First, we empirically confirm the Mitsubishi incident. Second, we test the hypothesis that a fuel efficiency gap exists in the Japanese automobile market as a whole. And finally, we test the hypothesis that a fuel efficiency gap exists for each carmaker individually. We use survey data collected by IDD, Inc. Group of real, on-road, fuel efficiency numbers. Regressing the numbers of real fuel efficiency on catalogue fuel efficiency that were obtained from the lab test and advertised by the carmakers gives us the average level of difference or gap that the market has. Then we regress real fuel efficiency on the same catalogue efficiency variable interacted with a production year variable indicating the year the vehicle in the observation was produced. By using this approach, we can see whether there is a widening fuel efficiency gap over time for the whole market. Finally, to answer the third question we regress real fuel efficiency on catalogue fuel efficiency interacted with the vehicle production year variable and a dummy variable indicating each carmaker. This allows us to understand whether there is a widening

⁴ <https://www.transportenvironment.org/publications/mind-gap-2015-closing-chasm-between-test-and-real-world-car-co2-emissions>

fuel efficiency gap over time for each of the carmakers. The results suggest that we were able to empirically confirm the Mitsubishi incident. However, we could not find a widening fuel efficiency gap over time for neither the market as a whole nor for each carmaker. This suggests that widening fuel efficiency gap due to data manipulation could be an isolated case exclusive to the carmaker Mitsubishi.

The rest of the paper is organized as follows, in Chapter 2 we will examine the effect of tax incentives on environment friendly vehicles. In Chapter 3, we will focus on the relationship between charging infrastructure and electric vehicles. In Chapter 4, we will discuss the fuel efficiency gap and data manipulation. Finally, in Chapter 5, we will present the conclusion of the paper.

References

Transport & Environment, 2015a. Mind the Gap 2015: Closing the chasm between test and real-world car CO₂ emissions. Transport & Environment.

2. The Effect of Tax Incentives on Sales of Environment-Friendly Vehicles

2.1. Introduction

The Tonnage and Acquisition Tax Cut for Environment-friendly Vehicles and the Eco-Car Subsidy were introduced in Japan in April of 2009.⁵ The purpose of these policies is to mitigate climate change by reducing the emissions of greenhouse gases from automobiles. These tax incentives are designed to make environment-friendly vehicles, which include more expensive vehicles such as hybrid-electric vehicles, more appealing. This will result in the increase of the market share for environment-friendly vehicles replacing conventional vehicles. Another aim of these policies is to support the sales of the automobile industry as a whole. The Japanese automobile industry was hit by a drop in demand from foreign markets due to the appreciation of the Japanese yen and the global financial crisis of 2008.

In this chapter, we estimate the effects of such policies on the sales of environment-friendly vehicles while controlling for other factors that affect the sales of a vehicle, such as vehicle price, gasoline price and income. We examine how responsive the Japanese consumer is to such incentives and how much of it contributed to the observed rise in sales of environment-friendly vehicles. We will analyze the sales data of a variety of vehicles, including hybrid-electric vehicles, low-emission vehicles and conventional vehicles. We will compare the demand for these types of vehicles before and after the introduction of the tax incentives

⁵ An environment-friendly vehicle is a vehicle with low greenhouse gases emissions and is one that is considered friendly to the environment. The question of which vehicle is considered environment-friendly and which is not depends on the country and on the context. The definition in Japanese policy is based on fuel economy and exhaust gas.

examining how the sales pattern may have changed.

There is a growing number of studies that examine the impact of policy incentives on the sales of environment-friendly vehicles. Gallagher and Muehlegger (2011) studied various policies designed to increase the adoption rates of hybrid-electric vehicles in the United States across the federal, state and local government level. The types of policies they studied were tax waivers, income tax credits and non-tax incentives such as high occupancy lane priority. They found that sales tax waivers contributed to more than 10 times of the increase in hybrid-electric vehicle sales when compared to income tax credits. They also found that the effect of rising gasoline price on the increase in adoption rates of hybrid-electric vehicles was higher than tax incentives. Diamond (2009) studied the impact of government incentives on hybrid-electric vehicles in the United States, and found that there was a weak relationship between adoption rates and tax incentives. They also found that policies that provide direct incentives, such as upfront payments upon purchase of a new vehicle tend to be the most effective. Chandra et al. (2010) examined the impact of a tax rebate policy for hybrid-electric vehicle sales in Canadian provinces. They estimated that 26% of hybrid-electric vehicles sold in the period of the tax rebate program were due to the tax rebate program itself. On the other hand, they also noted that the program subsidized consumers who were planning to purchase a hybrid-electric vehicle even if there was no subsidy. Beresteanu and Li (2011) studied hybrid-electric vehicle demand and the effect of the income tax credit incentives and gasoline price in the United States. The effect of the government incentive program was estimated as 20% of the sales of hybrid electric vehicles by the year 2006, while the increase of gasoline price from 1999 to 2006 attributed to 37% increase in sales numbers of hybrid-electric vehicles.

We can see from the studies reviewed above that the structure of a tax incentive is a strong determinant in its success and that tax waivers were more effective than income tax credit. For our analysis, the incentives used in Japan were tax waivers and lump-sum subsidies

to buyers. We expect to see a strong effect of these tax incentives in Japan compared to the mixed approach of tax incentives in countries such as the United States.

The contribution of this analysis is twofold. First, it includes all types of environment-friendly vehicles and not only hybrid-electric vehicles. We also include conventional vehicles. The nature of the tax incentives in Japan helped with that approach as it includes vehicles with low greenhouse gas emissions other than hybrid-electric vehicles. Second, the tax cut policy in Japan was more direct and easy to understand as a reduction in the taxes consumers paid upon purchase. The benefits or reduction in taxes were reaped quickly with no complications. In the case of the tax cut policies in the United States, in addition to the straightforward tax waivers, some other tax incentives were indirect and had an administrative cost on the part of the consumer. For example, an income tax credit scheme was implemented as tax incentives for hybrid-electric vehicles. This gives income tax credits to consumers who bought hybrid-electric vehicles which can be used to reduce the income tax that is collected. The benefits are not directly related to the taxes paid upon purchase, but related to other taxes that these consumers pay such as income taxes. This distinction is very important as to how differently will consumers react to the tax policies in Japan.

We begin in section 2.2 with an overview of the Tonnage and Acquisition Tax Cuts for Environment-friendly Vehicles and the Eco-Car Subsidy. In section 2.3, we explain the sources of the data used in this chapter and why this particular dataset has been chosen, in addition to the explanation on the method used in the analysis. In section 2.4, we interpret the estimated results from the analysis and its implications. Section 2.5 is concluding remarks.

2.2. Incentives for Purchasing Environment-Friendly Vehicles

The Tonnage and Acquisition Tax Cuts for Environment-Friendly Vehicles and the Eco-Car Subsidy were introduced in April 2009 in the FY2009 Tax Reform legislation,⁶ a document produced every fiscal year from the Tax Bureau of the Ministry of Finance. The policy was originally proposed by the Japanese Automobile Workers' Union⁷ and later passed by the Ministry of Finance. The tax cut was supposed to end by March 2012 but it was extended until April of 2015. The decision for the extension of this policy was documented in the FY2012 Tax Reform legislation.⁸ The extension was partly made because the appreciation of the yen had negatively affected global demand for Japanese automobiles. The program was extended in order to support automakers and help them make up for the loss in global markets with the increase of sales in the domestic market. The program was extended again after 2015 and still is ongoing as of the writing of this paper.

Table 2.1 explains the Tonnage and Acquisition Tax Cuts for Environment-Friendly Vehicles in details. Depending on the level of greenhouse gas emissions, a vehicle can be eligible for the program and be considered environment-friendly. There are three levels of tax cuts: 50%, 75% and 100%. The more fuel-efficient a vehicle is, the higher tax cut percentage category it will be. Hybrid-electric vehicles and electric vehicles are in the 100% tax cut category, which means that taxes are waived completely. For example, the Toyota Prius, a

⁶ The FY2009 Tax Reform document was retrieved in PDF form from this URL:

http://www.mof.go.jp/english/tax_policy/tax_reform/fy2009/tax2009a.pdf

⁷ The original request (Japanese) for the policy can be found in the following URL:

http://www.meti.go.jp/main/downloadfiles/zeisei24/youbou_165.pdf

⁸ The FY2012 Tax Reform document was retrieved from:

http://www.mof.go.jp/english/tax_policy/tax_reform/fy2012/tax2012a.pdf

hybrid-electric vehicle is eligible for a 100% tax cut, while the Honda Fit, a non-hybrid environment-friendly vehicle,⁹ is eligible for a 50% tax cut. The tax cut is applied for two taxes, the acquisition tax and the tonnage tax. Acquisition tax is the tax paid upon the purchase of the vehicle, while the tonnage tax is the tax paid in the mandatory vehicle inspection which should be done after three years from the time of the purchase and once every two years after that.

Table 2.2 explains the Eco-Car Subsidy. The first wave of the subsidy is implemented from April 2009 till September 2010. The second wave is from December 2011 till September 2012. The first wave of the program contains favorable treatment for the retirement of old vehicles. If you replaced a combustion-engine vehicle that you owned for 13 years or more with a environment-friendly vehicle, you receive 250,000 yen for buying passenger vehicle or 125,000 for buying a light-motor vehicle. When you buy an environment-friendly vehicle without replacing it for a combustion-engine vehicle, you receive 100,000 yen for buying a passenger vehicle or 50,000 yen for buying a light-motor vehicle. The second wave of the program does not contain the favorable treatment for retirement of old vehicles and simply offers 100,000 for buying an environment-friendly vehicle or 70,000 for buying a light-motor vehicle.

2.3. Data and Method

2.3.1. Data

Our data set contains the monthly sales numbers of the top 30 selling vehicles in Japan, most of which are eligible for the Tonnage and Acquisition Tax Cuts for Environment-friendly Vehicles and the Eco-Car Subsidy. We use the sales data as our dependent variable. Since the

⁹ Later model of the Honda Fit were hybrid-electric models.

tax incentives were introduced in April of 2009, we chose that date as around the midpoint of our data and decided to use the sales data from April 2006 to March 2013. The vehicles were chosen on the basis of data availability, continuity of sales from April 2006 until March 2013 and being among the top 30 selling vehicles in the market in Japan.

Table 2.3 shows the 30 vehicles with the corresponding maximum¹⁰ tax cut percentage and maker information. We obtained the data for the monthly sales numbers of the vehicle, from April 2006 until March 2013, from a statistic released monthly for the sales of new passenger cars by Japan Automobile Dealers Association.¹¹

For our independent variables, we use vehicle price, the average price of steel, average price of gasoline, average income per capita and total sales of vehicles. The prices for the vehicles in Japan are taken from the Manufacturer's Suggested Retail Price (MSRP) which is posted on the website of the manufacturer.¹² For older vehicle models, we used the MSRP from carsensor.net. The data set covers the MSRP prices for all 30 vehicles from April 2006 until March 2013. Steel price data were obtained from Japan Iron and Steel Recycling Institute¹³ and is time variant but not vehicle variant. Average monthly prices of regular gasoline for Japan were obtained from the website of the Oil Information Center, Institute of Energy Economics. They are offered on a weekly and monthly basis for the prices of different types of gasoline across Japan, and for the purposes of this analysis we will use the monthly data.¹⁴ The monthly

¹⁰ Many vehicles changed with the introduction of new models from non-eligible to eligible, and some rose to a higher rank of eligibility from 50% to 75%. Also, some new models of vehicles became hybrid models. Maximum here corresponds to the vehicles highest ranking of tax cut that it achieved during the time span of our sample.

¹¹The official title of the statistics is *Shinsha Jouyousha Hanbai Daisu Rankingu* (New Passenger Car Sales Ranking), which was retrieved from the following URL: <http://www.jada.or.jp/contents/data/ranking/index.php>

¹²The MSRP data was obtained from the official website of the maker for each of the 10 vehicles, the data of past editions of the vehicle were obtained from the archived catalogues posted on the website.

¹³ http://www.jisri.or.jp/market/market_kakaku29.html

¹⁴The official title of the statistics is *Kyuyusho Gasorin Keiyu Toyu Shujichosa* (Weekly Survey on Prices of

average income per capita data is from Family Income and Expenditure Survey¹⁵ and is produced monthly by The Statistics Bureau and the Director-General for Policy Planning of Japan's website.

Table 2.4 shows a summary of the descriptive statistics information for the dataset. Since the tax incentives were introduced in April 2009, data before and after the implementation of the tax incentives were used to perform the study and be able to compare the difference in sales numbers with and without the tax incentives. Thus, the time period of data spans from April 2006 until March 2013.

2.3.2. Method

We regress the sales numbers of environment-friendly vehicles on various explanatory variables using the fixed effects model¹⁶. We have two approaches to estimate the effect of the tax cuts on the sales of vehicles. In the first approach, we create dummy variables for the vehicles that received tax cuts, with three dummy variables for each of the levels of tax cuts (100%, 75% and 50%). We use these dummy variables to determine the effect of the three different percentages of the tax cuts on the sales of the environment-friendly vehicles. As for the subsidies, since they are only time variant and not vehicle variant we use dummy variables to indicate the period they were implemented. The equation to be estimated is as follows:

Gasoline, Light Oil, Kerosine). The data was retrieved from the following URL:
<http://oil-info.ieej.or.jp/price/price.html>

¹⁵ The data was retrieved from: <http://www.stat.go.jp/english/index.htm>

¹⁶ Hausman test shows fixed effects estimates to be more consistent.

$$\begin{aligned}
\ln Sales_{it} = & \alpha + \beta_1 \ln Prices_{it} + \beta_2 \ln Gasoline_t + \beta_5 \ln Income_t + \\
& \beta_4 TaxCut100_{it} + \beta_5 TaxCut75_{it} + \beta_6 TaxCut50_{it} + \beta_7 SubsidyOne_{it} + \\
& \beta_8 SubsidyTwo_{it} + \beta_9 \ln TotalSales_t + \beta_{10} Earthquake_t + SeasonDummy + \epsilon \quad (2.1)
\end{aligned}$$

In equation (1), $\ln Sales_{it}$, represents the logged sales of vehicle i for month i . $\ln Prices_{it}$, represents the logged price of vehicle i in month t . We control for price with this variable in order to isolate the effect of tax incentives from changes in price, but we run into the problem of endogeneity of price. We will use instrumental variable to fix this problem which we will discuss at the end of this section. $\ln Gasoline_t$, represents the logged price of regular gasoline in month t . Since environment-friendly vehicles are fuel-efficient, a rise in gasoline price could increase its sales since consumer want to save on fuel cost. We include gasoline price to control for this effect. Although we have four vehicles out of the thirty that aren't environment-friendly and therefore considered non-fuel-efficient, we still decided to include gasoline price. $\ln Income_t$, represents the logged per capita income in Japan for month t . This variable is included as a proxy for household budget constraint. $TaxCut100_{it}$, $TaxCut75_{it}$ and $TaxCut50_{it}$, are the dummy variables for vehicles eligible for 100%, 75% and 50% tax cuts respectively. For these dummy variables, when a vehicle is eligible for tax cuts, it takes the value of 1, otherwise, it takes the value of 0. The base for these dummy variables is $TaxCutZero$ or vehicles that are not eligible for any tax cuts. $\ln TotalSales_t$, represents the log of total sales of all vehicles in month t . We included this variable to control for any shifts in that could affect the demand for vehicles in the Japanese market as a whole. $Earthquake_t$, is a dummy variable indicating months t that are affected by the Great East Japan Earthquakes. There was a decrease in sales in these months due to the earthquake and this dummy variable captures that effect. These months are March and April of 2011. $SeasonDummy$, is a vector of dummy variables used to control for seasonality.

In the second approach, we create a new variable that measures how much consumers are saving with each purchase, in other words, a discount in monetary terms. We call it *TaxDiscount*. The vehicles which are not eligible for a tax cut have a zero discount in this variable. Eligible vehicles in this variable take the value of the amount that was cut from the taxes¹⁷. We regress sales on this discount amount variable and find the estimate. The equation for the second approach is as follows.

$$\begin{aligned} \ln Sales_{it} = & \alpha + \beta_1 \ln Prices_{it} + \beta_2 \ln Gasoline_t + \beta_3 \ln Income_t + \\ & \beta_4 TaxDiscount_{it} + \beta_5 SubsidyOne_{it} + \beta_6 SubsidyTwo_{it} + \beta_7 \ln TotalSales_t + \\ & \beta_8 Earthquake_t + SeasonDummy + \epsilon \end{aligned} \quad (2.2)$$

The only difference between equation (2.1) and equation (2.2) is that we swapped out *TaxCut100_{it}*, *TaxCut75_{it}* and *TaxCut50_{it}* with *TaxDiscount_{it}*. This new variable represents the value of discount in Japanese yen that consumers are gaining from buying vehicle *i* in month *t*.

We use many independent variables to control for factors other than tax cuts in this study, and one of the variables is the price. We run into the problem of endogeneity here since price is a function of sales. This causes inconsistent estimators and to fix this problem we use the instrumental variable (IV) fixed effects model instead. The instrumental variable we chose to use is the average price of steel. Steel price affects the production cost of the vehicle and it term cause a supply side shift that would affect the price. In other words, we can fix the endogeneity problem by using steel price, which affects sales of vehicles through its effect on vehicle price, as an instrument for vehicle price. We specifically used the average price of the H shaped beam steel and not a steel that has been melded to be a part of a vehicle. We do that

¹⁷ $TaxDiscount = Vehicle\ Price \times Tax\ Ratio \times TaxCut\ Ratio.$

to make our instrumental variable a representative of the general price of steel that is not affected by vehicles sales.

2.4. Result and Implications

Estimated results for the fixed effects model are shown in Table 5. We will focus on model 1 and model 3 of Table 5 which are the models corrected for seasonality. The coefficients of interest here are the tax cut dummy coefficients. The TaxCut100 coefficient is 1.225 and is significant at the 1% level. This could be interpreted as that sales for vehicles that became eligible for a 100% tax cut increased by 122.5% compared to before the introduction of the tax cuts. This result is to be expected, as this category is the most generous and includes hybrid-electric vehicles which increased dramatically in sales such as the Toyota Prius. Also, this was the easiest tax cut to understand because it was a tax exemption. The TaxCut75 coefficient is 0.325 and is significant at the 1% level. This has the same interpretations as above with a 32.5% increase in sales for vehicles eligible for the 75% tax cut compared to before the introduction of the tax cut. Most of the vehicles included in the study were in this category, 43% of them to be exact. We can see that the tax exemption was more effective compared to a 75% tax cut. This is certainly because of the 25% increase in discount of taxes. We also think it is because, a tax exemption is more appealing to consumers than a percentage cut. The TaxCut50 coefficient was insignificant. This result is odd; however, the insignificance of the 50% tax cut could be explained within our sample as the sales of vehicles eligible for 100% and 75% tax cuts were replacing sales that would have otherwise gone to vehicles eligible for a 50% tax cut. As for the subsidies, the coefficient for SubsidyOne is 0.132 and significant at the 5% level. This translate to a contribution of 13.2% increase in sales due to the subsidy. According to our result, the subsidy was less effective than the tax cuts for our sample. For SubsidyTwo, the coefficient is -0.168 and significant at the 5% level. This result is

contradictory to the expectation as it means that the second subsidy decreased the sales instead of increasing them, however this result will change when we see the IV fixed effect model. The other coefficient of interest is gasoline price which was insignificant. The reason gasoline price turned out insignificant in our sample, could be due to the types of vehicles we include. We have both environment-friendly vehicles and conventional vehicles. An increasing gasoline price is expected to increase the sales of environment-friendly vehicles, because they are more fuel-efficient. However, a rising gasoline price is expected to decrease the sales of conventional vehicles because the more expensive the gasoline would increase the fuel cost of non-fuel-efficient vehicles and therefore discourage sales. In our sample, only about 13% of the vehicles included are conventional vehicles, so we would expect the gasoline price coefficient to be positive and somewhat significant. Since in our results it was insignificant and considering that only 13% of our sample are conventional vehicles, there is a possibility that consumers in Japan are less responsive to gasoline prices compared to tax cuts when deciding to purchase an environment-friendly vehicle. In model 3 the coefficient of interest is TaxDiscount, its coefficient is 4.88e-06 and significant at the 5% level. This can be interpreted as a tax discount of 10,000yen increases sales by 4.88%. The SubsidyOne coefficient is 0.136 and significant at the 5% level (a 13.6% increase in sales). The coefficient of SubsidyTwo is -0.176 and significant at the 5% level (a 17.6 decrease in sales). Gasoline is insignificant in this model as well.

Next, we explain the instrumental variable fixed effects model shown in Table 6. We will focus on the corrected for seasonality model 1 and model 3 here as well. In model 1 TaxCut100 is 1.433 and significant at the 1% level. This means an increase of 143.3% due to the tax cut. TaxCut75 is 0.548 and significant at the 1% level. Which means an increase of 54.8% due to the tax cut. TaxCut50 is 0.382 and significant at the 1% level. Which translates to a 38.2% increase. We notice that in the IV fixed effects model, TaxCut50 is significant which

makes more sense. We can see stronger results for the tax cuts in the IV fixed effect model compared to the base fixed effect model and the effect of the tax cut is stronger the higher the tax cut percentage is. The gasoline price coefficients are insignificant in this model which reconfirms the results we obtained from the fixed effect model. The SubsidyOne coefficient is 0.283 and is significant at the 1% level. This means that sales vehicles eligible for the first subsidy wave increased by 28.3% compared to before the subsidy. The SubsidyTwo coefficients are insignificant in this model. We can see from this result that the second subsidy wave was less effective compared to the first subsidy wave. This results also makes more sense than the base fixed effect model where we saw negative results for the second subsidy wave. In Model 3 TaxDiscount is $6.25e-06$ and is significant at the 1% level. This means that for a 10,000yen discount sales increased by 6.25%. SubsidyOne is 0.236 and is significant at the 1% level (a 23.6% increase in sales due to the subsidy). SubsidyTwo and Gasoline are insignificant in this model. We think that by controlling for the endogeneity of price problem, we were able to obtain better results that are more in line with our theoretical expectations.

Tax incentives played the most important role in increasing the sales of environment-friendly vehicles in all regression models. Gasoline prices were expected to be related positively to sales since fuel-efficient vehicles benefit consumers by saving more when gasoline prices are high and most of our sample is of fuel-efficient vehicles, but the results came insignificant in all models. This result could be due to the 4 conventional vehicle models in our sample that are expected to have an opposite relationship with gasoline price compared to fuel-efficient vehicles. The effect of the first wave of the subsidy was significant and positive, but the effect of the second wave was not. This leads us to believe that tax cuts are more effective than subsidies for the Japanese automobile market.

2.5. Conclusion

This study estimated the impact of the Tonnage and Acquisition Tax Cut for Environment-Friendly Vehicles and the Eco-Car Subsidy, on the sales of environment-friendly vehicles in the Japanese automobile market. We used the sales data of the 30 top selling vehicles in the market from the period before and after the implementation of the tax incentives and measured their effect. Tax incentives in Japan had a larger role in the increase of the sales numbers of the environment-friendly vehicles, while gasoline prices had almost no impact compared to it, although we tested the impact of gasoline for the whole market and not just specifically for environment-friendly vehicles. One reason why the effect of tax incentives in Japan was strong is that the tax incentives in Japan are immediate and easy to understand. They fall in three categories, a complete tax exemption, a percentage cut of the tax to be paid and a lump-sum subsidy. The United States has a more complicated and non-unified approach for environment-friendly vehicles. It was a mix of tax waivers, which are similar to the tax cuts in Japan; income tax credits; and other non-monetary incentives. This approach is more complicated mainly because income tax credit had two barriers, the delay in gratification of cashing-in on the discount that the consumers obtained, which was reaped when they filed their taxes at the end of the year, and the administrative cost of the paperwork that needs to be done in order to obtain the income tax credit.

The result of this study has several implications for the environment-friendly vehicles market in Japan. First, consumers reacted substantially to tax cuts on automobile purchases when the tax cuts were direct and paid upon purchase. The effect of subsidies was significant but not as large as tax cuts. With the strong effect of tax incentives, environment-friendly vehicles are becoming more popular and we see a trend of these vehicles being the norm in the market with how consistently they top the sales charts each month, especially hybrid-electric vehicles. With the continuation of the tax incentives, environment-friendly vehicles have the

potential to eclipse conventional vehicles in Japan and that will certainly aid in reducing the CO₂ emission from the Japanese automobile market.

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Tables and Figures

Table 2.1: Tonnage and Acquisition Tax Cut for Environment-Friendly Vehicles

	Hybrid Electric Vehicle	Low-Emission Vehicles	Passenger	Low-Emission Vehicles	Heavy-Duty
		Exhaust gas down by 75% from 2005 standards	Exhaust gas down by 75% from 2005 standards	Exhaust gas down by 75% from 2005 standards	Exhaust gas down by 75% from 2005 standards
		Fuel Efficiency 25% above 2010 standards	Fuel Efficiency 15% above 2010 standards	Fuel Efficiency 25% above 2010 standards	Fuel Efficiency 15% above 2010 standards
Tonnage Tax cut	100%	75%	50%	75%	50%
Acquisition Tax cut	100%	75%	50%	75%	50%

Note: The effective period of tonnage tax cut is from 1 April 2009 to 30 April 2012 and that of acquisition tax cut is from 1 April 2009 to 31 March 2012. After March 2012, the fuel efficiency standards are revised to that of 2015.

Source: Japanese Automotive Dealers Association
<http://jama-english.jp/asia/news/2009/vol36/index.html>

Table 2.2: First and Second Waves of Eco-Car Subsidy

	First Subsidy Wave		Second Subsidy Wave
Period	Apr 2009 until Sept 2010		Dec 2011 until Sept 2012
Conditions	Replace a combustion engine vehicle used for over 13 years with an Eco-Friendly Vehicle	Buy an Eco-Friendly Vehicle	Buy an Eco-Friendly Vehicle
Subsidy amount	Passenger car: 250,000 yen	Passenger car: 100,000 yen	Passenger car: 100,000 yen
	Light-motor car: 125,000 yen	Light-motor car: 50,000 yen	Light-motor car: 70,000 yen
Budget	580,000 million		270,000 million

Source: <http://www5.cao.go.jp/keizai3/2012/1222nk/pdf/12-1-3.pdf> [In Japanese]

Table 2.3: Levels of Tax Cut

Maker	Model	Maximum Tax Cut
Toyota	Corolla	75%
Toyota	Vits	50%
Honda	Fit	50%
Toyota	Estima	50%
Nissan	Selena	75%
Honda	Step Wagon	75%
Toyota	Wish	75%
Toyota	Ractis	75%
Toyota	Passo	50%
Toyota	Crown	50%
Nissan	Note	100%
Nissan	Tiida	0%
Toyota	Alphard	75%
Toyota	Voxy	75%
Toyota	bB	0%
Mazda	Demio	100%
Nissan	Cube	75%
Toyota	Noah	75%
Suzuki	Swift	0%
Subaru	Legacy	50%
Toyota	Prius	100%
Toyota	Markx	0%
Toyota	Isis	75%
Honda	Odyssey	75%
Honda	Stream	50%
Toyota	Porte	50%
Toyota	Sienta	50%
Honda	Freed	75%
Nissan	Wingroad	50%
Toyota	Premio	75%

Table 2.4: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Obs
Sales (units)	4877.475	4476.563	3	45496	2520
Price (yen)	2115319	1057417	409500	6103650	2520
Income (yen)	522316.2	146141.9	413506	968846	84
Gasoline (yen/lier)	145.226	13.781	117	196	84
Tax Cut 100%	0.0266	0.161	0	1	2520
Tax Cut 75%	0.103	0.304	0	1	2520
Tax Cut 50%	0.179	0.383	0	1	2520
Tax Discount (yen)	16043.36	29048.03	0	140450	2520
Subsidy One	0.202	0.402	0	1	84
Subsidy Two	0.119	0.324	0	1	84
Total Sales (units)	266224.5	69960.35	108824	497959	84
Earthquake			0	1	84
Steel Price (yen/ton)	81078.57	15655.17	63700	129350	2520

Table 2.5: Fixed Effects Estimation Results

Variable	Model 1	Model 2	Model 3	Model 4
Const	-29.974*** (8.923)	-14.189*** (2.500)	-31.036*** (7.637)	-13.608*** (2.554)
<i>ln</i> Price	0.672*** (0.165)	0.686*** (0.172)	0.633*** (0.173)	0.658*** (0.177)
<i>ln</i> Gasoline	-0.094 (0.146)	-0.072 (0.114)	-0.106 (0.148)	-0.080 (0.115)
<i>ln</i> Income	1.027* (0.530)	-0.070** (0.025)	1.171** (0.480)	-0.074*** (0.025)
TaxCut100%	1.225*** (0.335)	1.200*** (0.329)	-	-
TaxCut75%	0.325*** (0.113)	0.296** (0.110)	-	-
TaxCut50%	0.100 (0.113)	0.073 (0.109)	-	-
TaxDiscount	-	-	4.88e-06 ** (2.28e-06)	4.45e-06* (2.27e-06)
SubsidyOne	0.132** (0.052)	0.137*** (0.047)	0.136** (0.053)	0.143*** (0.047)
SubsidyTwo	-0.168** (0.070)	-0.143** (0.062)	-0.176** (0.070)	-0.154** (0.062)
<i>ln</i> TotalSales	1.243*** (0.141)	1.095*** (0.047)	1.228** (0.134)	1.087*** (0.048)
Earthquake	-0.030 (0.156)	-0.095 (0.183)	-0.052 (0.157)	-0.112 (0.181)
Seasonality	Yes	No	Yes	No
Number of Obs	2520	2520	2520	2520
R-squared	0.156	0.15	0.116	0.108

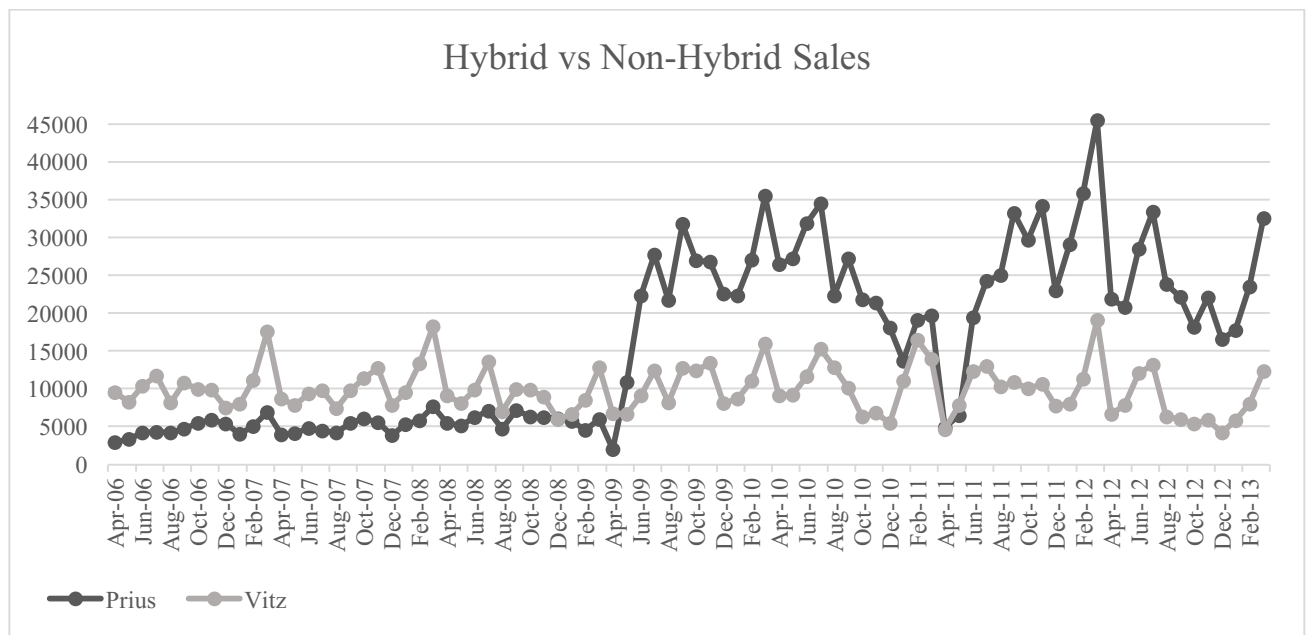
*** Significant at 1%; ** Significant at 5%; * Significant at 10% level

Table 2.6: IV Fixed Effects Estimation Results

Variable	Model 1	Model 2	Model 3	Model 4
Const	-28.95*** (-13.08)	-28.89*** (-12.17)	-23.77*** (-13.67)	-23.78*** (-13.10)
<i>ln</i> Price	1.715*** (12.77)	1.701*** (11.54)	1.365*** (14.01)	1.358*** (12.88)
<i>ln</i> Gasoline	0.202 (1.63)	0.187 (1.55)	0.168 (1.40)	0.158 (1.36)
<i>ln</i> Income	-0.147** (-3.04)	-0.136** (-3.05)	-0.134** (-2.87)	-0.125** (-2.91)
TaxCut100%	1.433*** (16.40)	1.429*** (16.18)	-	-
TaxCut75%	0.548*** (10.90)	0.543*** (10.27)	-	-
TaxCut50%	0.382*** (7.79)	0.376*** (7.12)	-	-
TaxDiscount	-	-	6.25e-06*** (13.30)	6.22e-06*** (12.81)
SubsidyOne	0.283*** (8.86)	0.278*** (8.46)	0.236*** (8.27)	0.234*** (8.12)
SubsidyTwo	0.0451 (1.08)	0.0405 (0.93)	0.0314 (0.77)	0.0280 (0.66)
<i>ln</i> TotalSales	1.054*** (20.69)	1.059*** (23.24)	1.048*** (21.22)	1.052*** (23.72)
Earthquake	0.0660 (0.82)	0.0674 (0.86)	0.0273 (0.35)	0.0286 (0.38)
Seasonality	Yes	No	Yes	No
Number of Obs	2520	2520	2520	2520
R-squared	0.357	0.358	0.3418	0.342

*** Significant at 1%; ** Significant at 5%; * Significant at 10% level

Figure 2.1: Change in Sales After Tax Incentives



April-09: Tax incentives and first wave of subsidy were implemented

Dec-11: Second wave of subsidy was implemented

3. Charging Infrastructure, Range Anxiety, and Sales of Electric Vehicles

3.1. Introduction

Electric vehicles are expected to reduce carbon dioxides emissions by replacing conventional vehicles, hybrid-electric vehicles and other types of vehicles. Nevertheless, in many countries, the consumer demand for electric vehicles is still low, even in countries with tax exemptions for electric vehicles. While over 665,000 passenger car electric vehicles were sold worldwide through 2014, they represent only 0.08% of total passenger car stock (Electric Vehicle Initiative, 2015).

Setting aside the high price of electric vehicles, one of the major obstacles to increasing sales might be consumer anxiety about new technology. Running out of battery is a prominent example of such anxiety that consumers might feel about electric vehicles. The range of the distance that could be driven by an electric vehicle with a fully charged battery is significantly less than the range of a conventional vehicle with a full tank of gasoline¹⁸. One solution to that problem that might help alleviate the driving range anxiety, is the construction of electricity charging stations. With enough charging stations in proximity, where consumers can charge their electric vehicles, the short driving range problem can be negated. However, charging stations are not cheap to build and firms are not willing to build charging stations if there was no demand for them to begin with. Therefore, government intervention is needed to fix this problem. One way to do so is to subsidize the construction of charging stations and driving the

¹⁸ A fully charged Nissan Leaf can drive 228km, while a fully tanked Toyota Prius can drive 1,280km.

demand of electric vehicles by increasing the availability of said charging stations.

In 2009, the Japanese government also implemented another policy that is aimed to stimulate the sales of electric vehicles by increasing the charging infrastructure. Under the Subsidy Program for Clean Energy Vehicle, the Japanese government provides half of the cost for constructing charging stations of electric vehicles from the fiscal year 2009 to 2012. Since the fiscal year 2013, the program has been expanded to cover a maximum rate of two thirds of the total cost. There are two types of charging stations that were subsidies, fast charging stations and regular charging stations. We will refer to regular charging stations as slow charging stations in this chapter¹⁹. As their name suggests, fast charging stations charge electric vehicles faster. Since then, Japan has installed the highest number of fast charging station in the world while it has placed less emphasis on slow charging stations (Electric Vehicle Initiative, 2013). While it seems obvious that charging infrastructure is an important driver for electric vehicle demand, it is still unclear how much demand is stimulated by additional investment in charging infrastructure. Even though the investment in charging infrastructure seems to mitigate the range anxiety, people might charge their electric vehicles at home in most cases. If this is true, then additional investment might not dramatically change the demand for electric vehicles. Consumers might be just content with charging their electric vehicles at home. The effect of range anxiety is also difficult to capture. Although we can expect that the range anxiety is higher for drivers who drive for longer periods, their demand for electric vehicles might be higher than others because of potential fuel cost saving of driving an electric vehicle.²⁰

Many previous studies have analyzed the demand for electric vehicles using stated choice approach (Beggs and Cardell, 1980; Beggs et al., 1981; Ewing and Sarigöllü, 1998;

¹⁹ A Nissan Leaf can be charged in about 40 minutes by a fast charging station and between 8 to 16 hours in a slow charging station. <https://www3.nissan.co.jp/vehicles/new/leaf/charge.html> (Japanese)

²⁰ Using the average price of 1 liter of gasoline and the average price of 1 kwh of electricity from our data, we calculated that a Nissan leaf approximately runs on average 0.29 km/yen and a Toyota Prius runs on average 0.27 km/yen. It is important to keep in mind that the Prius leads the industry in fuel efficiency yet for Japan an electric vehicle is cheaper to run.

Bunch et al., 1993; Golob et al., 1997; Brownstone et al., 2000; Hidrue et al., 2011; Achtnicht, 2012; Daziano, 2013; Axsen et al., 2013; Ito et al., 2013). These studies ask respondents, by using hypothetical survey questionnaire, to choose most preferable alternative from the set of profiles that have different levels of car attributes, such as price, engine power, fuel economy, and driving range. From the estimated coefficients of these attributes, one can calculate the marginal willingness to pay for improving particular attributes of an electric vehicle. Several studies among stated choice studies include the availability of charging infrastructure as the attribute of choice profile (Bunch et al., 1993; Brownstone et al., 2000; Achtnicht, 2012; Ito et al. 2013). These studies generally find that higher availability of charging stations increase choice probability of electric vehicles. For example, Ito et al. (2013) distinguished the slow charging station and fast charging station, and found that the willingness to pay for the latter is higher than that for the former. Some studies focus on range anxiety. Daziano (2013) summarizes that the mean estimated willingness to pay for a one-mile improvement of driving range in the past studies in US is 100 dollars per mile. Dimitropoulos et al. (2013) uses meta-analysis and reports that mean willingness to pay are between 66 and 75 US dollars for a one-mile increase in driving range.

While the results of these stated preference studies suggest that infrastructure investment and reducing range anxiety is an important driver for the diffusion of electric vehicles, most studies do not use actual sales data. One exception is a study by Sierzchula et al. (2014) that investigated electric vehicles' shares in 30 countries for the year 2012. They found that financial incentives, charging infrastructure, and local presence of production facilities are positively correlated with electric vehicle adoption rates in a statistically significant way. While their country level data can investigate a certain range of policy and economic characteristics, the small number of cross-section sample is too crude to efficiently capture the impact of various determinants on demand.

This study contributes to existing literatures in the following manner. First, it develops a simple theoretical model of willingness to pay for electric vehicles. We incorporate the effect of charging infrastructure and range anxiety into the model and discuss how they are related to the demand. Second, it empirically examines the effect of charging infrastructure and range anxiety on sales of electric vehicles. We investigate the demand for the Nissan Leaf, by using actual sales data in 47 Japanese prefectures in 2011 and 2012. Third, it investigates how additional infrastructure investment reduces carbon dioxide emissions. We discuss the cost efficiency of the subsidy policy and the possibility that the Fukushima Daiichi nuclear power plant accident lowered the abatement rates from driving electric vehicles since electricity production shifted from nuclear power to other sources that emits CO₂.

The rest of this chapter is organized as follows. Section 3.2, formulates a theoretical model as underpinnings for our empirical analysis. Section 3.3, explains the empirical methodology and data. Section 3.4, discusses the results and its implication. Section 3.5, discusses the impact of additional infrastructure on the reduction of carbon dioxide emission and its cost effectiveness. In section 3.6, we present concluding remarks.

3.2. Theoretical Model

We define a linear indirect utility for buying an electric vehicle (V_e) and for buying a conventional vehicle (V_c):

$$V_e = \beta_e + \beta_M(M - p_e - f_e \cdot l - y(l, q)),$$

$$V_c = \beta_c + \beta_M(M - p_c - f_c \cdot l - z \cdot l),$$

Where M is exogenously given income, p is the upfront cost of the vehicle, f is the fuel cost per distance unit, l is the driving distance that is assumed as exogenously given and depends on which region the consumer lives in. y is the anxiety cost from driving range measured in monetary terms, q is the number of charging stations in the region, z is the subjective external cost on environment per distance unit. β_e and β_c are constant terms of utility functions that represent composite benefit from choosing a specific car model, β_M is the marginal utility of income. For simplicity, we do not consider the future fuel cost or future external cost. We assume $\frac{\partial y}{\partial q} < 0$, that is, anxiety from electric vehicles driving range decreases when the number of charging stations in the region increases. We also assume $\frac{\partial y}{\partial l} > 0$, anxiety from driving range of electric vehicle is lower in regions where consumers drive longer distances. Subjective external cost on the environment z is assumed to be zero for consumers that do not care about the environment.

Assuming a linear indirect utility, the additional willingness to pay for an electric vehicle compared to a conventional vehicle can be calculated by taking the difference of the two indirect utility functions:

$$WTP = V_e - V_c = \beta + \beta_M(\Delta p + \Delta f \cdot l - y(l, q) + z \cdot l)$$

Where $\beta = \beta_e - \beta_c$, $\Delta p = p_c - p_e$, and $\Delta f = f_c - f_e$. We can investigate how the number of charging stations and the driving distance affect the willingness to pay for electric vehicles. We omit β_M and differentiate WTP by q and l :

$$\frac{\partial WTP}{\partial q} = -\frac{\partial y}{\partial q} \quad \text{B.1)}$$

$$\frac{\partial WTP}{\partial l} = \Delta f - \frac{\partial y}{\partial l} + z \quad \text{B.2}$$

The sign of equation (3.1) is positive because we assumed that $\frac{\partial y}{\partial q} < 0$. Additional charging stations will decrease the range anxiety; therefore, the willingness to pay for electric vehicles will increase. On the other hand, the sign of equation (3.2) can be positive or negative, depending on whether the fuel cost reduction Δf and environmental awareness effect, represented by external cost on environment z , is larger than the range anxiety effect. We will empirically examine in the next section whether the overall effect is positive or negative.

3.3. Data and Methodology

This study uses the sales numbers for the Nissan Leaf in Japan across 47 prefectures for 2 years (2011 and 2012). The sales data is obtained from the Japan Automobile Dealers Association. We regress the sales data on the number of fast charging stations that received the subsidy (FastCharge) in one estimation, then the number of slow charging stations that received the subsidy (SlowCharge) in another estimation. Finally, we combine both fast charging stations and slow charging station into one variable (Fast+Slow) and use it as an explanatory variable in the last model. The other explanatory variables we use in this estimation are, gasoline prices (GasPrice), electricity prices (ElecPrice), income per capita (Income), population (Population), the number of groups registered to Kids Eco-Club (EcoClub), average driving distance per vehicle in each region (DrivingDistance). Explanatory variables are prefectural level, except DrivingDistance, which is regional level. The number of charging stations is retrieved from Next Generation Vehicle Promotion Center. Gasoline prices are retrieved from the Oil Information Center of the Japanese Institute for Energy Economics and is the average price of regular gasoline in each prefecture. Electricity prices, income per capita

and population are retrieved from Statistics Bureau, Ministry of Internal Affairs and Communications. Since electricity price only changes depending on the electricity company, we have less variation here since there is one electricity company per region. Therefore, the electricity price variable is regional instead of prefectural. The number of groups that are registered to Kids Eco-Club is retrieved from the program's website.²¹ Kids Eco-Club is a supporting program by the Ministry of Environment for local group activity of children and the youth on environmental protection. The group can obtain various forms of support from the program for free. It is required to include at least one adult as a supporter for the group to register in the program. We use this variable as a proxy for environmental awareness of each prefecture. Average driving distance per vehicle in each region is based on the Survey on Motor Vehicle Fuel Consumption by Ministry of Land, Infrastructure, Transport and Tourism and the vehicle ownership data by the Automobile Inspection and Registration Information Association. The data is calculated by dividing the total distance of driving by gasoline using vehicles in each region of Japan by the total number of vehicle in each region.²² Table 3.1 summarizes the descriptive statistics.

Since the data is available only for two years, we use pooled OLS in this study. We log all the variables except for the dummy variables in order to interpret the estimated coefficients as elasticities. The estimated models are represented as follows:

$$\begin{aligned}
 \ln ElectricVehicleSales_i &= \alpha + \beta_1 \ln ChargingStations + \beta_2 \ln GasolinePrice \\
 &+ \beta_3 \ln ElectricityPrice + \beta_4 \ln Income + \beta_5 \ln Population \\
 &+ \beta_6 \ln EcoClubs + \beta_7 \ln DrivingDistance + \beta_8 YearDummy \\
 &+ \epsilon
 \end{aligned}
 \tag{B.3}$$

²¹<http://www.j-ecoclub.jp/>

²²Japan can be divided into ten regions and transportation administration is based on the division.

Here the term $\beta_1 \ln \text{ChargingStations}$, will vary depending on what charging stations variable we use. There are three variations, $\beta_1 \ln \text{FastCharge}$, $\beta_1 \ln \text{SlowCharge}$ and $\beta_1 \ln (\text{Fast} + \text{Slow})$. In other words, we estimate this model three times with three different groups of charging stations. The second model includes the area dummy and omits the electricity price variable:

$$\begin{aligned}
 \ln \text{ElectricVehicleSales}_i &= \alpha + \beta_1 \ln \text{ChargingStations} + \beta_2 \ln \text{GasolinePrice} + \beta_5 \ln \text{Income} \\
 &+ \beta_4 \ln \text{Population} + \beta_5 \ln \text{EcoClubs} + \beta_6 \ln \text{DrivingDistance} \\
 &+ \beta_7 \text{YearDummy} + \beta_8 \text{RegionDummy} + \epsilon
 \end{aligned} \tag{B.4}$$

Because of the high correlation observed between electricity prices and region dummies, we omit electricity price in the second specification. The correlation between electricity prices and the region dummies come from the fact that electricity prices are constant for prefectures within the same region, and varies only between regions, therefore when we create region dummies, electricity prices highly correlates with it.

3.4. Results

The results are shown in Table 3.2. Model 1 and 2 combines the number of fast charging stations with slow charging stations in a variable named Fast+Slow. Models 3 and 4 includes only fast charging stations, while models 5 and 6 includes only slow charging stations. Since there is a significant difference in charging speeds between these two types of infrastructure, we can expect that impact of investing in fast charging stations is stronger than that of investing in slow charging stations. The other difference in the models is that models 2, 4 and 6 include

region dummies and exclude electricity prices due to high correlation between it and the region dummies.

All of the coefficients on charging stations were positive and significant as expected. When we combine the number of fast charging station and slow charging station, the estimated coefficients are 0.422 and 0.447 in models 1 and 2, respectively. It suggests that a 10% increase in the number of charging stations is associated with increases of electric vehicle sales by 4.2% and 4.5%. In models 3 and 4, we see the effect of fast charging stations. The coefficients were 0.323 and 0.333 respectively. This suggests that a 10% increase in the number of fast charging stations increases the sales of electric vehicles by 3.2% and 3.3% for models 3 and 4 respectively. In models 5 and 6, we find that the coefficients for slow charging stations are 0.230 and 0.276, respectively. Thus, the results suggest that a 10% increase in slow charging stations associates with an increase in sales of electric vehicles by 2.3% and 2.8% for models 5 and 6 respectively. These results show that the impact of fast charging stations is stronger than the slow charging station. Moreover, we can see that overall effect of constructing charging stations is positive and having more charging stations will increase the sales number of electric vehicles.

The signs of the coefficient for gasoline price variables were positive as expected. Since an increase in gasoline price encourages consumers to buy a vehicle that does not need gasoline to run, this is a plausible result. Gasoline price was statistically insignificant in models that include regional dummies and significant otherwise. The significant coefficients for gasoline price were 3.587, 3.924 and 3.727 in models 1, 3 and 5 respectively. We can interpret this as a 10% increase in gasoline prices increases sales of electric vehicles by 4%.

Electricity prices were negative and significant in all models. This is expected since electricity is powering electric vehicles and an increase in price would discourage sales. The coefficients are -1.659 , -1.900 and -1.237 for models 1, 3 and 5 respectively. These results

suggest that the impact of electricity price on sales of electric vehicles might be lower than the impact of gasoline price. Many of the current charging station in shopping mall and public spaces provide the charging services for free, therefore the impact of electricity price might be mitigated by this reason.

The coefficient of average driving distance was negative and statistically significant except for models 4 and 5. These results suggest that when average driving distance increase by 1%, sales of electric vehicles decrease by 0.9%, 1.52%, 0.99% and 1.56% for models 1, 2, 3 and 6 respectively. If this term can be interpreted as a result of the range anxiety effect, fuel cost efficiency effect and environmental awareness effect, then the range anxiety effect would be stronger than other two effects according to this result: longer average distance discourages sales of electric vehicles.

Lastly, Eco-Clubs is a variable added to measure the effect of environmentalism on the decision to buy an electric vehicle. The coefficients were statistically insignificant in all models that we examined. We cannot make any strong statement on the effect of environmental awareness on electric vehicle sales from the Eco-Clubs coefficients.

3.5. Effect on Abatement

In this section, we use the estimated results to infer the effect of the subsidy policy on the abatement of carbon dioxide emissions. The Japanese government covers half of the cost of building one charging station, which amounts to approximately an average of 3.75 million yen. Let us assume that, by increasing the number of charging stations that receives a subsidy by 10%, sales of electric vehicles will increase by 4.5%, which is obtained from our estimated coefficient on the combined variable of charging stations of model 2. Let us also assume that this increase is replacing either hybrid-electric vehicles or conventional vehicles. In other words, the number of total vehicle is unchanged and only the composition of the types vehicles

changes. We use the Honda Fit as a reference model to figure out how much abatement could be gained from a replacement of it by a Nissan Leaf. Since the Honda Fit has a conventional model and a hybrid-electric vehicle model, it is useful for the purpose of comparisons. Figure 3.1 shows the estimated results on the abatement of carbon dioxide in ten regions in Japan. When an electric vehicle replaces a hybrid-electric vehicle (HV), a 10% increase in charging stations can result in an abatement of 128.843 t-CO₂/Year at the highest (Kanto region) and 2.729 t-CO₂/Year, at the lowest (Okinawa region). When we assume that an electric vehicle replaces a conventional vehicle (CV), a 10% increase in charging stations results in an abatement of 258.117 t-CO₂/Year at the highest (Kanto region) and 5.760 t-CO₂/Year at the lowest (Okinawa region).

Figure 3.2 shows the abatement levels we obtained in figure 3.1 as a share of the total emissions from the household sector in each region. These figures show that while abatement levels may be high for a certain region, that does not necessarily mean that the share is a large percentage of average household emissions of that same region. For example, Kanto region has the largest amount of CO₂ abatements in Figure 1.3, but it has the lowest share of abatement when divided by household emissions. On the other hand, total abatement levels in the Kyushu region is lower than Kanto, but it achieves a comparatively higher share of abatement at around 0.65%. Results suggest that Kyushu have the highest potential of reducing carbon dioxide emissions from increasing charging infrastructure, while Kanto have the lowest potential.

We can calculate the cost effectiveness of the subsidy program for charging stations by dividing abatements from increasing the charging infrastructure by total expenditure for the subsidy. The result is summarized in Table 3.3 for the ten regions in Japan. The highest cost-effectiveness for the case of electric vehicles replacing conventional vehicles was for Kyushu at 8.783 million yen/t-CO₂. This is significantly worse when compared to the estimated cost of reducing CO₂ by representative measures, which ranges from 4,600 yen/t-CO₂ to 11,700 yen/t-

CO₂ (Oka et al 2005). Under our current assumptions, subsidizing charging infrastructure might be a relatively expensive way to mitigate climate change and it might be better to invest in other means of abatements before resorting to subsidizing charging stations.

One limitation of our calculation is that it relies on the stock number of electric vehicles existing in the market to measure the cost-effectiveness. This number is very low for the data sample we are using, the abatement cost in our analysis could become closer to the cost of the other measures to reduce CO₂ if the stock number of electric vehicles increases.

One might claim that the cost-effectiveness is negatively affected after the disaster of the Fukushima Nuclear Power Plant. This is based on the fact that most nuclear power plant has been stopped for the safety concern and the electricity is provided by means that are not emission free in substitution. While it is true that cost-effectiveness is negatively affected, it does not change significantly from before the disaster. This is represented in Table 3.4 that shows the difference of abatement levels before and after the disaster. The largest difference is in the Chubu region where the abatement potential is reduced by 1.72% due to the Fukushima Disaster. The slight change in abatement potential is due to the marginal change in electricity generation CO₂ emissions before and the after the disaster. As shown in Figure 3.3, there is no dramatic change in electricity generation CO₂ emissions between the years 2010, 2011 and 2012 for each electric power company.

3.6. Conclusion

We have investigated the factors that affect electric vehicle sales in Japan and found that higher number of charging stations is associated with an increase of electric vehicle sales. We have also found that areas where consumers have a higher average driving distance have lower electric vehicle sales. This suggests that the range anxiety effect is stronger than the fuel cost saving effect. We also examined how much abatement of CO₂ would be gained with an

increase in the current stock of electric vehicles due to a hypothetical 10% increase in the number of charging stations using our estimate coefficients. We calculated the cost effectiveness of the abatement that would be gained from the 10% increase in charging infrastructure. We used half the average cost of building a charging station as the expenditure the government needs to pay as subsidy. The cost of abatement for this subsidy is considerably more expensive compared to the estimated cost of representative measures of reducing CO₂ (Oka et al 2005).

Lastly, contrary to expectations, the effect of the Fukushima Nuclear Plant disaster on abatements forgone due to the switch from nuclear energy to other sources which increased carbon dioxide emissions was not as dramatic as expected. Electric power companies were fairly good at keeping their emissions low even after the disaster, since the change in CO₂ emission coefficient did not change significantly.

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Tables and Figures

Table 3.1: Descriptive Statistics

Variable	Mean	S.D.	Min	Max	Obs
Electric vehicle Sales (units)	227.926	248.021	35	1424	94
Slow Charger (units)	52.46809	59.12711	4	335	94
Fast Charger (units)	27.67	21.292	4	121	94
Gas Price (yen/liter)	313.66	167.637	142.7	504.1	94
Electricity Price (yen/kWh)	17.825	1.301	16.1	21.86	94
Income (yen)	419,655.3	49,506.93	289,916	531,325	94
Population (person)	2,714,043	2,678,479	580,000	13,200,000	94
Total Sales (units)	64,672.38	61,455.71	11,825	298,522	94
Eco Clubs (units)	60.44681	52.73521	3	264	94
Driving Distance (thousands KM)	149.461	16.488	124.354	170.931	94

Table 3.2: Estimated Results

Dependent Variable: Sales numbers of EVs							
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	
Cons	-19.814 (12.716)	-20.503 (14.510)	-21.156 (12.936)	-23.455 (15.287)	-24.387* (13.204)	-24.525* (14.677)	
Fast + Slow	0.422*** (0.101)	0.447*** (0.113)	-	-	-	-	
Fast	-	-	0.323*** (0.087)	0.333** (0.131)	-	-	
Slow	-	-	-	-	0.230*** (0.077)	0.276*** (0.079)	
Gasoline Price	3.587* (1.801)	2.818 (2.073)	3.924*** (1.836)	3.067 (2.190)	3.727* (1.883)	3.429 (2.099)	
Electricity Price	-1.659*** (0.526)	-	-1.900*** (0.553)	-	-1.237** (0.541)	-	
Average Income	0.139 (0.284)	0.558* (0.311)	0.079 (0.290)	0.455 (0.326)	0.184 (0.297)	0.555* (0.317)	
Population	0.594*** (0.094)	0.485*** (0.110)	0.721*** (0.077)	0.639*** (0.104)	0.703*** (0.091)	0.579*** (0.099)	
Eco-Clubs	-0.003 (0.057)	-0.008 (0.057)	-0.013 (0.059)	-0.001 (0.060)	0.0478 (0.057)	0.015 (0.058)	
Average Distance	-0.904** (0.410)	-1.515* (0.899)	-0.985** (0.423)	-1.324 (0.950)	-0.705 (0.424)	-1.555* (0.916)	
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes	
Area Dummy	No	Yes	No	Yes	No	Yes	
Adjusted R-Squared	0.852	0.878	0.846	0.864	0.838	0.873	

Significance level

*** = 1%, ** = 5%, * = 10%

Table 3.3: Cost Effectiveness (million Yen/t-CO₂)

Region	Cost effectiveness vs HV	Cost effectiveness vs CV
Hokkaido	18.666	9.297
Tohoku	21.777	10.776
Kanto	24.585	12.272
Hokuriku	18.454	9.160
Chubu	36.273	17.769
Kinki	23.802	11.898
Chugoku	31.553	15.430
Shikoku	36.796	18.257
Kyushu	17.707	8.783
Okinawa	35.724	16.928

Table 3.4: The Effect of the Fukushima Disaster (t-CO₂)

Region	Abatement CV (Before)	vs Abatement CV (After)	vs Difference
Hokkaido	28.588	28.435	-0.54%
Tohoku	75.605	74.990	-0.81%
Kanto	260.241	258.117	-0.82%
Hokuriku	54.472	53.672	-1.47%
Chubu	102.578	100.814	-1.72%
Kinki	128.184	126.163	-1.58%
Chugoku	50.607	50.453	-0.30%
Shikoku	16.108	15.919	-1.17%
Kyushu	142.962	140.690	-1.59%
Okinawa	5.760	5.760	0.00%

Figure 3.1: Level of Abatement of Carbon Dioxides (t-CO₂)

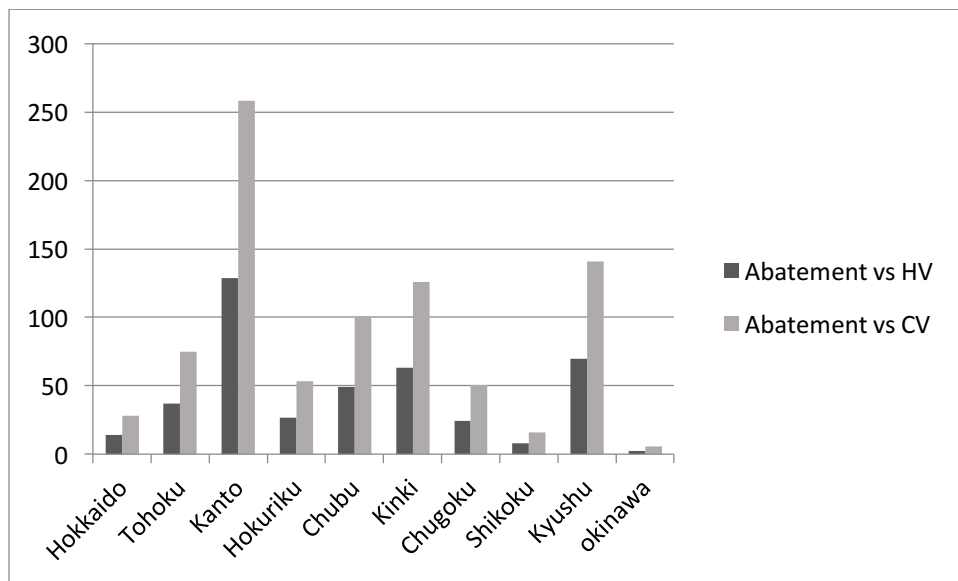


Figure 3.2: Share of Abatement of Carbon Dioxides (%)

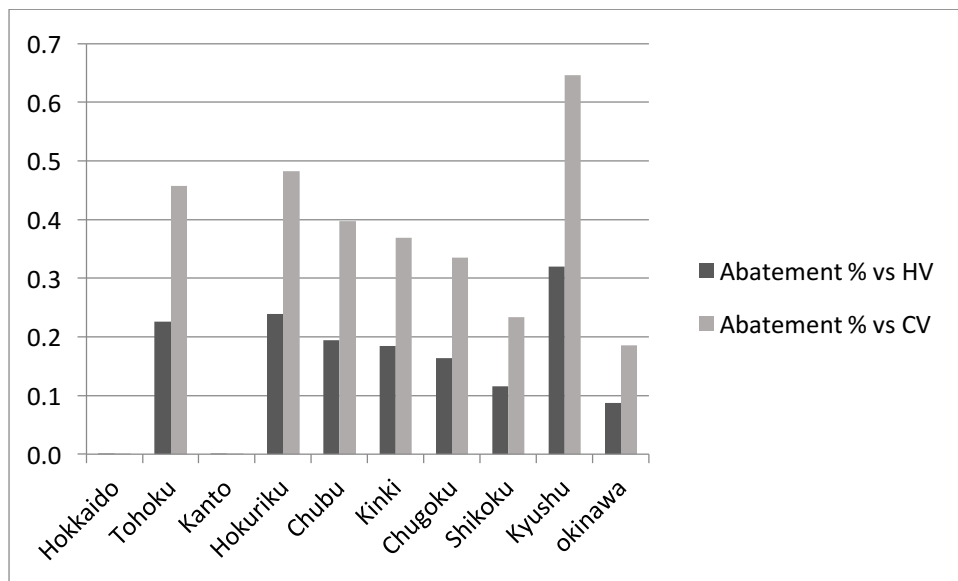
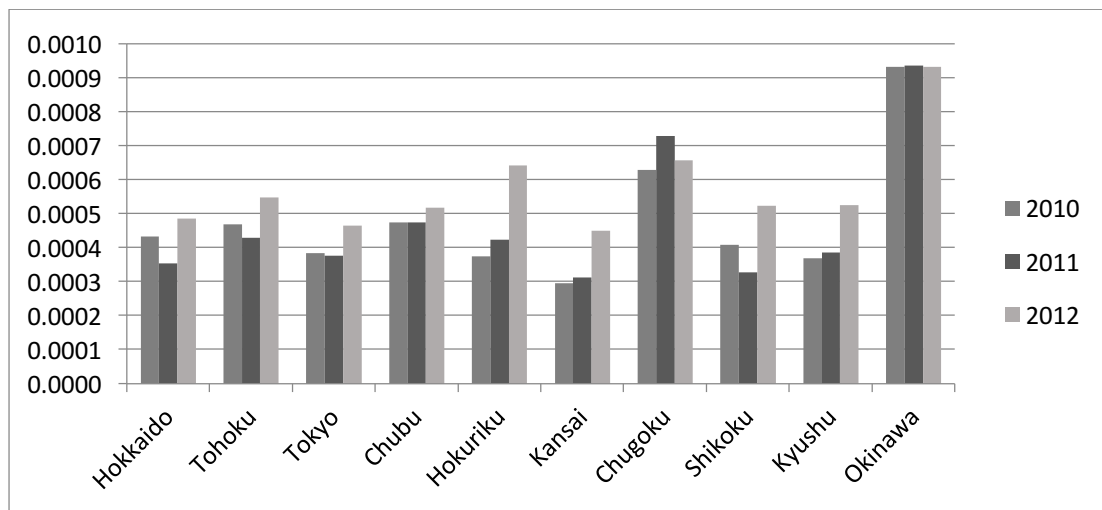


Figure 3.3: Electricity Generation CO₂ Emissions (CO₂/kWh)



4. Fuel Efficiency Gap: Evidence from Japan

4.1. Introduction

Fuel efficiency is an important factor for consumers who are deciding which vehicle to purchase, particularly for those who care about operation cost. The fuel efficiency number described in the catalogue of the vehicle will play a significant role in purchasing decisions, drivers seldom achieve fuel efficiencies close to the ones advertised in the catalogue when they drive the vehicle on the road. This difference is to be expected for several reasons such as the driving behavior, road condition, etc. But when this difference between on-road (real) fuel efficiency and advertised (catalogue) fuel efficiency is consistently getting larger with time, there is the possibility that something other than driving behavior and road conditions that are making catalogue fuel efficiency increase year by year, while real fuel efficiency comparatively shows less of an increase. We will call this discrepancy between catalogue fuel efficiency and real fuel efficiency, the fuel efficiency gap.

According to research done by T&E (2015) in Europe, the fuel efficiency gap is becoming wider with time. It has increased from 8% in 2001 to 40% in 2014. New models of cars would boast better fuel efficiency numbers in their catalogues but the numbers on the road aren't improving. If the driver's behavior, road condition and other aspects related to the driver or the place and time, are not changing in a way that is negatively affecting real fuel efficiency, then this should not be the case.

Incidents of fuel efficiency test manipulation could offer a possible explanation for the widening fuel efficiency gap. Carmakers could be manipulating the catalogue fuel efficiency numbers. If this is true then it will lead to the increasing gap between real fuel efficiency and catalogue fuel efficiency. There are two famously known incidents of manipulation. The first

is Mitsubishi, which had manipulated the road load test numbers to get better figures in the fuel efficiency test. We will refer to this incident as the Mitsubishi scandal from now on. The second is Volkswagen, which had installed devices in their vehicles that would detect when it is being tested and calibrate the car so that it would give better results on the fuel efficiency test. Those could be two isolated cases, but it is still worth it to test the possibility that fuel efficiency manipulation is a trend that might include other carmakers as well. In that case the fuel efficiency gap will continue to become wider and policymakers and consumers alike might be misled when making their decisions if they do not consider that there might be a fuel efficiency gap caused by manipulation.

This study investigates the fuel efficiency gap for Japan using on-road fuel efficiency data. The data was obtained from a survey²³ asking drivers, who decided to participate, to record their car fuel consumption data in a smart phone app which will automatically calculate the fuel efficiency number. We have three main goals for this study that can be summarized as follows. First, we will try to empirically confirm the Mitsubishi manipulation incident. Second, we will determine whether the fuel efficiency gap exist in the Japanese automobile market, and if it is getting wider with time. This would allow us to see whether Japan has the same widening fuel efficiency gap problem (that was suggested by the T&E research) as Europe, and if so then something should be done to address it from a policy standpoint. Finally, we will determine whether major carmakers in Japan have a widening fuel efficiency gap by examining the relationship between catalogue fuel efficiency and real fuel efficiency for vehicles produced in different years. The second and third objective of this study will allow us to know whether fuel efficiency manipulation in Japan is a widespread incident or an isolated incident such as the case with the Mitsubishi scandal.

There are several empirical studies that investigate automobile fuel efficiency. Kwon

²³ Survey done by IDD, Inc. Group

(2005) investigated trends of fleet cars fuel efficiency and new cars fuel efficiency in Great Britain. The paper concluded that there is a 10% gap of fuel efficiency between fleet cars and new cars. However, this study compares aggregated numbers and the 10% increase in fuel efficiency is due to technology advancement and engine size. In our study, we are trying to see the gap of the fuel efficiency between laboratory tests and on the road. As this sample is of drivers with eco-driving training, it is not an ideal representation for the purposes of an average daily driver, of which most are not trained for eco-driving.

This topic is also related to several papers that focus on manipulation invoked by incorrect design of incentives. Ghanem et al (2014) investigated manipulation in self-reported data by Chinese cities of daily air pollution concentration. They found that 50% of the cities reported dubious air pollution levels. Jacob et al (2003) detected teachers cheating on students test scores by looking at unexpected fluctuations in test scores and suspicious patterns of answers. They observed that frequency of cheating responds strongly to minor changes in incentives.

This paper contributes to previous literatures in following two ways. First, we develop a simple empirical model for detecting fuel efficiency gap over time. In this model will be able to check for a widening fuel efficiency gap for the whole sample and for samples of individual carmakers. Second, we will use real world fuel efficiency data from a survey conducted by IDD, Inc. Group, we will call this survey e-nenpi.²⁴

The rest of this chapter is organized as follows. In the next section, we give background information on the fuel efficiency gap and manipulation incident. In section 4.3, we introduce the data and methodology. In section 4.4, we will present and discuss the results. In the last section, we will give concluding remarks.

²⁴ After the website name of the IDD, Inc. Group survey. The word nenpi means fuel efficiency in Japanese.

4.2. Background

4.2.1. Fuel Efficiency Gap and Manipulation Scandal

As we have mentioned in the introduction, according to T&E (2015), the fuel efficiency gap in Europe had risen from 8% in 2001 to 40% percent in 2014. In addition, the report shows how much of the improvement in fuel efficiency in European countries is due to the gap. While there is a 35.5 g/km improvement of fuel efficiency, only 13.3 g/km of it is reflected in real fuel efficiency, the 22.2 g/km remaining in the improvement made by catalogue fuel efficiency, is due to the gap and is not achieved in real on road driving.

From our data that we obtained from e-nenpi, we can construct a graph showing the fuel efficiency gap between the catalogue fuel efficiency and real fuel efficiency as a percentage. The fuel efficiency gap in Japan is shown in Figure 4.1. We use data between 2009 and 2015, each data point is the percentage difference that we calculate using the following formula $\left[\frac{Catalogue - Real}{Real} \times 100 \right]$. We can see that there is a gap, visually, but we cannot know if there is a widening tendency to the gap. Because there are many factors affecting the fuel efficiency gap, we cannot discern whether it is due to manipulation or other factors by just looking at this figure alone.

As we have mentioned before, according to T&E (2015), this gap is consistently widening in the case of Europe, the reason for that could be that drivers had gotten worse, or because of increased traffic congestion, unless we do an empirical analysis we will not know for sure. One explanation for the fuel efficiency gap is fuel efficiency manipulation.

The incentives for carmakers to manipulate is an important factor to this puzzle and to understand the reason behind carmakers manipulating we can look at a known manipulation case, the Mitsubishi scandal.

Mitsubishi Motors has announced on April 20th, 2016 that catalogue fuel efficiency of

four light motor vehicles were manipulated during testing for fuel efficiency. This was done in order to show a higher number than what the vehicles are actually capable of in the catalogue. Mitsubishi has admitted that the manipulation started with the 2013 models. The four car models are EK Wagon, EK Space, Dayz and Dayz Rooks. The latter two are Nissan models manufactured by Mitsubishi. They have estimated that the total number of affected vehicles is 625 thousand units. Mitsubishi has also estimated that catalogue fuel efficiency of these vehicles was manipulated to be 5 to 10 percent better. This incident has sparked rage among the consumers who were basing their purchase decision on the catalogue fuel efficiency. This is important because car buyers consider the savings from buying fuel efficient vehicle that requires less gasoline than other choices in the same category. Also, car buyers who care about the environment and want to contribute by emitting less CO₂, do factor fuel efficiencies in their buying decisions

Fuel efficiency tests are run by the Ministry of Land, Infrastructure, Transport and Tourism (MILT). Because this test is run inside a laboratory, there are many elements from driving on a real road that are unaccounted for. Examples of such elements are, wind resistance and tire resistance. Mitsubishi, whom like any other carmakers in Japan; estimated the wind and tire resistance by doing an in-house road load test, had manipulated those numbers.

There are many other ways a car manufacturer can manipulate the fuel efficiency test. In Europe, both resistance test and laboratory test are done by the manufacturer which can lead to even more ways to manipulate the results. The next factor we can look at to know the reason why manipulation could be the cause of the fuel efficiency gap are policies aimed at reducing CO₂ emissions from the transport sector and particularly passenger vehicles.

4.2.2. Policy

As we have mentioned before, the transportation sector is a significant contributor to total CO₂ emissions in Japan and around the world. Governments in developed countries such as the United States, Japan and many European countries have been leaning towards incentivize consumers to buy fuel-efficient vehicles. They generally achieve that by subsidizing the vehicle purchases and technological advancements in the automobile industry to cut emissions of CO₂. This had led many governments to implement policies designed to induce carmakers to develop vehicles that are fuel-efficient. These incentives range from tax cuts to other non-monetary benefits, such as allowing fuel-efficient vehicles to park in premium spots or use high-occupancy lanes. However, the vehicle must meet certain fuel efficiency requirement in order to be eligible to these incentives²⁵. Although the intentions behind these incentives were to eventually reduce CO₂ emissions, they might have induced the carmakers to manipulate in order to meet the requirements of these policies and make their vehicle eligible for such benefits.

As we have detailed in section 2.2, in Japan, in April 2009, a tax cut policy has been introduced that gave acquisition and tonnage tax cuts for eligible vehicles on many levels, ranging from a 50% cut to a full exemption from taxes. In addition, there were two waves of subsidies for vehicles that are eligible. A lump-sum is payed back to the consumers who bought vehicle that meets the requirement of the subsidy. If we took the tax cuts as an example and look at the requirement from table 2.1, we can see that for low-emission vehicles, which are the subject of the topic of this chapter, must 25% above the 2010 fuel efficiency standards. This stipulation here might be an incentive for carmakers to manipulate the fuel efficiency test, instead of investing in technologically improving the fuel efficiency of their vehicles.

²⁵ Refer to Tables 2.1 and 2.2 to see example for such requirements in Japan.

To sum it all up, the ease in which a carmaker can manipulate fuel efficiency tests coupled with the requirement for eligibility of tax cuts and subsidies might encourage carmakers to manipulate. This might have created a race in the automobile market to produce new vehicle models that emit less CO₂ and manipulation could be a part of this race as suggested by the T&E research for Europe.

There are several reasons why manipulation has serious implications for environmental policy. First, if catalogue fuel efficiency numbers are used to measure the progress in CO₂ emission abatement from the automobile industry, then these numbers will be very misleading. As we have shown, with a fuel efficiency gap that becomes wider each year, most of this progress is not actually achieved by drivers on the road and mostly comes from numbers that come from the lab tests. Vehicles are emitting a lot more on the road than these numbers would suggest. Second, consumers consider the fuel efficiency of the vehicle before they purchase it and take this number into account. They consider how much they can save by buying a more fuel-efficient vehicle or how much they can reduce their CO₂ footprint. When this number is not reliable, consumers' choices will not lead to the results they intended. The third reason has to do with policy. Many policies have been introduced to induce consumers to buy fuel-efficient vehicles. Tax cuts, subsidies, special privileges such as high occupancy lane access and parking lot access are some examples. These policies have been designed to cut emissions of carbon dioxide but with each vehicle emitting more carbon dioxide than advertised for the same distance, the goals of these policies will not be met when we look at the total emissions cut from on-road driving. The problem is that it is difficult to measure what each driver emits on the road and it is easier to just use the catalogue fuel efficiency number when designing such policies. But if this number is incorrect or does not reflect real numbers, policymakers cannot design adequate policies for their specific goals.

4.3. Data and Methodology

4.3.1. Data

The data we use for this study is from a comprehensive survey conducted by IDD, Inc. Group. The company collects data from voluntary participants who are incentivized to join the survey because it will give them detailed information on how they are performing in terms of fuel efficiency. Each data point in the survey is collected when a participant visits a gas station to refuel and then uses a free application on their smartphone to upload their fuel consumption data. Then IDD, Inc. Group will process this information, extract the real fuel efficiency numbers and compile it for the survey. The real fuel efficiency number is calculated by using the amount of fuel used in the last fueling and dividing it by the distance driven since the last fueling visit. With this survey, we can collect information about on-road fuel efficiency achieved by drivers. We use this information in conjunction with the catalogue fuel efficiency results, from the laboratory test of the same vehicle that the consumer has driven to conduct our study. The e-nanpi data has other vehicle information, such as the name of manufacturer, model, transmission type and engine displacement as well as driver information such as approximation of driving behavior and target fuel efficiency.

We use the survey data that was compiled in October 2015 for light-motor vehicles. For the purposes of this study, light motor vehicles are the most susceptible to fuel efficiency manipulation such as the case of the Mitsubishi scandal, therefore we think using light motor vehicles is sufficient for this analysis. It is important to note that, every data point in our sample represents a refueling visit by a customer in the month of October of 2015, different refueling visit in the same period of time by the same customer are treated as different data points.

4.3.2. Methodology

The method used for the estimation is IV OLS. We use real fuel efficiency as our dependent variable. The model is represented as follows:

$$\begin{aligned} Real = & \beta_0 + \beta_1 Catalogue + \beta_2 Catalogue \times Time + \beta_3 Catalogue \times Time \times EK \\ & + \beta_4 Catalogue \times Time \times Maker + \beta_4 X + \beta_5 Z + \epsilon \end{aligned}$$

Here, *Real* is the on-road fuel efficiency of a vehicle in a data point. It is measured by kilometers per liter of gasoline consumption (km/l). *Catalogue*, is the fuel efficiency advertised in the catalogue of a vehicle. This is the fuel efficiency attained from the laboratory test. *Time*, is a variable that indicates the year of the production of the vehicle. In this data, we have vehicle production years that dates from 1990 to 2015. All of the vehicles in our dataset are from October of 2015, but the production date is what varies. For example, we can have the real fuel efficiency in October of 2015 of a vehicle that was produced in the year 2000. The *Real* variable will reflect this vehicle's real fuel efficiency in October of 2015 and the *Time* variable will reflect that this vehicle was produced in the year 2000. *EK*, is a dummy variable that takes the value of 1 for the Mitsubishi scandal vehicles and 0 otherwise. *Maker*, is a vector of dummy variables, each indicating vehicles from a certain carmaker. For example, the dummy variable *Nissan*, takes the value of 1 for vehicles produced by Nissan and 0 otherwise. We decided to use *Honda* as the base category for this vector of dummy variables. We chose *Honda* as the base because Honda vehicles have the highest real fuel efficiency on average for this sample which makes it easier to compare the other carmaker dummies. The approach we take here helps us figure out many of the question that we posed in this chapter. The coefficient

β_1 tells us the relationship between real and catalogue fuel efficiency. Here we expect that a portion of the advertised catalogue efficiency is achieved on road, so this coefficient would be less than one and more than zero. The coefficient β_2 shows whether a fuel efficiency gap exists in the Japanese automobile market. It also shows whether the gap is widening or not. Since we interact the fuel efficiency with the production year of the vehicle, if the portion of catalogue fuel efficiency that is achieved on-road is getting less and less (the coefficient is negative) then a gap exists. Next, for β_5 and β_4 , we interact the catalogue and time variables with the EK dummy variable and the Makers dummy variables respectively. The former shows us the manipulation incident empirically and the latter shows us whether a fuel efficiency gap exists for each carmaker individually, just like how β_2 shows us the fuel efficiency gap for the entire sample. X , is a vector of vehicle-variant variables. This includes Transmission, a dummy variable taking the value of 1 if the vehicle has manual transmission and 0 otherwise; Eco-Mode, a dummy variable taking the value of 1 if the vehicle has an eco-driving mode and taking the value of 0 otherwise; and Turbo-Mode, a dummy variable taking the value of 1 if the vehicle has a turbo driving mode and 0 otherwise. An Eco-driving mode makes the vehicle more fuel efficient on the expense of horsepower and Turbo-driving mode makes the vehicle perform better in terms of horsepower on the expense of fuel-efficiency. Z , is a vector of user-variant variables. This includes level of care, a vector of three dummy variables that indicates whether the user takes good care of his or her vehicle. The first of these three dummy variables are Good Care, this variable takes the value of 1 if the user chooses the first option (good care) in a question in the survey asking if he or she takes good, moderate or bad care of their vehicle and 0 otherwise, the second dummy variable is Bad Care and it takes the value of 1 if the user answers the same question with the answer bad care, and the third is Moderate Care and it takes the value of 1 if the user answered as moderate care. The Moderate Care dummy variable is used as the base for this vector of dummy variables. The level of care dummy variables are

subjective but we decided to keep them in our estimation even if it will only serve as an approximation of the customers driving behaviour. The user-variant variables also include Target fuel efficiency and Odometer, both measured by km/l. The Target fuel efficiency is what the user aims to achieve as a fuel efficiency when driving his/her specific vehicle and Odometer is how many km/l the specific vehicle of the data point has been driven. Lastly, Gasoline price is included as a control variable, it is measured by yen per liter. We include gasoline price because it could affect driving behavior. If gasoline prices are high, drivers tend to make an effort to drive more efficiently and in term affecting the real fuel efficiency number.

In the equation above we have an interesting relation between real fuel efficiency and catalogue fuel efficiency. We use catalogue fuel efficiency as a determinant for real fuel efficiency. This makes sense in theory but there is a problem with that approach. We know that consumers who want to emit less would choose vehicles that have a high rating of catalogue fuel efficiency. Therefore, Real fuel efficiency also affects catalogue fuel efficiency. Consumer who achieve higher fuel efficiency tend to buy vehicles with higher catalogue fuel efficiency. In that sense catalogue fuel efficiency is correlated with a missing variable, which is captured by the error term. This violates one of the classic conditions for OLS, leading to biased estimates of coefficients. Therefore, we use IV OLS and find an instrument that is correlated with catalogue efficiency but is not chosen by the consumer. The instrument we use is the laboratory test method. In Japan, there are two methods for testing a vehicles fuel efficiency, these pertain to the laboratory test done by the MILT and not to the road load test done by the manufacturers. The two methods are called 10 • 15 and JC80.

JC80 is the newer method. It is slightly stricter than 10 • 15. Most cars have been tested in both methods but some have been tested by one or the other. As the test methods are exogenous and consumers have no choice in which method is used to test the cars, we thought that this is a fitting instrument to use in our model. We created a dummy variable indicating

which method was used to test the vehicle, for vehicles which are tested by both methods we randomly chose one of the methods and assigned a 1 or a 0 for it in the dummy variable depending on which one it was. We will run an IV OLS regression separately for each year and compare the results. In the next section, we will present the results of the regressions.

We expect the EK interaction term to be positive. We know that vehicles included in EK have manipulated fuel efficiencies. After controlling for catalogue fuel efficiency EK dummy variable vehicles will have less real fuel efficiency compared to other vehicles. There is no expected sign for the maker interaction term as there is no indication that a fuel efficiency gap exists in any of them off the bat. If we get negative coefficient then this will prove that the fuel efficiency gap exists in the Japanese market, and that is what this study is aiming to do. We will also run the same regression without using instrumental variable (OLS instead of IV OLS) to robust check the results we get.

4.4. Results and Discussion

The main result is shown in table 4.2 under IV OLS Model 1 and IV OLS Model 2. This result is from the IV OLS model and includes the vehicle and user control variables. The catalogue coefficient is 0.255 and significant at 1% level. This suggests that, controlling for other variables that affect the on-road fuel efficiency, drivers are seeing 0.255 km/liter for each 1 km/l advertised in the catalogue. This will serve as the natural difference between real and catalogue fuel efficiency that are not captured by the other variables in the model. On average 25.5% of catalogue fuel efficiency is achieved on the road. First let's look at the catalogue interaction with time variable. The coefficient is 0.0003 and significant at the 1% level. This suggest that a fuel efficiency gap does not exist in the Japanese automobile market, since negative values for this coefficient (β_2), indicate that for each 1 km/l in the catalogue fuel efficiency real fuel efficiency is achieving less and less of it with time. In contrast, positive

values of this coefficient indicate an improvement of on-road fuel efficiency for each 1 km/l of catalogue fuel efficiency year over year. Since we got positive values for β_2 , we can at least refute a widening fuel efficiency gap for our sample. The EK interaction variable is -0.0015 and significant at the 1% level. This empirically confirms the manipulation incident since it is negative. As for the other carmakers, they are either positive and significant or negative and insignificant. This suggests that the EK incident is the only case of manipulation and a fuel efficiency gap does not exist for any of the other carmakers. We obtained similar results in the OLS model shown under OLS Model 1 and OLS Model 2 in table 4.2. One difference between the IV OLS Models and OLS Models is that in OLS Model 2, we see that there is a fuel efficiency gap for our sample of the Japanese market as indicated by the coefficient for catalogue fuel efficiency interacted with time. The coefficient here is -0.00155 and is significant at the 1% level. However, this is the only sign of a widening fuel efficiency gap and since we consider the OLS Model to be inferior to the IV OLS Model, we do not think that this result is a sufficient evidence for a fuel efficiency gap.

If we return and answer our main three questions here from these results, we can see that the manipulation incident is indeed empirically confirmed. However, we could not find strong evidence of a widening fuel efficiency gap for the whole sample nor for any individual carmaker. This suggests that in the case of our sample from the Japanese automobile industry, unlike what the T&E research suggested for Europe, the Mitsubishi manipulation incident is an isolated case and not a widespread phenomenon.

4.5. Conclusion

Fuel efficiency for the vehicles on the market that are obtained from lab tests, gauge the technological advancement and progress made in the automobile industry. Also, governments have many policies designed to incentivize such technological advancement

based of fuel efficiency numbers from lab test results. In addition, consumers in this day and age are becoming more and more aware of the environment and how fuel-efficient vehicles contribute to CO₂ abatement. Many consumers care about fuel cost saving from buying fuel-efficient vehicles. Considering all these factors, the fuel efficiency number written in the catalogue of the vehicle is an important for vehicle purchasing decisions for consumer and policymaking decisions. If the fuel efficiency numbers were manipulated then neither government could devise good policies, nor consumers could make sound vehicle buying decision. From our analysis, we could not confirm a widening fuel efficiency gap in the Japanese automobile market. A widening fuel efficiency gap could be evidence for fuel efficiency data manipulation. This suggests that the manipulation incident that happened in Japan is an isolated case. Considering the importance of stopping fuel efficiency manipulation, and the ease of manipulating lab test results. Having the Mitsubishi scandal happen might be a good thing in general for the consumers and government. It acts as a cautionary tale for other carmakers to not engage in such practices.

Since we have found no evidence of a widening fuel efficiency gap in our sample, then we can conclude that the Japanese automobile industry does not have an apparent and widespread fuel efficiency data manipulation problem.

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Tables and Figures

Table 4.1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Obs
Real Fuel Efficiency (KM/L)	15.373	3.747	3	45496	127556
Catalogue Fuel Efficiency (KM/L)	21.173	4.65	409500	6103650	127556
Time	17.019	5.793	1	26	127556
EK Dummy	0.027	0.163	0	1	127556
Suzuki	0.313	0.464	0	1	127556
Subaru	0.098	0.298	0	1	127556
Daihatsu	0.287	0.452	0	1	127556
Toyota	0.006	0.076	0	1	127556
Mazda	0.034	0.181	0	1	127556
Mitsubishi	0.062	0.241	0	1	127556
Nissan	0.033	0.18	0	1	127556
Good Care	0.675	0.468	0	1	127556
Bad Care	0.059	0.236	0	1	127556
Target Fuel Efficiency (KM/L)	16.225	4.874	7	99	127556
Turbo Dummy	0.411	0.492	0	1	127556
Manual Dummy	0.641	0.48	0	1	127556
Eco Dummy	0.183	0.387	0	1	127556
Odometer (KM)	75425.56	61714.23	30	528961	127556
Gasoline Price (Yen/L)	103.683	16.927	0	1526	127556
Fuel Efficiency Test Method	0.295	0.456	0	1	127556

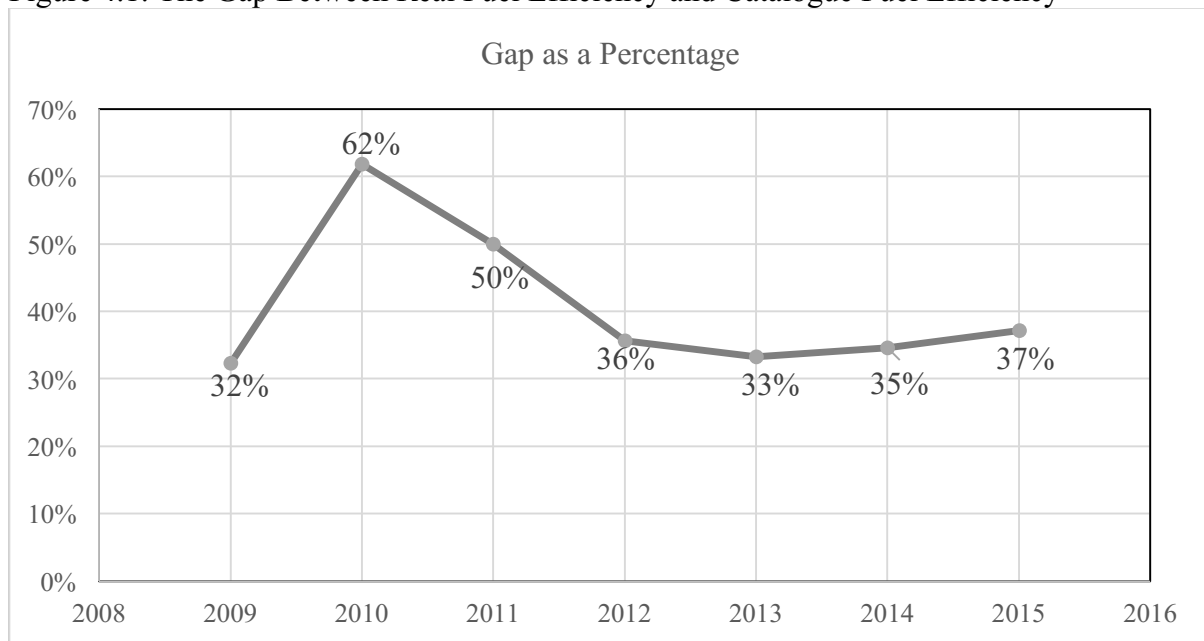
Table 4.2: IV Fixed Effects Estimation Results

Variable	IV OLS Model 1	IV OLS Model 2	OLS Model 1	OLS Model 2
Const	3.379*** (10.62)	6.556*** (26.43)	3.007*** (18.66)	4.756*** (85.31)
Catalogue Fuel Fuel Efficiency (C)	0.255*** (11.72)	0.385*** (20.20)	0.285*** (46.97)	0.523*** (124.90)
$C \times \text{Time } (t)$	0.00137*** (3.59)	0.00123** (3.17)	0.000875*** (7.33)	-0.00155*** (-14.02)
$EK \times C \times t$	-0.00151*** (-15.11)	-0.00180*** (-18.01)	-0.00151*** (-15.13)	-0.00182*** (-18.17)
$Suzuki \times C \times t$	0.000872*** (13.47)	0.00107*** (15.54)	0.000840*** (13.94)	0.000847*** (13.57)
$Subaru \times C \times t$	-0.00000843 (-0.08)	0.00179*** (14.88)	-0.0000484 (-0.50)	0.00129*** (12.87)
$Daihatsu \times C \times t$	0.0000224 (0.28)	0.000304*** (3.65)	-0.0000452 (-0.72)	-0.0000784 (-1.20)
$Toyota \times C \times t$	-0.000142 (-0.94)	0.000311 (1.72)	-0.000159 (-1.04)	0.000102 (0.58)
$Mazda \times C \times t$	0.000585*** (4.86)	0.000848*** (6.95)	0.000533*** (4.71)	0.000539*** (4.70)
$Mitsubishi \times C \times t$	0.00131*** (9.21)	0.0000666 (0.45)	0.00128*** (9.12)	0.0000425 (0.29)
$Nissan \times C \times t$	0.000536*** (4.15)	0.000917*** (6.80)	0.000562*** (4.42)	0.000960*** (7.20)
Good Care	-0.114*** (-6.09)	-	-0.108*** (-5.88)	-
Bad Care	0.0026 (0.07)	-	0.00225 (0.06)	-
Target Fuel Efficiency	0.245*** (25.00)	-	0.243*** (24.73)	-
Turbo Dummy	-0.380*** (-10.39)	-	-0.337*** (-18.10)	-
Manual Dummy	1.234*** (31.21)	-	1.194*** (49.07)	-
Eco Dummy	-0.262*** (-6.44)	-	-0.297*** (-9.21)	-
Odometer	0.00000802*** (38.92)	-	0.00000789*** (44.73)	-
Gasoline Price	0.00840*** (6.12)	-	0.00836*** (6.12)	-
Number of Obs	127556	127556	115231	127556
R-squared	0.4661	0.3477	0.4663	0.3537

*** Significant at 1%; ** Significant at 5%; * Significant at 10% level

Note: Catalogue fuel efficiency is indicated by C , and Time is indicated by t

Figure 4.1: The Gap Between Real Fuel Efficiency and Catalogue Fuel Efficiency



Note: Gap percentage = $\left(\frac{\text{Catalogue} - \text{Real}}{\text{Real}} \times 100 \right)$

5. Conclusion

In this paper, we have examined three main topics. First, we examined the effect of tax incentives on environment-friendly vehicles. Second, we studied the relationship between charging infrastructure and electric vehicles, and how increasing the number of charging infrastructure could alleviate the anxiety from short range that is negatively affecting the sales of electric vehicles. Lastly, we focused on fuel efficiency data manipulations and whether there is a fuel efficiency gap in the Japanese automobile market or not.

In this paper, through our main three topics, we learned that in the Japanese automobile market, tax cuts are highly effective, especially tax exemptions that target hybrid-electric vehicles. The subsidy program had a positive effect on the sales of environment-friendly vehicles, however, it was less effective than the tax cuts. Therefore, it might be more effective for the government to focus on tax cuts and less on subsidies in the Japanese automobile market. One limitation of this analysis is that we do not take into account that the tax incentives might have subsidized consumer who were planning to buy environment-friendly vehicles anyway. According to Chandra et al (2010), there is a free rider problem in the case of the Canadian automobile market. They found that rebate programs mostly subsidized consumers planning to buy hybrid-electric vehicles anyway. They also conclude that the rebate program could have been designed to diffuse the hybrid-electric technology through taking advantage of the economies of scale effect. However, the small numbers of hybrid-electric vehicles sold in Canada does not warrant the scale effect as an advantage of the tax rebate. A portion of the positive effect of tax incentives on the sales in our paper might have due to the free rider problem noted in the Chandra et al (2010). On the other hand, unlike the case of the Canadian market, we see some signs of a positive scale effect that might have been caused by the 2006 tax incentives as 26 out of the 30-top selling models were environment-friendly vehicles by 2013. We also learned that increasing the number charging infrastructure, especially fast

charging stations could have a positive effect on the sales of electric vehicles. However, the policy introduced by the government to subsidize the cost of building a charging station by covering half of the cost (raised to two thirds later), can be considered an expensive measure when comparing its abatement cost to the estimated cost of representative measures of reducing CO₂. This cost-effectiveness issue in our analysis is conditional on the stock number of electric vehicles that are owned by consumers and changing that number could have an economies of scale effect where it becomes comparable to other measures of abatement cost. Lastly, our results show that for light motor vehicles sold in 2015, drivers achieved 0.26 km/l for every 1 km/l achieved in the fuel efficiency lab test, while controlling for other factors. However, when we examined whether there was an increasing fuel efficiency gap between real fuel efficiency and catalogue fuel efficiency over time, we could not find any evidence of that for the Japanese automobile market. We also looked at each carmaker individually to find whether they have an increasing fuel efficiency gap throughout the years and we could not find evidence that a fuel efficiency gap exists for any of the carmakers. We were able to confirm the Mitsubishi fuel efficiency scandal in our results but couldn't find any similar pattern to it for any of the other carmakers.

As we mentioned in the beginning of this paper, with governments in developed countries becoming more aware of the need to reduce CO₂ emissions and turning to the transport sector and environment-friendly vehicles to achieve CO₂ emission cuts. There are many options available for such programs that promote the sales of environment-friendly vehicles. From what we learned in Japan, we know that tax cuts are essential for the sales of environment-friendly vehicles and that without a sufficient charging infrastructure, electric vehicles might not be competitive in the market. Also, if governments want to promote environment-friendly vehicles, it is important to check for the difference between real and catalogue efficiency and whether there is any manipulation regarding testing for fuel

efficiency, especially since most policies, such as the tax cuts in Japan use catalogue fuel efficiency as a basis for which vehicle should be eligible for the tax cuts. If fuel efficiency manipulation becomes a widespread practice, government projections for its transport sector abatement programs would not be reliable anymore since they rely mostly on catalogue fuel efficiency data. Also, consumers' buying decisions based on catalogue fuel efficiency would be misguided and most of the intended environmentalist behavior by the green consumer through driving an environment-friendly vehicle would be lost.

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