Doctoral Thesis

博士論文

Investigating the impact of consumer behavior on the East Asian transportation sector

（東アジアの運輸部門における消費者行動の影響に関する研究）

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Graduate school of Frontier Sciences

The University of Tokyo

INVESTIGATING THE IMPACT OF CONSUMER BEHAVIOR ON THE EAST ASIAN TRANSPORTATION SECTOR

By

SUNBIN YOO

A dissertation submitted in partial fulfillment of
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To the Faculty of The University of Tokyo:

The members of the Committee appointed to examine the dissertation of SUNBIN YOO find it satisfactory and recommend that it be accepted.

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INVESTIGATING THE IMPACT OF

CONSUMER BEHAVIOR ON THE

EAST ASIAN TRANSPORTATION SECTOR

Abstract

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This study investigates the diverse impact of consumer behaviors in the East Asian Transportation Sector, including energy rebounds, travel behavior, and mode choices according to environmental awareness.

In the first part, this study decomposes the impacts of consumer preferences and technological advancement towards CO_2 emissions through the econometric approach, then explore the existence and the size of the rebound effects–energy efficiency improvements and fuel consumption in Japan and Korea, using three analyses. First, whether Japanese environmental policies, including fuel economy standards and financial incentives for fuel-efficient automobiles, are correlated to the aggregated fuel consumption rebounds in the transportation sector was investigated. The findings show that the Japanese fuel economy standards are highly correlated to the energy rebound effect, by enabling higher fuel consumption at lower costs and thus inducing a higher energy usage. The factor showing the highest correlation is the increase in the sales of hybrid vehicles, which has been backed up with the financial incentives.

Second, using a random coefficients discrete choice model, this study answers whether consumer preference or technological development contributes to the CO_2 emissions more. To do so, the automobile demands of Japan are estimated. Here, the model explicitly allows consumer preferences for fuel economy to evolve, and the estimation results confirm such a change. Then consumer behavior is simulated, enabling consumers in 2009 to choose automobiles from 2013 and vice versa. The results imply that both consumer preferences and technological advancement are essential: without technological advancement and increases in consumers' appreciation for fuel-efficient cars, CO_2 emissions cannot reduce.

Third, whether a different transportation set of policies - fuel tax reductions, electric vehicle subsidy abolition, and a diesel car price increase - in Korea decreased emissions, is investigated, based on the Korean automobile demand. After the automobile demand of Korea is estimated, a counterfactual simulation analysis to examine the impact of policies on automobile sales and emissions is conducted. The studies reveal that consumers' preferences toward fuel-efficient automobiles have increased over time and that current Korean policies would not result in emissions reductions.

The second part of this study focuses on the travel behaviors, by exploring factors influencing travel distances in Japan, through investigating income group, region, hybrid interest, travel purposes, vehicle type, and demographics, with the data collected by surveys. Findings indicate that hybrid ownership is positively correlated to travel distances regardless of income level and hybrid interest, and the income has a positive relationship with travel distances. The results imply the existence of travel distance and fuel usage rebounds the highlights the need for implementing differentiated policies, primarily according to the socio-demographical identity of individuals.

The third part of this study explores whether different perspectives towards the environment are correlated to the people's bike-sharing choice in Tokyo and Shanghai. Notably, in both cities, results indicate that positive aspects such as conserving the natural environment

are not correlated to bike-sharing decisions when people are commuting. On the other hand, our results show that when people are going and returning from shopping, positive perspectives are highly correlated to the bike-sharing demands. The results, therefore, provide insights to policymakers that promoting bike-sharing would require considering diverse perspectives of environmental awareness, as well as situational factors and socio-demographic factors.

To conclude, this study estimates the impact of consumer behavior on the East Asian transportation sector from diverse perspectives. Based on five empirical studies, this study provides guidelines to policymakers in the East Asian transportation sector, by highlighting that consumer behaviors differ by countries and situations and calculating the size of rebounds.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Dedication

Chapter One

Introduction

1.1 Consumer Behavior

The hazards of increasing carbon dioxide (hereinafter CO_2) emissions urge reductions worldwide. In particular, CO_2 emissions from the transportation sector, which accounted for one-quarter of all CO_2 emissions in 2016, have not decreased, unlike in other sectors such as power generation and manufacturing. This observation has encouraged worldwide efforts to find solutions that reduce emissions in the transportation sector.

Many countries have aimed to reduce CO_2 emissions with various policies, which can be broadly categorized into two types. One approach addresses the supply side and attempts to induce the effort by manufacturers to develop and produce environmentally friendly products. Examples would include the regulation of fuel economy standards to produce fuel-efficient vehicles and increasing the number of bikes and bike-sharing stations installed, by financially supporting the installation costs of bike-sharing programs, through the government incentives.

The other approach addresses the demand side would include the attempts to use financial incentives to promote the purchases of eco-friendly cars and raising environmental awareness of the public to gradually substitute to fuel-efficient vehicles, change behaviors, and choose environmentally friendly modes. However, whether these policy measures are effective is unanswered. Even though the comprehensive integration of viable technologies is facilitated at the supply side level, consumer behavior would play an essential role in reaching such targets.

Consumer behavior indeed affect the transportation sector. By consumer behavior, it refers to consumer choices in automobile purchases or mode choices, and travel behavior. Both have a significant impact on emissions and fuel usages. For consumer choices, previous works have explored the relationship between consumer choices and automobile demands, and further, emissions and consumer choices. F. Sprei and Bauner, 2011 examined how a consumer chooses automobiles, according to their socio-demographic demographics. Hackbarth and Madlener, 2013 and Galarraga, Kallbekken, and Silvestri, 2020 analyzed how consumer choices affect the decisions of alternative fuel vehicles in Germany and Spain. Choisdealbha, Timmons, and Lunn, 2020 explained that consumer choices affect vehicle choices, and further, vehicle emissions. Adding to the previous works, whether consumer behavior induces emission increase (direct rebound) by examining automobile demands and simulating their behaviors and comparing it with the impacts of technological development. In that sense, Klier and Linn, 2012 and Knittel, 2012 which have investigated how consumer choices even affect vehicle attributes by inducing firms to produce fuel-efficient vehicles, compromising other vehicle attributes such as vehicle weights and displacements.

Financial incentives may induce consumers to purchase cars or travel more, resulting in emissions rebounds. Yet, previous works have controversial conclusions on, whether financial incentives also attract consumers to choose environmentally friendly goods such as alternative fuel source cars is not explored; for example, previous works are arguing financial incentives help consumers choose electric vehicles ((Breetz and Salon, 2018 and X. Chen et al., 2018) while the other strands of previous works argue it is not always the case; Caulfield, Farrell, and McMahon, 2010 demonstrated that financial incentives and environmental problem are not contributing to the hybrid vehicle adoptions.

To further back up, the travel behavior of consumers is also investigated. Travel behavior also affects emissions and fuel usages (W. Li and Kamargianni, 2018 and Aamaas, Borken-Kleefeld, and G. P. Peters, 2013). There is considerable research on the climate effects of daily travel, including research on socioeconomic impact factors of regular travel and associated climate change effects (Reichert, Holz-Rau, and Scheiner, 2016). However, this is less true with the travel distances of the more extended period. This is even though long-distance trips cause more than 50% of passenger-transport-related climate effects (Aamaas, Borken-Kleefeld, and G. P. Peters, 2013), urging the need to investigate the travel behavior of the longer term.

Consumer behavior is also affected by the type of environmental awareness. Y. Tran, Yamamoto, and Sato, 2020, W. Y. Chen and Cho, 2019, Penz, Hartl, and Hofmann, 2019 and Whitmarsh and O'Neill, 2010 concluded that having a pro-environmental awareness is correlated with people's choices on environmentally friendly behavior in the transportation sector. Notably, environmental awareness is connected to public transportation or bike usages (P. Zhao and Shengxiao Li, 2017, P. Zhao, Shengxiao Li, et al., 2018). Of course, technological innovations would reduce emissions. Still, at the same time, policymakers worldwide believe that raising public environmental awareness can encourage the public to use environmentally friendly mobility along with technological innovations.

1.1.1 Importance of Investigating East Asian Transportation Sector

In East Asia, the passenger transportation demand has increased dramatically; as of 2016, in China, Japan, and Korea, more than 250 million passenger cars were registered. (IEA Energy statistics). Along with the number of vehicles increase, the demand for oil has increased by nearly 60% in China, Japan, and Korea since 2004 (IEA Energy Statistics). Passenger cars have accounted for more than 50% of the increase (Matsuhashi and Ariga, 2016) in demand, resulting in emissions and fuel usages increase.

For China, the demand for passenger vehicle has increased significantly with the rapid economic growth. From 1991 to 2015, the total number of vehicle production was increased from 700,000 units to 24 million units. One of the solutions Chinese government suggested was the introduction of bike-sharing. do so, the Chinese government introduced European bike-sharing systems to increase demand for green transport by raising public awareness that using bike-sharing can alleviate urban traffic problems.

For Japan, as a part of its overall program to meet standards set under the Paris Agreements Intended Nationally Determined Contribution (INDC), the Japanese government initiated financial incentives and certified fuel economy standards to tackle greenhouse gas emissions generated through transportation. In December 2015, local Japanese governments adopted a reduction target for the transportation sector to reach 30% of the 2015 level by 2030. Measures include the improvement of fuel economy, the promotion of next-generation automobiles and the utilization of special zones as structural reforms for global warming measures. Furthermore, Japan also started to promote the use of bikes-sharing. In Tokyo, to address the environmental problems, the Japanese government introduced bike-sharing within Tokyo City, promoting the dependency on motor vehicles. The Japanese government also announced polices including the establishment of bike-sharing system and increasing the on-road bike lanes in 2016. Bike-sharing in Tokyo have multiple cycle ports installed within a given area, where people can rent and return from the ports. Additionally, the Tokyo metropolitan government is also increasing the number of services and parking areas to boost user convenience.

Korea, the world's 10th largest CO_2 emitter (Netherlands Environmental Assessment Agency), came up with a "paradoxical" policy set. In 2017, it abolished all financial incentives and subsidies for diesel-fueled vehicles, while simultaneously decreasing the diesel and gasoline fuel tax rates. By removing a so-called 'clean-diesel' policy, the Korean government hoped to make aware to consumers of the environmental harms of diesel. As for the fuel tax reductions, the Korean government anticipated to reduce consumers' financial burden. As a result, diesel automobiles sales in Korea initially decreased with the government's announcement of the removal of financial incentives but began to increase again after fuel tax adjustments. Meanwhile, as the gasoline tax rate has also been reduced, gasoline automobiles sales in Korea have increased, from 56.52% in January 2018 to 61.84% in December 2018. The increased number of gasoline cars would result in more emissions, and this is probably caused by either diesel car owners substituting to gasoline cars or consumers starting to buy new vehicles due to the fuel tax reductions.

To come up with a better policy set that enables us to achieve the CO_2 reduction target efficiently, the evaluations on, which approach is more effective, among many other policy options in respective countries: financial incentives, fuel tax regulations, subsidies towards alternative fuel source vehicles and promoting bike-sharing usages is necessary.

1.2 Institutional Background: East-Asian Transportation Policies

Even though geographically close, East Asian countries have a different, contrasting policy sets, resulting in different consumer behaviors. In this section, this study briefly introduce the transportation policies in East Asia and discuss their differences.

Financial Incentives and Fuel Taxes: Japan and Korea

Japan and Korea have a different policy set to promote fuel-efficient and alternative power source vehicles. While the Japanese government focused on improving the level of fuel economy regardless of the power source, the Korean government focused on limiting the diesel usage irrespective of the fuel economy level.

In Japan, even though the contents and manners of policies are similar to the corporate average fuel economy (CAFE) of the US, as mentioned in Konishi and M. Zhao, 2015, financial incentives in Japan are mainly focused on promoting hybrid cars and light-duty vehicles with lighter weights, higher fuel efficiency, and lower displacements because Japanese fuel economy standards require not only a high level of fuel economy but also lighter weights. As a result, due to a higher level of fuel economy of hybrid vehicles (around 30-40km/l) than regular cars (about 16km/l), and approximately 34.75% lighter weights of light-duty cars on average than regular cars (Ministry of Land, Infrastructure, Transport, and Tourism), hybrids and light-duty vehicles are more likely to receive financial subsidies than regular cars. Additionally, plug-in hybrids are exempt from weight taxes regardless of fuel economy standards in Japan.

As a result, hybrid and light-duty vehicles have been gaining popularity in the Japanese automobile market. For example, the cumulative number of hybrid cars sold in Japan has continuously increased from 74,183 in 2002 to 6,568,960 in 2017, according to the Japanese Ministry of Land, Infrastructure, and Transport, and light-duty vehicles in Japan comprise almost 40% of the new car market. On the other hand, Korea, the world's 10th largest CO_2 emitter (Netherlands Environmental Assessment Agency), came up with a "paradoxical" policy set. In 2017, it abolished all financial incentives and subsidies for diesel-fueled vehicles, while simultaneously decreasing the diesel and gasoline fuel tax rates. By removing a so-called 'clean-diesel' policy, the Korean government hoped to make aware to consumers of the environmental harms of diesel. As for the fuel tax reductions, the Korean government anticipated reducing consumers' financial burden. As a result, diesel automobiles sales in Korea initially decreased with the government's announcement of the removal of financial incentives but began to increase again after fuel tax adjustments. Meanwhile, as the gasoline tax rate has also been reduced, gasoline automobiles sales in Korea have increased, from 56.52% in January 2018 to 61.84% in December 2018. The increased number of gasoline cars would result in more emissions, and this is probably caused by either diesel car owners substituting to gasoline cars or consumers starting to buy new vehicles due to the fuel tax reductions.

The average gasoline price sold at gas stations nationwide in the second week of October 2018 was 1,674.9 KRW (Korean won) per liter, up by 15.4 KRW from the previous week. Diesel for automobiles also rose 16.5 KRW to 1,477.9 KRW (Korea National Oil Corporation) while crude oil, mostly imported by South Korea, stood at $82.0 a barrel. The Deputy Prime Minister of Korea argued that since oil prices have exceeded $80 per barrel, it could put pressure on small business owners, small businesses, and working-class people, and a cut in oil taxes will help the economy by addressing their difficulties and increasing disposable income. Still, this policy can encourage people to purchase diesel cars, encouraging more emissions in the end.

Furthermore, the Korean government officially announced that the subsidies towards hybrid cars would be abolished entirely, and subsidies for electric cars would decrease gradually. In 2018, the Korean government provided 12,000 USD for electric cars but reduced the amount of subsidy to 9,000 USD in 2019, and planning to decrease further.

Bike-Sharing Schemes in Shanghai and Tokyo

Despite its limited experience compared to the United States and Europe, Asia has recently become the fastest-growing market for bike-sharing (Shaheen, Guzman, and H. Zhang, 2010). Starting from the 2010s, the Chinese and Japanese governments; 2nd and 6th emitters in the world, introduced a bike-sharing system based on smart-phone applications on top of the existing bike-sharing system, expecting an increase in the number of people using bike-sharing, and eventually, a reduction in emissions, like other countries. The increase of bike-sharing of these two countries does contribute to the global growth rate for bike-sharing to reach 37% (Meddin, 2013).

For China to reinstate the deteriorated cycling environment due to rapid urbanization and motorization, the Chinese government actively promoted the use of bike-sharing. To do so, the Chinese government introduced European bike-sharing systems to increase demand for green transport by raising public awareness that using bike-sharing can alleviate urban traffic problems. Within a few years, Hangzhou, Wuhan, Shanghai, Zhuzhou have built scaled urban bike-sharing systems, and mainland China has become the largest bike-sharing market in the world (Tang, Pan, and Fei, 2017). Furthermore, the new generation of dock-less bike-sharing programs (e.g., ofo and Mobike) emerged in Chinese cities with the development of mobile internet. This new bike-sharing program integrates mobile payments and GPS tracking with big data and is considered the fifth generation of bike-sharing Si et al., 2019, and was successful in encouraging Chinese people to use bike-sharing; more than 13% of total commuters used bike-sharing services during peak hours in Shanghai (Y. Zhang and Mi, 2018).

According to statistics, as of May 2013, mainland China has a total of 105 bike-sharing systems in service, 13,317 public bike stations, and 398,181 bike-sharing for use. Up to July 2015, it has rapidly grown to more than 300 operations in service, 1 million shared bikes for use (Tang, Pan, and Fei, 2017). On the other hand, in Tokyo, to address the environmental problems, the Japanese government introduced bike-sharing within Tokyo City, promoting the dependency on motor vehicles. The Japanese government also announced policies, including the establishment of the bike-sharing system and increasing the on-road bike lanes in 2016. Bike-sharing in Tokyo have multiple cycle ports installed within a given area, where people can rent and return from the ports. Additionally, the Tokyo metropolitan government is also increasing the number of services and parking areas to boost user convenience.

Connected with the private companies, the Japanese government is also actively promoting the proliferation of bike-sharing. Starting from 2011, bike-sharing services are extended from Yokohama, Koto, Sendai, Chiyoda, and Minato, reaching more than 5,600 bicycles nationwide at the year 2017, with the 250,000 memberships and 521 ports. [1].

1.3 Research Objective

The three East Asian countries are challenging towards increasing emissions and fuel usages from the transportation sector, while they all have different policies and circumstances. This difference would let consumers behave differently according to the region, and the following emissions and implications would vary as well. Understanding the differences in consumer behavior from the transport sector is critical because of its increasing prominence as a source of emissions in most countries and its relevance to the preparation of climate change mitigation strategies.

This study explores four essential perspectives for understanding consumer behaviors: First, this study examines the existence of "direct rebound" in terms of the automobile market. As a solution to decrease oil dependency in the transportation sector, governmental policies, mainly fuel economy standards and financial incentives given to fuel-efficient cars are designed to facilitate the improvement of the vehicle fuel economy levels. However, this might enable consumers to consume fuel at a lower cost, eventually raising oil usage. To this end, the environmental policies were investigated: whether fuel economy standards and financial incentives for consumers ended up increasing fuel usages and costs.

Second, this study tests the automobile demand of Japan and Korea, allowing consumer preferences for fuel economy to evolve over the years. Then consumer behavior is simulated, enabling environmentally cautious consumers to purchase fuel-efficient automobiles and allowing non-environmentally cautious consumers to choose less fuel-efficient cars. This study further provides a comparative implication between Japan and Korea, on the policy impacts and different consumer demands. The results would imply how much of consumer

[1]Data source: https://www.japantimes.co.jp/life/2017/10/21/lifestyle/pedal-power-bike-sharing-services-expand-in-japan

preferences, technological advancement, and policies are important in emissions.

Third, this study investigates how Japanese people travel. Reducing vehicle travel distances would be one of the promising options to reduce oil dependence eventually. However, the factors affecting travel distances are not investigated yet, which makes developing effective transportation-related policy difficult. Therefore, this study explores factors influencing travel distances in Japan, through investigating income group, region, hybrid interest, travel purposes, vehicle type, and demographics, with the data collected by surveys.

Fourth, this study explores how environmental awareness people's behavior in choosing transport modes by investigating how environmental awareness interacts with bike-sharing choices. Particularly, Bike-sharing is one of the promising transportation options which can decrease on-road carbon dioxide emissions. However, there is a lack of previous works investigating whether different types of environmental awareness affect bike-sharing demands. Consumers' behaviors would change according to the perceptions, encouraging people to make pro-environmental choices because conserving natural environment is a good deed, would not be effective if people are more likely to change behaviors because they fear the negative outcomes of natural disasters or environmental pollution. As this study investigates Shanghai and Tokyo, possible differences towards environmental awareness may occur therefore investigating bike-sharing demands towards one general, broad "environmental awareness" might produce misleading result. To address this problem, this study categorizes environmental awareness into three types. Then their impacts on motivating citizens to choose bike-sharing in Tokyo and Shanghai are estimated.

The transportation sector has already become a crucial contributor to fuel dependency and CO_2 emissions that require international and trans-discipline solutions. Given this, this study provides implications to have a better understanding of emission and its associated impacts in the transportation sector and suggests policy solutions. Implications from this research can be extended to other countries. As tackling the oil dependency and on-road emissions are crucial not only for developed countries but also to developing countries, investigating consumer behavior in transportation sector using our study as a reference will provide meaningful policy implications to achieve emissions and oil usage reductions successfully.

Chapter Two

Automobile Demands and Direct Rebounds

2.1 Background of Japanese Environmental Policies and Rebounds

2.1.1 Direct Rebounds in the Transportation Sector

As a solution to decrease oil dependency, Japanese environmental policies, mainly fuel economy standards and financial incentives given to fuel-efficient cars are designed to improve vehicle fuel economy levels. However, this might enable higher fuel consumption at a lower cost, eventually raising oil usage (West et al., 2017).

Starting from William Stanley Jevons in 1865, economists have studied the relationship between energy efficiency improvements and fuel consumption and have found what later became known as the rebound effect: efficiency improvements enable microeconomic decisions, such as lower private marginal costs of fuel and thereby higher fuel consumption, that cause higher levels of energy consumption at the macroeconomic level (Munyon, Bowen, and Holcombe, 2018). The evidence of rebound effects in the transportation sector is also confirmed by previous studies arguing that increasing the fuel economy of automobiles does not necessarily lead to a proportionate reduction in fuel consumption. Automobiles with a higher fuel economy can travel farther at lower costs. This also indicates that the lower cost-per-mile increases the miles traveled, (West et al., 2017) or an increase in total oil consumption despite fuel economy levels improvements ("Energy Efficiency And Consumption - The Rebound Effect - A Survey" 2000).

The research gap comes from the fact that previous studies have found the existence of rebounds, but there is no consensus on the scale of its effect (Moshiri and Kamil, 2017; D. L. Greene, 2012). Furthermore, no study considers the fuel cost rebounds in the transportation sector, an increase in fuel costs coming from the fuel usage rebounds that consumers should afford. If not investigated, the Japanese environmental policies might also result in an increase in oil dependency and financial burdens to consumers.

To this end, this study investigates whether the Japanese environmental policies - fuel economy standards and financial incentives for consumers - ended up increasing fuel usages and costs. Using the aggregate-level data on the Japanese automobile industry, this study estimates whether financial incentives increased the total fuel usages and total fuel costs, mainly by encouraging financial incentives increased the overall fuel usages and total fuel costs, primarily by encouraging consumers to purchase a new car or replace their original car with a new one. This study calculates the fuel usage by considering the number of automobiles sold, fuel economy improvement, and driving distance.

The results show a rebound effect in fuel usage and fuel costs, regardless of the estimation method. The main driving forces behind rebounds are financial incentives, fuel economy standards, and the increase in the sales of light-duty vehicles and hybrid vehicles due to greater distances driven.

This study contributes to two strands of literature. First, this study investigates the size of the rebound effect in the field of transportation. Previous empirical research has found the existence of, but not reached a consensus on, the scale of the rebound effect. Previous works also attempted to find a scale of a rebound in the field of the transportation sector. Small and Dender, 2007 used US panel data from 1961 to 2001 to estimate a long-run rebound effect of 22% in the US transportation sector. D. L. Greene, 2012 examined the rebound effect for the same sector during the same period and obtained an almost identical rebound effect of 23%. On the other hand, Moshiri and Kamil, 2017estimated the rebound effect for passenger transportation in Canada and found a high average rebound effect of 82-88%.Borger, Mulalic, and Rouwendal., 2016 estimated a rebound effect of 7.5-10% in Denmark's transportation sector. Stapleton, Sorrell, and Schwanen, 2017a also evaluated the rebound effect for passenger transportation in Great Britain to be around 19%. Dimitropoulous, Oueslati, and Sintek, 2018 found a short-term rebound of 10-12% and a long-term rebound of 26-29%. As the scale of rebound varies, this paper adds to the literature by calculating the size of rebound effects, specifically investigating the impact of financial incentives on the number of sales of hybrids and light-duty vehicles.

This study also specifically investigates the most popular hybrid powertrains - Toyota Prius,Toyota Aqua, and Honda Insight - and their impacts on total fuel usage, total fuel costs, and sales. Previous studies indicate that the increased use of hybrid electric vehicles - mostly Toyota Prius - increases fuel usage (Nässén and Holmberg, 2009; Kagawa et al., 2013; W. Li and Kamargianni, 2018; Hamamoto, 2019, and consumers were attracted to replace their cars with the Prius (P. d. Haan, G.Mueller, and Peters., 2006; P. d. Haan, A. Peters, and Scholz, 2007). In the same line, this study contributes by investigating whether the increase in hybrid electric vehicles exacerbates negative environmental externalities because the significant increases in hybrid sales will cancel out the reduction of fuel usage due to the improved fuel economy.

Second, this study contributes to the existing energy policy literature by showing the rebound effect on fuel usage and costs, after accounting for vehicle attributes, firm specifications, hybrid automobiles, driving distances, and gasoline prices. The literature on the energy rebound effect tends to look at the rebound effect from technological improvements in energy consumption ("Energy Efficiency And Consumption - The Rebound Effect - A Survey" 2000). While some studies try to evaluate the policy effectiveness on reducing rebounds, (Stepp et al., 2009, Creutzig et al., 2011) previous works find that the energy efficiency standards trigger rebound effects (K. Wang and Akar, 2019;Y.-J. Zhang et al., 2015).The literature looks less at the rebound effects of energy policies created to control such rebound effects (Vivanco, Kemp, and Voet, 2016), which is an important step towards identifying which energy policies work in reducing fuel usage.

This study uses the characteristics of Japanese fuel economy standards to determine whether they have lessened or amplified the energy rebound effect. Such an analysis is necessary to assess the impact of fuel economy standards.

2.1.2 Environmental Policies in the Japanese transportation sector

As the Japanese government acknowledges the necessity to reduce oil dependency in the transportation sector, it has provided financial incentives to encourage consumers to buy more fuel-efficient automobiles. From the consumer perspective, the Japanese government offers financial incentives to encourage consumers to buy more fuel-efficient cars. Unlike other countries, in Japan, these incentives mainly focus on promoting light-duty vehicles equipped with lighter weight, higher fuel economy, and lower displacement and hybrid cars.

In Japan, there are mainly two types of tax reductions; car tax reductions, which are acquisition tax reductions based on fuel economy standards, and subsidies, which are determined by the fuel economy levels. To obtain tax exemptions and subsidies, a car should satisfy 2020 fuel economy standards. The amounts of tax exemptions and subsidies largely depend on the fuel economy level of the car; for example, if a car has a level more than 40% higher than the 2020 fuel economy standards, the car will obtain full exemptions.

For subsidies, an automobile is eligible for 100,000 JPY of financial subsidies if it has a greater level of fuel economy than the Fiscal Year 2010 Fuel Economy standards, and it is eligible for 7,000 JPY of subsidy if it is a light-duty vehicle, according to the document published by the Ministry of Land, Infrastructure, Transport and Tourism (2013).

Table 2.1 Tax Exemption Standards

Criteria	Car Tax Exemption
Fuel Economy 40% Higher Than the Year 2020 Fuel Efficiency Standard	Full Exemption
Fuel Economy 30% Higher Than the Year 2020 Fuel Efficiency Standard	80% Reduction
Fuel Economy 20% Higher Than the Year 2020 Fuel Efficiency Standard	60% Reduction
Fuel Economy 10% Higher Than the Year 2020 Fuel Efficiency Standard	40% Reduction
Fuel Economy Equal to Than the Year 2020 Fuel Efficiency Standard	20% Reduction

These tax schemes are mainly limited in that incentives are consumption-oriented, which is likely to increase automobile sales and cause direct emission rebounds at an aggregated scale. Furthermore, the Japanese policy is the strictest in the world, allowing only 4% of all automobiles to be eligible for incentives over 10 years, as cars must satisfy both fuel economy and weight standards. Although an automobile may exceed fuel economy levels of 30 km/l, if its weight does not meet the standard, it is not eligible for the incentives.

This study also finds that financial subsidies adopted in Japan are not effective in motivating consumers to purchase fuel-efficient automobiles; granting everyone the same amount of money (10,000 JPY) is not attractive, as those who purchase an automobile eligible for financial subsidies are granted the same amount of money regardless of the automobile's original price, as in Yoo, Wakamori, and Yoshida, 2019.

Besides, these measures are not designed to consistently monitor or track the travel behaviors of drivers, which in turn lets drivers drive more due to the improved level of fuel economy of a newly bought automobile. If not investigated, whether those policies cause fuel usages and costs to increase will remain unknown. Therefore, this study separately investigates the impact of these tax reductions and the fuel economy standards on total fuel usages. Furthermore, this study examines fuel costs, which represent an expenditure of fuel usages. This study looks into the former to explore the impacts of the current Japanese energy incentives schemes on the environment, and the latter to scrutinize the financial implications for drivers.

2.2 Motivation: Direct Rebound and CO_2 Emissions

The Japanese government successfully improved the fuel economy level as policies fostered the proliferation of fuel-efficient automobiles. Figure 2.1 shows the improvements in the weighted average of fuel economy levels and gasoline changes in Japan, with the gasoline usages between 2006 and 2016. One immediate finding from this figure is that the fuel economy level has continuously improved since 2006 and dramatically improved after 2009. This striking increase was due to the introduction of some famous hybrid cars, such as Toyota Prius and Honda Insight. Therefore, the figure indicates that the average fuel economy has improved the weighted fuel economy levels by approximately 40%, It would let us expect the oil dependency from the transportation sector in Japan to be reduced significantly during that period.

However, as shown in Figure 2.1, this study observes only a 4% decrease in gasoline consumption of the transportation sector from 2007 to 2016 (EIA, 2016). Hence, it seems like technological development is not proportional to oil dependency, as one would expect to see a reduction in fuel usage if the fuel economy improved. This indicates the existence of fuel usage rebounds. Such a discrepancy seems to reflect the fact that consumers either drive more or choose to purchase/replace vehicles after the financial incentives, eventually increasing emissions. This urges the necessity to investigate Japanese environmental policies,

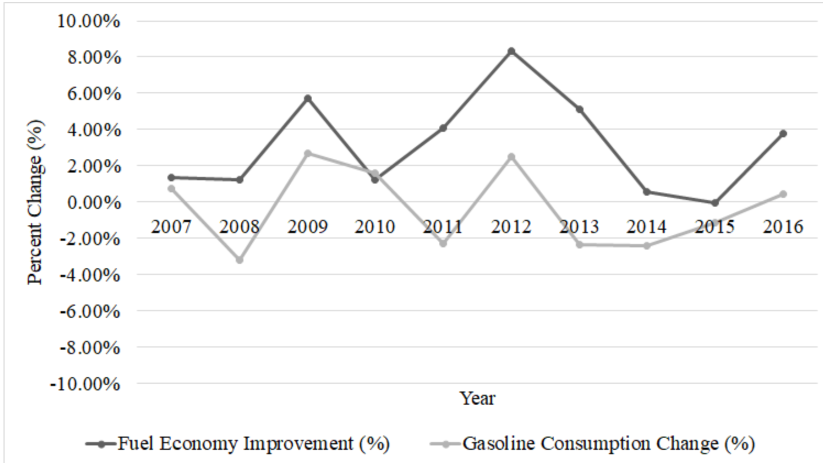

Figure 2.1 Evolution of the Weighted Averaged Fuel economy and Gasoline Consumption in Japan

whether it has caused rebounds and how much.

2.3 Methodology: Investigating the Rebounds

2.3.1 Data Descriptions

This study used an original, product-differentiated dataset, representing 90% of total automobile sales in Japan from 2006 to 2016. This study first collected data on new car sales. In principle, this study could also collect information on used car sales, but they account for only approximately 10% of the total car sales in Japan in any given year (Japan Automobile Manufacturer Association). This study collected primary data on new car sales by each model from the Japan Automobile Dealers Association. Data on models by foreign manufacturers are only recorded if the models are ranked in the top twenty best-selling models. In the data, domestic manufacturers include Daihatsu, Honda, Mazda, Mitsubishi, Nissan, Subaru, Suzuki, and Toyota. Foreign manufacturers include Audi, BMW, Mercedes, Peugeot, Volkswagen, 149 and Volvo. In total, this study collects 1,860 vehicle models between 2006 and 2016.

This study then matches each vehicle model to data on vehicle attributes, such as horsepower, vehicle weight, and fuel economy, from Carsensor.net, which provides information on all available cars in Japan. [1] To compensate for the lack of information on fuel type, this study adds a dummy variable for whether each car model is a hybrid. [2] Table 2.2 displays descriptive statistics of the variables, where the results of dummy variables were excluded from the Table.[3] Approximately 160 car models were available for each year during the sample period. Although the Table shows the raw data for each variable, when estimating the model, this study uses the log values of all variables.

According to Table 2.2, this study finds that the number of automobiles sold differs significantly by whether a car receives subsidies, tax exemption, or neither. For example, the average value of a car sold without any financial incentives is approximately 1/3 of the importance of a car receiving tax benefits. This suggests the possibility that the increase in the number of sales would trigger the increase in fuel usage and costs from an aggregate perspective.

In investigating rebound effects, this study need to know the driving distances and car types. this study include driving distance in the model according to the different car types, as in Table 2.3.

[1] https://www.carsensor.net/

[2] this study includes dummy variables for Toyota Prius Hybrids, Honda Insight Hybrids, and Toyota Aqua Hybrids, which only have hybrid cars. this study do not apply the dummy variable to other car models, such as the Toyota Camry, which include both hybrids and ICE.

[3] this study also includes dummy variables on foreign cars, light vehicles, company-fixed effects, and model-fixed effects of Toyota Aqua, Toyota Prius, and Honda Insight. The three hybrid models were the first models to enter the market.

Table 2.2 Descriptive Statistics

	N	Mean	Std. Dev.	Min.	Max.
Automobiles Without Financial Incentives					
Automobile Price (in 10,000JPY)	1,424	250.386	185.712	68.8	1253.8
Unit sold (Unit)	1,424	19,754	31,626	10	226,725
Fuel Efficiency (km/l)	1,424	14.585	4.102	5.5	24.5
Displacement (cc)	1,424	1,846.603	984.733	656	5,662
Horsepower (HP)	1,424	142.520	81.3556	45	570
Weight (kg)	1,424	1,314.551	349.292	700	2,720
Automobiles Receiving Subsidies					
Automobile Price (in 10,000JPY)	183	234.751	120.487	100	930
Unit sold (Unit)	183	32,422	35,837	10	202,838
Fuel Efficiency (km/l)	183	17.739	3.958	10.8	27.6
Displacement (cc)	183	1,625.585	441.736	996	3,498
Horsepower (HP)	183	125.656	37.496	69	306
Weight (kg)	183	1,347.486	296.674	900	1,920
Automobiles Receiving Tax Exemptions					
Automobile Price (in 10,000JPY)	222	235.012	173.061	74.5	1090
Unit sold (Unit)	222	52,020	72046.85	56	317,675
Fuel Efficiency (km/l)	222	25.707	5.222	15.4	40.8
Displacement (cc)	222	1,350.757	730.672	658	3,498
Horsepower (HP)	222	100.369	58.440	49	314
Weight (kg)	222	1,157.477	350.495	620	2,080

Table 2.3 Standards of Different Types of Automobiles in Japan.

Small Cars	- Length: Less than 4.7m - Width: Less than 1.7m - Height: Less than 2.0m - Total Displacement: Less than 2,000 cc.
Regular Cars	- Capacity: Less than 10 people - Exceeds the standard of a small car. - Height: less than 2.0m - Total Displacement: more than 2,000 cc.
Light-duty Vehicles (LDV)	- Length: Less than 3.4m - Width: Less than 1.5m - Height: Less than 2.0m - Total Displacement: Less than 660 cc.
Hybrid Vehicles	- Gasoline - Electric Hybrid Engine

Note: Hybrids are decided by the fuel type regardless of the automobile type.

This study also employs driving distance data to account for the driving behaviors of consumers according to the car type, and this study obtains data from the Ministry of Land, Infrastructure, Transport and Tourism, Japan. Ideally, this study would use survey-based driving distance data. However, due to data availability, this study uses aggregate-level driving distance data. Additionally, this study was not able to acquire the aggregate-level driving distances of hybrid automobiles before 2010. Therefore, since previous researches (D. Greene, 1990;Dahl and Sterner, 1991; Barla et al., 2009;Weber and Farsi, 2018) state that driving distance is highly correlated with fuel costs, this study first estimated the driving distance value for hybrid automobiles before 2010 and for other types of vehicles through extrapolation, as in the appendix. Even though this approach has limitations, this study believes it can provide insight into whether consumers purchase hybrid automobiles, motivated by policies, and whether fuel usages and costs change. Additionally, as the aggregated driving distance is classified by all types of cars, not only hybrids, the implications would provide meaningful evidence of changes in consumer behavior according to the vehicle type.

2.3.2 Difference-in-Difference Approach

To investigate whether Japanese energy policies caused rebound effects, this study estimates the policy effect on fuel usages and costs in the transportation sector. Because of frequent and continuous policy changes, one could argue that a simple before-after comparison would be useful for inferring the effects of policy changes. However, other policy changes, such as adjustments in the fuel economy standard, could impact the existence and scale of rebound effects. Therefore, this study treats automobiles receiving financial incentives as a treatment group and cars that are not eligible for financial subsidies as a comparison group.

With this in mind, this study uses a standard differences-in-differences (DID) method with controls to capture the causal effect of policy changes on the energy rebound effect. The DID method is gaining popularity due to its simplicity. It is based on a quasi-experimental research design that compares the mean value of a dependent variable over time between treatment and control groups to investigate potential causal relationships and determine the size of the effect of the treatment (Hird and Pfotenhauer, 2017). Here, the DID method allows us to distinguish changes in the dependent variables due to one-time policy changes versus changes in the trend growth or level. DID framework in this study is focused on the comparison of the impact of before and after the financial incentives on the fuel usages and fuel cost, controlling for other relevant variables. By using other automobiles not eligible for the financial incentives as a control group, the DID model captures the differences in fuel usages and fuel costs in Japan with and without the financial incentives. To further investigate the impact of the time trend on fuel usages and expenses, this study also includes a time trend variable, which starts in 2009, as the financial incentives began in 2009. Another reason why this study uses the DID framework is for its potential to avoid many of the endogeneity problems that typically happen when comparing heterogeneous observations (Bertrand, Duflo, and Mullainathan, 2004).

To calculate total fuel usage, this study takes the product of the inverse of the fuel economy levels (l/km) and the number of sales as an indicator of the total fuel usage of drivers, as in equation (2.1). Here, this study defines the total fuel usages of automobile i at time t as:

$$TFU_{it} = Q_{it} * (1/E_{it}) \tag{2.1}$$

Where Q_{it} denotes sales quantity and E_{it} represents fuel economy of automobile i in year t. Then this study multiply driving distance as:

$$TFUD_{i,a,t} = TFU_{it} * D_{at} \tag{2.2}$$

D_{at} is the driving distance of automobile type a of year t, where the car type is regular cars, hybrid cars, small cars and light-duty vehicles. Next, this study employed the total fuel cost by multiplying the gasoline prices in equation (2.1) for each year to yield equation (2.3).

$$TFC_{it} = TFU_{it} * FC_t \tag{2.3}$$

where TFC_{it} refers to the total fuel cost of product i in year t, FC_t is the gasoline cost in year t. this study also consider driving distance as in equation (2.4):

$$TFCD_{i,a,t} = TFU_{it} * FC_t * D_{at} \tag{2.4}$$

While consumers might not explicitly see total fuel usage, total fuel cost directly increases consumers' expenditure as greater driving distances would result in more fuel costs if all drivers are maximizing their driving distances. Estimating this variable not only gives us the impact of automobiles towards consumers' welfare but also provide clear evidence on rebounds as gasoline prices are directly included as a control variable, particularly when driving distances were considered. To be more specific, including gasoline prices will give us insights into whether fuel costs affect consumers, particularly when the gasoline prices increase, for example, whether consumers would use more fuels even when the gasoline price is high.

This study take account of subsidies and tax reduction standards provided by the Japanese Government. Thus automobile price in this study represents price with incentives. All variables in the estimating process are in log values.

Table 2.4 Description on Dependent Variables

Dependent Variables	**Descriptions**
Sales (Q)	The Number of Automobile Sold
Fuel Economy (E)	Fuel economy (km/l)
Total Fuel Usage (TFU)	Fuel Usage for 1 km * Q
TFU * Distance (TFUD)	Fuel Usage for 1 km * Q *Distance
Total Fuel Cost (TFC)	Fuel Usage for 1 km * Q * Fuel Cost
TFC * Distance (TFCD)	Fuel Usage for 1 km * Q* Fuel Cost*Distance

Note: Hybrids are decided by the fuel type regardless of the automobile type.

To this end, this study employs six dependent variables, as in Table 2.4: total fuel usage (TFU), total fuel usage multiplied by driving distance, total fuel cost (TFC), total fuel cost multiplied by driving distance, sales and fuel economy levels. What this study expects to see from the models is the marginal effect of rebound when taking account of the number of sales. Therefore, this model will allow us to see how the dependent variables change if this study allow one more automobile model to be eligible for financial incentives. This study also includes sales and fuel economy levels as dependent variables to investigate the impact of explanatory variables on them and compare the magnitudes. For example, if the coefficient of the 2015 tax reform variable is higher when estimated with sales than with fuel economy levels, the implications would be that that specific year would cause more sales increases than the fuel economy improvements.

To produce unbiased estimators of the models, this study design assumes that the dependent variables are not correlated to the policy variables. In the case of experimental studies, this assumption is fulfilled by random assignment into treatment and control groups. However, in policy studies, the treatment assignment is usually not random because there exist specific criteria for obtaining tax exemptions; for example, whether a certain automobile will get tax reduction or not is decided by the automobile's fuel economy levels. If financial incentives are correlated with fuel economy levels, then the DID estimator will produce biased estimators (Ringquist and Kostadinova, 2004). Testing for correlations, this study

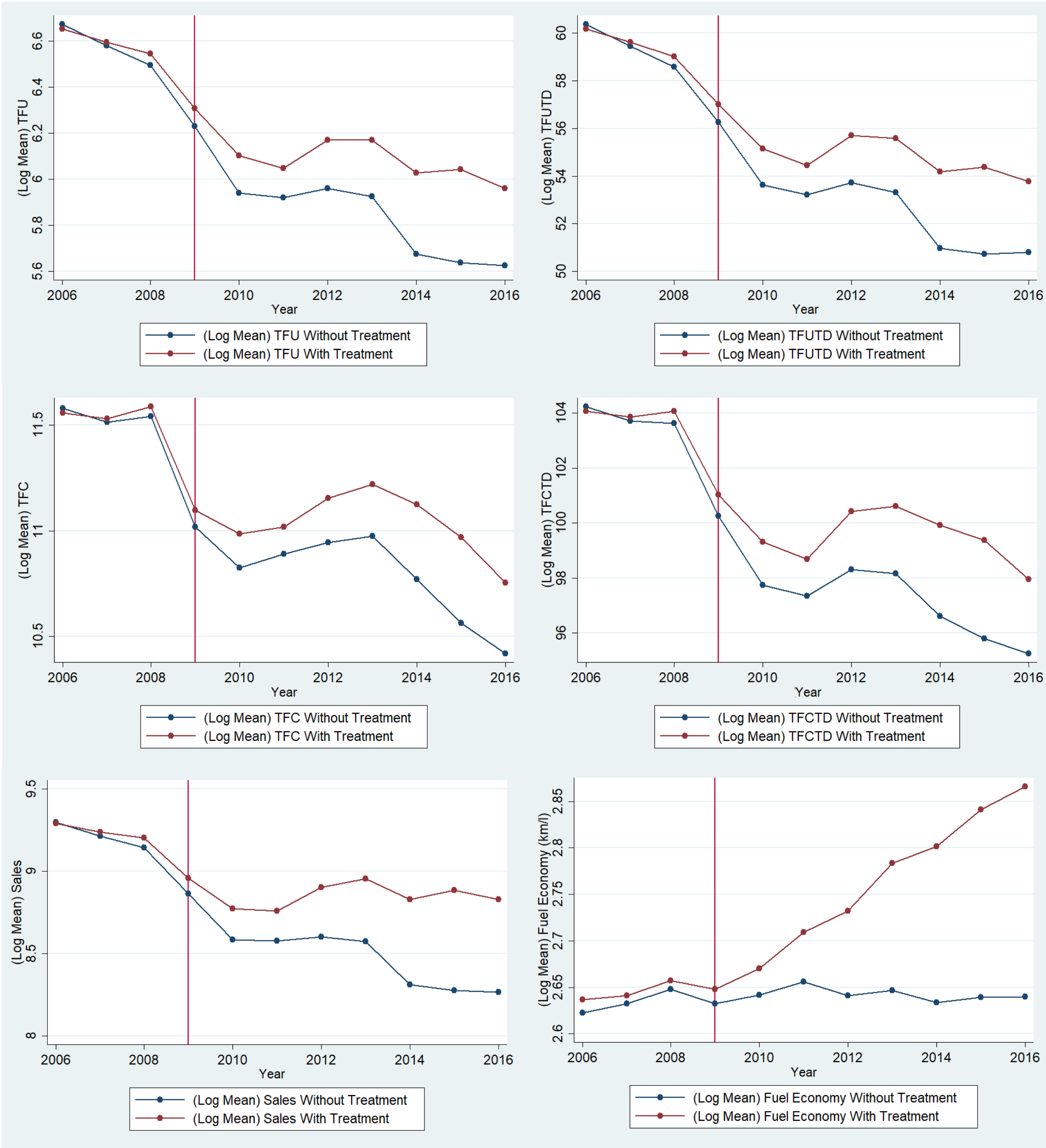

Figure 2.2 Log-mean value of dependent variables

found that the correlation between fuel economy levels and green subsidies is 0.11 and that between fuel economy levels and tax exemptions is 0.50.

While using the DID methodology, it is also essential to test the common trends assumption that the trends would be the same in 244 hybrid or high-efficiency automobiles, as well as other cars in the absence of treatment. This study test this and present the results in Figure 2.2 to find that both the treatment group (cars with financial incentives) and the control group composed of other cars face decreasing trends. This study sees that the parallel trend holds, as the trends before the year 2009 were constant and consistent over time and started to change after 2009. This shows the differences between the treatment group and the control group (automobiles without financial incentives), validating the DID framework and the resulting estimates.

This study also include individual events in the model as interaction terms with the fuel economy variable, as this study acknowledge that these are crucial to consumers' behavior and fuel usage, as shown in Table 2.5. This study notably considered the average levels of fuel economy in the years 2006, 2007, and 2009 to be improved dramatically compared to the other years, as the fuel economy standards and financial incentives were adjusted and amended in those years. Therefore, to reflect such a change into this model, this study added them as variables by multiplying the year dummy with a fuel economy value.

Similarly, in 2015, Japanese tax reforms increased the total acquisition tax from 5% to 8% and decreased automobile sales (PwC, 2013). By controlling those specific events and trends as variables, this study compares the magnitudes of such patterns in terms of fuel economy standards, hybrid electric vehicle sales, and tax reductions.

This study excludes yearly fixed effects in the model since an essential part of this study includes controlling for annual fluctuations of gasoline prices and their impact on sales. This study still believes that the main role of the yearly fixed effects, capturing unobserved heterogeneity over time, can be played by the annual changes in gasoline prices, which usually serve as a proxy for the global economic situation of each year. To further account for such heterogeneity over time, this study includes the interaction variable of fuel economy and sales. This study also has to account for the linear trend growth changes after 2009, the year of interest for the DID method. Therefore, for this study, this study had to compromise between including yearly fixed effects or including the variables for gasoline price, the interaction between fuel economy and sales, and post-2009 trend growth.

As this study are interested in investigating whether financial incentives–tax exemptions and subsidies– increased fuel usages and costs in the Japanese transportation sector, this study estimate the final model in equation (2.5) (following Qui and He, 2017, Carley et al., 2017):

$$
\begin{aligned}
Y_{ijt} = \lambda_1 dT_{ijt} + \lambda_2 dS_{ijt} + \lambda_3 T_t + \alpha_0 + \alpha_1 P_{ijt} \\
+\beta_1 FE_{ijt} * I_{2006} + \beta_2 FE_{ijt} * I_{2007} + \beta_3 FE_{ijt} * I_{2009} + \beta_4 Q_{ijt} * I_{2015} \\
+\gamma_1 X_{ijt} + \gamma_2 Hybrid_{ijt} + \delta_1 FC_t + \zeta_j + \epsilon_{ijt}
\end{aligned}
\tag{2.5}
$$

Y_{ijt} represents each dependent variable of automobile i of manufacturer j at year t, dT_{ijt} is a dummy variable for tax exemption, and dS_{ijt} is a dummy variable for green subsidy. For example, if a car is eligible for a green subsidy, then $dS_{ijt} = 1$. Therefore λ_1 and λ_2 captures the impact of tax exemptions and green subsidies towards fuel usages and costs, respectively. T_t represents year trends from 2009, indicating that λ_2 shows the impact of post-treatment period. P_{ijt} is the automobile price.

$FE_{ijt} * I_{2006}$, $FE_{ijt} * I_{2007}$, and $FE_{ijt} * I_{2009}$ are the interaction term between fuel economy and the year dummy variable–specifically when the fuel economy standard was implemented and adjusted, which are 2006, 2007 and 2009, and $Q_{ijt} * I_{2015}$ is the interaction term between sales quantity and tax reform, which might have an impact on the number of automobile sold, where Q_{ijt} stands for the number of automobile sold, and I_{2015} is a year dummy variable for year 2015.

X_{ijt} is vehicle attributes such as weight, displacement, horsepower, and light-duty vehicle status, $Hybrids_{ijt}$ indicates the hybrid dummy variables, and FC_t is the gasoline price of year t. Also, ζ_j represents firm-fixed effects, and $\epsilon_{Y_{ijt}}$ is the error term.

Table 2.5 Description on Event Variables

Year	**Descriptions**
2006, 2007, 2009	Fuel Economy Standards Adjustments
2009	Financial Incentives Implemented
2014, 2015	Income Tax Reform

This model allows us to investigate not only the policy implications but also the impacts of hybrid electric vehicles on total fuel usage and fuel costs. Hybrid electric vehicles were regarded as one of the promising options to reduce fuel usages in the passenger transportation sector. However, if the coefficient is positive, then the total fuel usage of Japan is expected to increase. This is either due to the hybrid electric vehicle sales rising faster than the fuel economy improvements or due to drivers driving more, resulting in more fuel usage despite the fuel economy improvements. This provides the implications on rebounds effects caused by newly innovated technologies, which are planned initially to mitigate adverse environmental externalities.

Size of Rebounds

This study mainly discusses the results with statistical significance, taking the driving distance as the dependent variable. This study has four models for each result. Model (i) uses the automobile price and policies as controls, and Model (ii) uses the automobile price, policies, and vehicle attributes but without year trend effects. Model (iii) adds year trend effects to Model (ii), and Model (iv) is the full Model, which adds company fixed effects to Model (iii). Regardless of the results, this study finds that Model (i), Model (ii), and Model (iii) overestimate the variable coefficients due to the lack of fixed effects and control variables. Therefore, this study focus on Model (iv), the full model. Nevertheless, the coefficients in Model (ii), Model (iii), and Model (iv) were mostly consistent, indicating the robustness of the estimation results. Regardless of the models, however, this study finds statistically significant estimates for financial incentives, showing the strong relationship between these incentives and the rebounds.

Overall, automobile prices had negative coefficients. This indicates that automobiles were normal goods, which corresponds to the conventional economic theories. Regardless of the relatively higher prices, hybrid electric vehicles show positive coefficients, implying higher sales. This suggests the impact of the market penetration of hybrid electric vehicles, which is consistent with the recent works. This is because producers of hybrid electric vehicles deliberately priced them lower than the industry average to penetrate the automobile market and encouraged consumers to perceive hybrid electric vehicles to be affordable as well as environmentally friendly (J. M. Sallee, 2008).

Additionally, the coefficient for the gasoline price is positive in all of the model specifications. This is due to the Japanese fuel efficiency improvements, which allowed consumers to purchase or replace old automobiles with new ones, even though the gasoline price increased. This implies a rebound effect in fuel usage, triggered by the increase in automobile sales.

Turning to the rebounds, Table 2.6 shows the estimates with total fuel usage as the dependent variable, and Table 2.7 shows the same with the product of total fuel usage and driving distance as the dependent variable. Result estimates were consistent and generally similar to other previous estimates.

Table 2.6 Results: Dependent variable: TFU.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.655***	-2.755***	-2.672***	-3.010***
	(0.069)	(0.209)	(0.209)	(0.202)
Policies				
Green subsidy	0.765***	0.611***	0.683***	0.626***
	(0.126)	(0.127)	(0.128)	(0.122)
Car Tax Exemptions	0.276*	0.750***	0.884***	0.816***
	(0.117)	(0.123)	(0.127)	(0.126)
Fuel Economy * Year 2006	0.043***	0.046***	0.030***	0.031***
	(0.009)	(0.009)	(0.009)	(0.009)
Fuel Economy * Year 2007	0.040***	0.042***	0.026**	0.025**
	(0.009)	(0.009)	(0.009)	(0.009)
Fuel Economy * Year 2009	0.028*	0.028*	0.049**	0.046
	(0.010)	(0.010)	(0.015)	(0.014)
Time Trend			-0.0867***	-0.0899***
			(0.0211)	(0.0203)
Sales * Year 2015	0.029	0.029*	0.050**	0.047**
(Income Tax Reform)	(0.015)	(0.014)	(0.015)	(0.014)
Gasoline Price	0.942*	0.988*	0.579	0.466
	(0.469)	(0.450)	(0.459)	(0.436)
Vehicle attributes				
Weight		3.649***	3.706***	3.992***
		(0.377)	(0.376)	(0.360)
Displacement		-0.441	-0.652*	-1.533***
		(0.325)	(0.327)	(0.320)
Horsepower		1.244***	1.287***	2.134***
		(0.262)	(0.261)	(0.260)
Light-Duty Vehicles		0.767***	0.676***	1.000***
		(0.190)	(0.190)	(0.185)
Hybrid Cars				
Toyota Prius				2.300***
				(0.524)
Toyota Aqua				2.872***
				(0.658)
Honda Insight				-1.234*
				(0.533)
Constant	4.805*	-13.20***	-10.41***	-8.557**
	(2.402)	(2.917)	(2.983)	(2.846)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1806	1806	1806	1806
R-sq	0.099	0.174	0.182	0.270

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table 2.7 Results: Dependent variable: TFU*Travel Distance.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.614***	-2.738***	-2.649***	-3.008***
	(0.069)	(0.209)	(0.209)	(0.202)
Policies				
Green subsidy	0.756***	0.586***	0.663***	0.612***
	(0.126)	(0.128)	(0.128)	(0.122)
Car Tax Exemptions	0.326**	0.813***	0.956***	0.841***
	(0.118)	(0.123)	(0.127)	(0.126)
Fuel Economy * Year 2006	0.045***	0.049***	0.031***	0.032***
	(0.009)	(0.008)	(0.009)	(0.009)
Fuel Economy * Year 2007	0.042***	0.044***	0.027**	0.025**
	(0.009)	(0.009)	(0.009)	(0.009)
Fuel Economy * Year 2009	0.037**	0.038***	0.017*	0.013
	(0.010)	(0.010)	(0.011)	(0.010)
Time Trend			-0.093***	-0.095***
			(0.021)	(0.020)
Sales * Year 2015	0.024	0.025	0.048**	0.045**
(Income Tax Reform)	(0.015)	(0.014)	(0.015)	(0.014)
Gasoline Price	0.863	0.913*	0.475	0.333
	(0.471)	(0.452)	(0.461)	(0.436)
Vehicle attributes				
Weight		3.632***	3.693***	3.980***
		(0.378)	(0.377)	(0.360)
Displacement		-0.451	-0.677*	-1.566***
		(0.326)	(0.328)	(0.320)
Horsepower		1.252***	1.298***	2.187***
		(0.263)	(0.262)	(0.260)
Light-Duty Vehicles		0.677***	0.579**	0.936***
		(0.190)	(0.191)	(0.185)
Hybrid Cars				
Toyota Prius				2.739***
				(0.524)
Toyota Aqua				3.337***
				(0.658)
Honda Insight				-0.785
				(0.533)
Constant	13.98***	-3.743	-0.748	1.195
	(2.411)	(2.928)	(2.992)	(2.845)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1806	1806	1806	1806
R-sq	0.095	0.170	0.179	0.272

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

This study finds that the estimates are quite similar in Tables 2.6 and 2.7, which reconfirms the existence of the rebound effect, regardless of the choice of the dependent variable. This indicates that more attention should be paid to the total fuel usage than to the distance driven, as the results suggest that driving distance does not significantly affect the rebounds. As the estimates are similar, this study focus on the results after taking into account the driving distances.

Note that the treatment group is automobiles receiving financial incentives after 2009, and the control group is automobiles without any incentives. In Table 2.6, this study finds that the rebound effect on fuel usage from the treatment group, mainly due to the increase in the number of automobiles sold, is caused by Japanese policies. First, this study confirms that the treatment group uses approximately 70.8% more fuel if a car is eligible for the green subsidy and 121.8% if it receives tax exemptions, compared to the control group. Recall that the dataset is at the product level. Hence, the resulting parameters indicate the marginal rebound effects of allowing one more car model to be eligible for the green subsidy. For example, if one additional car model becomes available for the green subsidy, then this newly eligible car will use 70% more fuel than non-eligible vehicles, mainly due to the sales increase of that model. This can be easily supported by the descriptive statistics, as this study, can find that the number of sales increases when an 349 automobile is eligible for the incentives.

Second, results indicate that fuel economy standards also cause fuel usages rebounds; the results imply that a change of 1% in the 2006 standards caused an increase of 3.1% in fuel usage, while the same change in the 2007 standards caused a rise of 2.5%. This also shows that fuel economy improvements will increase the total fuel usage, as such improvement allows consumers to drive more at lower costs.

Third, this study finds the rebound effect due to the increasing popularity of light-duty vehicles and hybrid automobiles. The results indicate that the light-duty vehicles have 171.8% higher fuel usage than non-light duty vehicles, which are mainly regular cars, and this study also finds that the Toyota Prius and Aqua use more than twice as much gasoline as non-Prius or non-Aqua cars. This study believes this is due to the differences in the number of sales; for example, the number of Prius sold is approximately ten times higher than the average number of non-Prius automobiles sold.

This study finds that the year trend decreases fuel usages by 9%. This is because the average fuel economy level of automobiles drastically increased from 2009. However, this study finds that the positive effects of the year trend are canceled out by financial incentives, fuel economy standards, hybrid automobiles, and light-duty vehicles, reconfirming that the rebound still exists.

Tables 2.8 and 2.9 represent the parameter estimates when taking total fuel costs and total fuel cost multiplied by driving distance as the dependent variables. This study focuses on Table 2.8, as the estimates in the two tables are similar. While most of the estimates were consistent, the coefficient for gasoline price is positive, implying that higher gasoline costs would raise total fuel costs.

This study also finds rebounds; fuel costs increase due to financial policies and the rise of light-duty and hybrid automobiles sales, consistent with the results from Tables 2.8 and 2.9. First, this study finds the rebound effect from the treatment group amounts to 84% from cars qualifying for green subsidy and 132% from those qualifying for tax exemption compared to the control group. Second, this study confirms that fuel economy standards cause rebounds of 3.2% in 2006, 2.5% in 2007, and 1.3% in 2009. Third, this study finds a cost rebound effect in light-duty vehicles and hybrid automobiles due to their popularity among consumers, while the light-duty vehicles have 154% higher fuel usage. Similar to the result in Table 2.6 and Table 2.7, the result indicates that the time trend decreases fuel usage by 9.5%.

In summary, this study confirms that there are rebound effects in the Japanese automobile sector. First, this study finds that the impact of the sales increase would be much more significant than the effect of driving distance on fuel usages and fuel cost, as this study does not find any significant differences in the estimates after applying driving distances. Second, this study finds that the treatment group uses more fuel and faces more financial burdens due to its high fuel costs compared to the control group. For example, if this study allows one more automobile model to be eligible for the green subsidy, that automobile will use 70% more fuel than the cars that are not eligible. This applies to car tax exemption, for if this study let one more automobile model receive tax exemption benefits, that automobile will use 132% more fuel and will cause the fuel cost to increase proportionately. Third, the results indicate that light-duty vehicles use approximately 171% more fuel than non-light duty vehicles. This is because of the rising popularity of light-duty vehicles in Japan, as there are twice as many light-duty vehicles as non-light duty vehicles. This also applies to the popular hybrid automobiles.

Table 2.8 Results: Dependent variable: TFC.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.655***	-2.755***	-2.672***	-3.010***
	(0.069)	(0.209)	(0.209)	(0.202)
Policies				
Green subsidy	0.765***	0.611***	0.683***	0.626***
	(0.126)	(0.127)	(0.128)	(0.122)
Car Tax Exemptions	0.276*	0.750***	0.884***	0.816***
	(0.117)	(0.123)	(0.127)	(0.126)
Fuel Economy * Year 2006	0.043***	0.046***	0.030***	0.031***
	(0.009)	(0.009)	(0.009)	(0.009)
Fuel Economy * Year 2007	0.040***	0.042***	0.026**	0.025**
	(0.009)	(0.009)	(0.009)	(0.009)
Fuel Economy * Year 2009	0.035***	0.037***	0.017	0.014
	(0.010)	(0.010)	(0.011)	(0.010)
Time Trend			-0.087***	-0.090***
			(0.021)	(0.020)
Sales * Year 2015	0.028	0.028*	0.049**	0.046**
(Income Tax Reform)	(0.015)	(0.014)	(0.015)	(0.014)
Gasoline Price	1.942*	1.988***	1.579***	1.466***
	(0.469)	(0.450)	(0.459)	(0.436)
Vehicle attributes				
Weight		3.649***	3.706***	3.992***
		(0.377)	(0.376)	(0.360)
Displacement		-0.441	-0.652*	-1.533***
		(0.325)	(0.327)	(0.320)
Horsepower		1.244***	1.287***	2.134***
		(0.262)	(0.261)	(0.260)
Light-Duty Vehicles		0.767***	0.676***	1.0–***
		(0.190)	(0.190)	(0.185)
Hybrid Cars				
Toyota Prius				2.300***
				(0.524)
Toyota Aqua				2.872***
				(0.658)
Honda Insight				-1.234*
				(0.533)
Constant	4.805*	-13.20***	-10.41***	-8.557**
	(2.402)	(2.917)	(2.983)	(2.846)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1806	1806	1806	1806
R-sq	0.102	0.177	0.185	0.273

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table 2.9 Results: Dependent variable: TFC*Travel Distance.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.614***	-2.738***	-2.649***	-3.008***
	(0.069)	(0.209)	(0.209)	(0.202)
Policies				
Green subsidy	0.756***	0.586***	0.663***	0.612***
	(0.126)	(0.128)	(0.128)	(0.122)
Car Tax Exemptions	0.326**	0.813***	0.956***	0.841***
	(0.117)	(0.123)	(0.127)	(0.126)
Fuel Economy * Year 2006	0.045***	0.049***	0.031**	0.032**
	(0.009)	(0.009)	(0.009)	(0.009)
Fuel Economy * Year 2007	0.042***	0.044***	0.027**	0.025**
	(0.009)	(0.008)	(0.009)	(0.009)
Fuel Economy * Year 2009	0.037***	0.038***	0.017	0.013**
	(0.010)	(0.010)	(0.011)	(0.010)
Time Trend			-0.093***	-0.095***
			(0.021)	(0.020)
Sales * Year 2015	0.024	0.025	0.048**	0.045**
(Income Tax Reform)	(0.015)	(0.014)	(0.015)	(0.014)
Gasoline Price	1.942*	1.988***	1.579***	1.466***
	(0.469)	(0.450)	(0.459)	(0.436)
Vehicle attributes				
Weight		3.632***	3.693***	3.980***
		(0.378)	(0.376)	(0.360)
Displacement		-0.451	-0.677*	-1.566***
		(0.326)	(0.328)	(0.320)
Horsepower		1.252***	1.298***	2.187***
		(0.263)	(0.262)	(0.260)
Light-Duty Vehicles		0.677***	0.579**	0.936***
		(0.190)	(0.191)	(0.185)
Hybrid Cars				
Toyota Prius				2.739***
				(0.524)
Toyota Aqua				3.337***
				(0.658)
Honda Insight				-0.785
				(0.533)
Constant	13.98***	-3.743	-0.748	1.195
	(2.411)	(2.928)	(2.992)	(2.846)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1806	1806	1806	1806
R-sq	0.097	0.173	0.182	0.274

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table 2.10 shows the estimation results for sales. As one can expect, the coefficient for automobile price is negative, meaning that automobile is a normal good.

Another notable finding is that the estimates are entirely consistent with the results in Tables 2.6, 2.7, 2.8, and 2.9. The results indicate that the financial subsidies are positively related to the number of automobiles sold, implying that a higher number of cars were sold in the treatment group, which is consistent with the descriptive statistics. For instance, allowing one more model to receive the green subsidy would increase automobile sales by 72.8%, while there would be a 121.7% increase if the car tax exemption were allowed. Increasing fuel economy standards would also increase the number of sales by 3.3% in 2006, and 2.7% in 2007. This implies that increased automobile sales due to the Japanese environmental policy represent a large part of the rebounds.

In the same line, the light-duty vehicles and hybrids have positive coefficients, indicating their popularity among consumers. The estimates of vehicle attributes imply that consumers do evaluate these characteristics. Table 2.11 presents the estimation results with the fuel economy as a dependent variable. The results imply that the green subsidy will improve the fuel economy by 10.2%, while the car tax exemptions would improve the fuel economy by 40%. This indicates that the fuel economy level of the treatment group rises with Japanese financial incentives. The fuel economy standards also contributed to the fuel economy improvements, by 2% in 2006, 3% in 2007, and 4% in 2009. It was noted that lower levels of car weight, displacement, and horsepower would increase the fuel economy. Width is also positively correlated with fuel economy.

This study also finds that the estimated coefficient of the time trend in Table 2.10 is -0.076. In contrast, the coefficient of fuel economy has a positive value of 0.0139, indicating that the average fuel economy has been improved by 1.3%, and overall vehicle ownership decreased by 7.6%. Therefore, this study confirms that the negative coefficients of the time trend in Tables 2.6, 2.7, 2.8 and 2.9 are due to the fuel economy improvement and the overall decrease in vehicle ownership, starting from 2009. Hence, this study noticed that the coefficients in Table 2.11 are smaller than the coefficients in Table 2.10. This might indicate that the impact of financial incentives on facilitating fuel economy improvements might be smaller than the effect on sales, which will increase emissions. This study discusses this problem along with policy implications in Section 2.4.

Table 2.10 Results: Dependent variable: Sales (Q).

	Model (i) **Limited Controls**	**Model (ii)** **Limited Controls**	**Model (iii)** **Limited Controls**	**Model (iv)** **Full Model**
Automobile Price	-1.051***	-2.764***	-2.695***	-3.047***
	(0.070)	(0.214)	(0.215)	(0.207)
Policies				
Green subsidy	0.906***	0.718***	0.778***	0.728***
	(0.128)	(0.131)	(0.132)	(0.126)
Car Tax Exemptions	0.810***	1.196***	1.307***	1.217***
	(0.119)	(0.126)	(0.130)	(0.129)
Fuel Economy * Year 2006	0.0425***	0.0459***	0.0324***	0.0330***
	(0.009)	(0.009)	(0.010)	(0.009)
Fuel Economy * Year 2007	0.041***	0.042***	0.029**	0.027**
	(0.009)	(0.009)	(0.010)	(0.009)
Fuel Economy * Year 2009	0.037***	0.038***	0.022	0.018
	(0.010)	(0.010)	(0.011)	(0.011)
Time Trend			-0.0721***	-0.0761***
			(0.022)	(0.021)
Sales * Year 2015	0.032*	0.032*	0.050**	0.046**
(Income Tax Reform)	(0.015)	(0.015)	(0.016)	(0.015)
Gasoline Price	0.998*	1.056*	0.716	0.582
	(0.475)	(0.462)	(0.472)	(0.447)
Vehicle attributes				
Weight		3.107***	3.154***	3.446***
		(0.387)	(0.386)	(0.369)
Displacement		-0.733*	-0.908**	-1.837***
		(0.333)	(0.337)	(0.328)
Horsepower		1.198***	1.233***	2.134***
		(0.269)	(0.269)	(0.266)
Light-Duty Vehicles		0.453*	0.377	0.722***
		(0.195)	(0.196)	(0.190)
Hybrid Cars				
Toyota Prius				2.714***
				(0.537)
Toyota Aqua				3.173***
				(0.675)
Honda Insight				-1.157*
				(0.544)
Constant	9.283***	-4.539	-2.215	-0.169
	(2.435)	(2.996)	(3.068)	(2.917)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1806	1806	1806	1806
R-sq	0.187	0.235	0.240	0.326

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table 2.11 Results: Dependent variable: Fuel Economy (E).

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.40***	-0.084	-0.022	-0.037***
	(0.008)	(0.019)	(0.019)	(0.018)
Policies				
Green subsidy	0.141***	0.107***	0.095***	0.102***
	(0.013)	(0.012)	(0.011)	(0.011)
Car Tax Exemptions	0.533***	0.446***	0.423***	0.401***
	(0.013)	(0.011)	(0.011)	(0.011)
Fuel Economy * Year 2006	-0.0001	-0.0006	0.002*	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
Fuel Economy * Year 2007	0.0003	0.0002	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Fuel Economy * Year 2009	0.001	0.002	0.003***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Time Trend			0.0146***	0.0139***
			(0.002)	(0.002)
Sales * Year 2015	0.004*	0.004**	0.0002	0.0002
(Income Tax Reform)	(0.002)	(0.001)	(0.001)	(0.001)
Gasoline Price	0.0569	0.069	0.137**	0.117**
	(0.050)	(0.041)	(0.041)	(0.039)
Vehicle attributes				
Weight		-0.543***	-0.552***	-0.546***
		(0.034)	(0.034)	(0.032)
Displacement		-0.292***	-0.256***	-0.304***
		(0.029)	(0.029)	(0.029)
Horsepower		-0.046	-0.053*	0.0003
		(0.024)	(0.023)	(0.023)
Light-Duty Vehicles		-0.314***	-0.299***	-0.278***
		(0.017)	(0.017)	(0.017)
Hybrid Cars				
Toyota Prius				0.414***
				(0.047)
Toyota Aqua				0.301***
				(0.059)
Honda Insight			0.077	
				(0.048)
Constant	4.488***	8.666***	8.195***	8.388***
	(0.256)	(0.263)	(0.266)	(0.256)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1806	1806	1806	1806
R-sq	0.751	0.836	0.842	0.856

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Placebo Tests

The empirical analysis in this study has a possibility of spurious correlation. Fuel usage may increase because of other vehicle attributes, and a relationship with policies or hybrids may be just a coincidence, as the analysis is based on observational data. If this were the case, the estimates are no more valid. Therefore, to raise reliability in the estimates, this study implemented a "placebo test" that allowed us to verify the consistency of the results, as fuel usages and cost increase with financial incentives and hybrid automobiles. The results are attached in the Appendix.

2.3.3 Correlation Analysis between Variables

The dependent variables in the model are correlated, as the total fuel usage is a product of the sales quantity and the fuel economy, and the total fuel cost is a product of the gasoline price and the total fuel usage. Therefore, this study test the sensitivities of the dependent variables. this study expect sales to have a stronger correlation than fuel economy, as the initial hypothesis predicts.

Table 2.12 Results of pairwise correlations: sensitivity analysis of dependent variables

	TFU	$TFU * Distance$	TFC	$TFC * Distance$	$Sales$	E
TFU	1.000					
$TFU * Distance$	0.9991	1.0000				
TFC	0.9935	0.9890	1.0000			
$TFC * Distance$	0.9962	0.9934	0.9992	1.0000		
$Sales$	0.9392	0.9386	0.9374	0.9399	1.0000	
E	0.2939	0.2962	0.2947	0.2976	0.4616	1.0000

Table 2.12 reports the results of correlation analysis by pairwise correlation coefficients. The results show that the total fuel usage and total fuel costs and sales are closely related (99% and 98%, respectively). Fuel economy (E) shows a low correlation with other variables,

ranging from 0.29 to 0.46, while those variables are a result of interactions between sales, driving distance, and fuel costs. This suggests that controlling total fuel costs and total fuel usage will mainly depend on regulating the quantities sold or the driving distance, rather than on improving the fuel economy in the short term. The results in Table 2.12 imply that the impact of sales exceeds the increase in the fuel economy level, leading to the urgent necessity of redesigning the Japanese energy policy.

2.4 Policy Implications for Preventing Rebounds

The main contribution of this research is that this study finds evidence of rebound effects. This study also finds that sales increase with the gasoline price and income tax reform. This suggests the necessity of policy revisions considering the increasing trends of automobiles sales, regardless of macroeconomic shocks. This is not to say that promoting environmentally-friendly vehicles is a futile endeavor; given a choice between a car with a low fuel economy and another with high fuel economy, this study as a society would prefer vehicles with high fuel economy on the roads rather than the alternate scenario. Therefore, there is still a need for policies that provide high fuel-efficient automobiles as a financially viable substitute for low fuel-efficient cars.

To reduce oil dependency, the Japanese government should change the focus of its energy policies from promoting energy-efficient vehicles to raising the marginal costs of fuel (or driving distance). The confirmation of the rebound effect in fuel usage would imply that drivers take advantage of the high fuel economy of their hybrid vehicles, leading to more driving and higher fuel usage. The consumer-level subsidies mentioned above do not change the marginal cost of driving distance or fuel usage. On the other hand, fuel taxes can lower the driving distance and fuel usage for each vehicle. Policies have to induce the consumer to consume less fuel (OECD, 2010).

A second possible strategy is to shift financial incentives from the consumers to the producers, which has two foreseeable effects. The first is to stop the arbitrary rise in automobiles sales by lowering the financial incentives for consumers. The second is to raise the financial incentives for producers' research and development (OECD, 2010). Previous researches (Ahn, Jeong, and Y. Kim, 2008; Francis Sprei and Karlsson, 2013; MacKenzie and Ohndorf, 2012) shows that consumers regard fuel economy as a vital vehicle attribute, inducing automobile manufacturers to improve the fuel economy of their vehicles to gain market share.

While there could be other policies that could be implemented in addition to policy recommendations, results imply that the focus of Japanese environmental standards should change from inducing consumers to buy more fuel-efficient automobiles to influencing consumers to purchase and consume less fuel for transportation. Simply focusing on policies that induce customers to buy more fuel-efficient cars may prove a costly policy to reduce fuel usage and emissions, an issue that was also brought up in (Kagawa et al., 2013)

2.5 Conclusion of Automobile and Direct Rebound

This study finds a form of direct rebound effects caused by the increase in automobile sales and driving distance. The results show that both total fuel usage and total fuel costs rose, and even that rapid increases in automobile sales canceled out the potential positive impacts of fuel economy improvement. This was caused mainly by the entrance of light-duty and hybrid electric vehicles because of tax reductions and fuel economy standards, which led to increased driving distances caused by fuel economy improvements.

This study has some limitations to be addressed in further studies. First, demand estimation based on consumer information can be added to examine the impact of consumers' demographic factors on purchasing behavior, particularly when they are choosing hybrid electric vehicles. Because this study analyzed the given phenomenon rather than consumer demand, it is more focused on finding explanations other than consumer preferences or choices. Adding such factors would improve the explanatory power of the study. Second, this study may include macroeconomic variables to extend the scope of this research for cross-national comparisons. This study reflected the macroeconomic situations by adding the gasoline price to the dependent variable, and this can be developed through including other macroeconomic variables, such as GDP per capita, disposable income, and interest rates. This would provide important implications if analyses in multiple countries were added. Answering those questions with consumer data would not only offer explanations to firm behaviors but also suggest strategies to stimulate firms to reduce total fuel usage while fulfilling consumers' needs.

Chapter Three

Decomposing Consumer Preferences in Transportation Sector

The emissions consequences from transportation critically hinge on how consumers switch between vehicles with various fuel efficiency levels and car types. Using a random-coefficient discrete choice model, the automobile demand of consumers is estimated, then the market share and emissions consequences under various financial incentives schemes were simulated. In this Chapter, Japan and Korea are examined, on how the consumers behave in different circumstances, and how the emissions implications change.

3.1 Japanese Consumer Behaviors

3.1.1 Introduction of Japanese Consumer Behaviors

Thanks to the various policies in Japan to cope with the increasing emissions from the transportation sector between 2006 and 2016, the sales-unweighted fuel economy level of new cars improved by 22% and the sales-weighted fuel economy level improved by 40%. Moreover, this gap is not constant over time but varies across years. It is expected that changes in consumer preferences may explain the discrepancy between the sales-unweighted and sales-weighted fuel economy levels because the former mainly reflects the technological advancement of supply and the latter mainly reflects consumer preferences. To this end, this study applies a model that explicitly allows consumer preferences for fuel economy to vary over time and estimate this model using aggregated data on the Japanese automobile industry. Although the standard model used in the literature typically assumes that consumer preferences do not change over time, this study explicitly allow time-varying consumer preferences to separately identify the effects of changes in consumer preferences from the impact of technological change on automobile choice behavior.

This study contributes to two strands of the literature. First, to the best of the knowledge, this study is the first to decompose the effects of consumer preferences and technological advancement on CO_2 emissions. Previous works have focused on either consumer preferences or technological development: Potoglou and Kanaroglou, 2007, Ziegler, 2012, and Al-Alawi and Bradley, 2013 found that financial incentives increase consumer demand for hybrid automobiles. On the contrary, Anderson et al., 2011 and Schipper, 2008 highlighted the importance of technological advancement for reducing emissions because improved fuel economy can decrease fuel consumption. For the Japanese automobile market, Konishi and M. Zhao, 2015 explored the policy effects by simulating the influence of financial incentives on automobile demand. However, few studies evaluate the combined impact of technological advancement and consumer preferences on emissions. Previous works have investigated how other vehicle attributes are compromised to increase fuel economy by estimating automobile demand from the perspective of manufacturers (Klier and Linn, 2012, Knittel, 2012). Hence, this study explains the evolution of fuel economy using consumer preferences. From that perspective, this study continues the work of D'Haultfoeuille, Durrmeyer, and Fevrier, 2016 by estimating automobile demand, considering consumers' environmental cautiousness as an essential factor. This study also contributes by investigating the impacts of technological development on emissions.

Second, the results contribute to the field of energy policy evaluation. Previous works (Choo and Mokhtarian, 2004, F. Sprei and Bauner, 2011, Hackbarth and Madlener, 2013, J. Kim, Rasouli, and Timmermans, 2014) have found that improved fuel economy standards and financial incentives attract more consumers to purchase automobiles. However, these incentives should be carefully designed with consumer preferences in mind because increased consumer preferences might also raise emissions. For example, Gallagher and Muehlegger, 2011, Diamond, 2009, J. Sallee, 2011, and Jenn, Azevedo, and Ferreira, 2013 stated that if bought by less environmentally cautious consumers, these incentives might end up increasing the number of automobiles sold. Furthermore, Bitsche and Gutmann, 2004, P. D. Haan, Mueller, and A. Peters, 2006, P. D. Haan, G.Mueller, and Scholz, 2009, "Energy Efficiency And Consumption - The Rebound Effect - A Survey" 2000, and West et al., 2017 found that the increased number of automobiles sold could counteract the potential emission reduction. However, to design more effective energy policies, technological advancement and consumer preferences on emissions should be separately analyzed. This study provides such an analysis by conducting counterfactual simulations as well as by calculating and decomposing the effects of these factors on emissions. Therefore, the contribution is that this study provides estimates of CO_2 reductions after separately analyzing consumer preferences and technological advancement.

3.1.2 Discrepancy between Consumer Preference and Technological Advancement in Japan

Over the past two decades, the fuel efficiency of automobiles has improved significantly thanks to the development of new technologies such as high-efficiency direct-injection gasoline engines (i.e., hybrid-electric engines). Panel (A) in Figure 3.1 shows the average fuel economy levels in Japan from 2006 to 2016. It is clear that the sales-unweighted simple fuel economy level, which is denoted by the dashed line, has continuously improved since 2006 with a slightly steeper increase after 2009 due to the introduction of hybrid cars such as the Toyota Prius and Honda Insight as well as the amendment of the fuel economy standards. When closely looking at the sales-weighted fuel economy level, which is denoted by the solid line and that reflects consumer preferences for fuel economy, this has improved along with the sales-unweighted simple fuel economy level, but with an even sharper increase between 2009 and 2012 due to the provision of financial incentives to purchase fuel-efficient cars, as discussed in the next subsection, and/or gasoline prices, as shown in Panel (B) in Figure 3.1.[1] The improvement after 2013 is flatter than the average fuel economy level.

Moreover, when looking at Panel (C) of Figure 3.1, which shows total CO_2 emissions from the transportation sector in Japan, the symmetric patterns can be observed; CO_2 emissions sharply decreased between 2009 and 2012 and remained flat after 2013. These observations indicate that technological development alone cannot explain the emission patterns over this period and suggest that this study must consider both consumer preferences and technological advancement to understand the reduction in CO_2 emissions.

Contrary to the expectation, as one can see from Panel (B) in Figure 3.1, it is observed that only 11.9% reductions in CO_2 emissions from the transportation sector from 2008 to 2015, according to the document published by the Japanese Ministry of Environment. Hence, it seems that technological development does not explain the emissions over the period, because CO_2 emissions would be supposed to decrease more given the fuel economy improvement discussed above.

This indicates a decrease in consumer's environmental cautiousness, because such a discrepancy seems to reflect the fact that consumers are less concerned about the emission consequences that result from their automobile choices. This is mainly because increased

[1]Gasoline prices in Japan were relatively stable during thesample period, as shown in Panel (B) in Figure 3.1, although there were some fluctuations. Consumers take gasoline prices into account when they purchase their automobiles, as shown by Konstantakis, Milioti, and Michaelides, 2017, M.Sallee, E.West, and Fan, 2016, and Busse, Knittel, and Zettelmeyer, 2009. For example, the improvement in sales-weighted fuel economy from 2009 to 2012 could be related to the rise in gasoline prices from 2009, indicating consumers have been encouraged to buy fuel-efficient automobiles to save fuel costs.

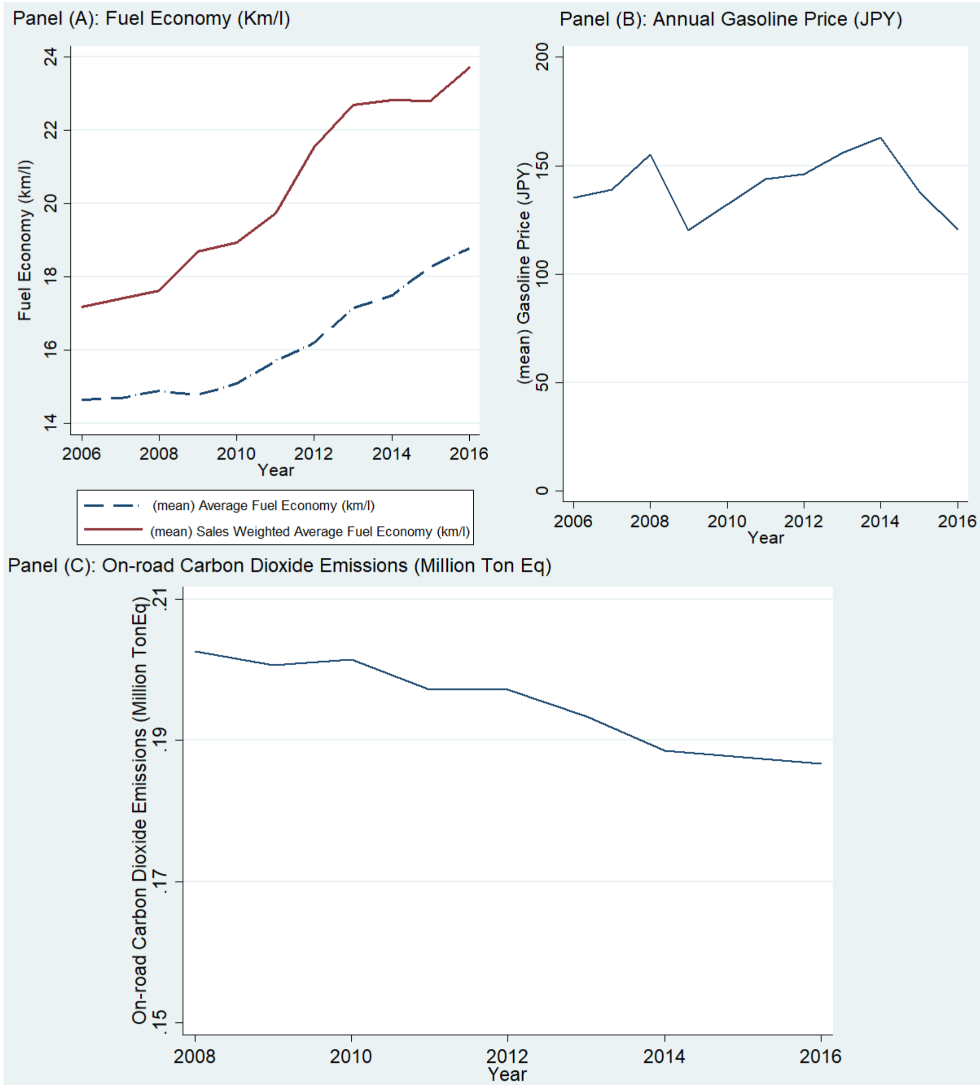

Figure 3.1 Evolution of Average Fuel Economy, Gasoline Prices, and CO_2 Emissions
Note: In Japan, more than 90% of passenger vehicles are gasoline fuel type vehicles. Therefore this study focuses on the gasoline cars.

CO_2 emission impact customers only in the long term, as Wu et al., 2016 stated. Consumers may not be fully aware of how their behavior influences their future welfare because of the delay between action and resulting consequences. Second, because the environment is a public good (Nordhaus, 2015), consumers may place greater value on vehicle attributes, such as automobile price, weight and size other than CO_2 emissions.

3.1.3 Random Coefficients and Yearly-Changing Preferences

This study uses the same data as in Chapter 2 but applies different methodologies in this Chapter. Given that the data typically consist of aggregated market shares and micro-level product characteristics, this study uses a standard technique from the literature, namely the random coefficients discrete choice model (BLP model) developed by S. T. Berry, 1994 and S. Berry, Levinsohn, and Pakes, 1995.

Given that the data typically consist of aggregated market shares and micro-level product characteristics, this study uses a standard technique from the literature, namely the discrete-choice demand model, developed by S. T. Berry, 1994 and S. Berry, Levinsohn, and Pakes, 1995. Assume that consumer i, $i = 1, \dots, M_t$, buys car j from an available automobile set, denoted by $\mathcal{J}_t$, in year t. Each consumer i always has the option not to purchase any automobiles, which is denoted by $j = 0$ and is called the "outside option." In other words, for any t, $j = 0$ is included in $\mathcal{J}_t$. The indirect utility of consumer i from choosing automobile j in year t is given by

$$u_{ijt} = \boldsymbol{x}'_{jt}\boldsymbol{\beta}_t - \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}, \tag{3.1}$$

where $\boldsymbol{x}_{jt}$ denotes the vector of observed vehicle attributes (such as fuel efficiency and riding capacity) for automobile j in year t, p_{jt} denotes the *after* tax/subsidy price of automobile j in year t, ξ_{jt} denotes an unobserved attribute of automobile j, which is observed by consumers and car manufacturers and may be correlated with automobile prices, and ϵ_{ijt} denotes a random utility shock. α is a price coefficient that is assumed to be homogeneous in this study to ease the computational burden, whereas $\boldsymbol{\beta}_t$, which represents a vector of the evaluation for each automobile attribute, is assumed to be time-varying to capture changes in consumer preferences. Note that p_{jt} includes all taxes and subsidies.

Now, defining the first three terms, which are unrelated to the personal taste of consumer i in equation (3.1) as δ_{jt}, i.e., $\delta_{jt} \equiv \boldsymbol{x}'_{jt}\boldsymbol{\beta}_t - \alpha p_{jt} + \xi_{jt}$, this study can rewrite equation (3.1) as

$$u_{ijt} = \delta_{jt} + \epsilon_{ijt}.$$

This study call δ_{jt} the mean utility of product j, because this level of utility is shared by all consumers, though all consumers have different levels of utility in the end due to ϵ_{ijt}. This study assume that $\delta_{jt} = 0$ for any (j, t) for normalization and consumer i maximizes his/her utility by choosing product j that provides the highest utility. In other words, he/she chooses product j if and only if $u_{ijt} \geq u_{ilt}$ for any $l \in \mathcal{J}_t \backslash \{j\}$. Each individual is now characterized by $\boldsymbol{\epsilon}_{it} = [\epsilon_{i0t}, \ldots, \epsilon_{iJt}]$. Integrating all consumers' automobile choices, this study can obtain the market share for product j as

$$s_{jt}(\theta|\boldsymbol{p}, \boldsymbol{x}, \boldsymbol{\xi}) = \int_{A_{jt} \in M} dF(\boldsymbol{\epsilon})$$
$$\text{with} \quad A_{jt} = \{\boldsymbol{\epsilon}_i | u_{ijt}(\theta|\boldsymbol{x}, p, \xi) \geq u_{ilt}(\theta|\boldsymbol{x}, p, \xi)\},$$

where θ is the set of parameters defined as $\theta = (\alpha, \boldsymbol{\beta}_t)$ and A_{jt} is the set of individuals who purchase automobile j in year t. As is common in the literature, this study assume that ϵ_{ijt} follows the extreme value Type I distribution, which enables us to obtain an analytical formula for the choice probability that individual i chooses product j:

$$\Pr(d_{ijt} = 1|\boldsymbol{\theta}) = \frac{\exp(\delta_{jt})}{1 + \sum_{l \in J_t} \exp(\delta_{lt})},$$

where d_{ijt} is an indicator function, which takes a value of one when consumer i purchases automobile j in year t, and zero otherwise. Thus, by aggregating these consumers, this study can obtain the market shares for product j and the outside option as

$$s_{jt}(\theta|\boldsymbol{p}, \boldsymbol{x}, \boldsymbol{\xi}) = \frac{\exp(\delta_{jt})}{1 + \sum_{l \in J_t} \exp(\delta_{lt})},$$
$$s_{0t}(\theta|\boldsymbol{p}, \boldsymbol{x}, \boldsymbol{\xi}) = \frac{\exp(0)}{1 + \sum_{l \in J_t} \exp(\delta_{lt})}.$$

Thus, using the inversion technique developed by S. T. Berry, 1994, i.e., dividing both sides of the equations above and taking the logarithm, this study obtain the following equation:

$$\ln(s_{jt}) - \ln(s_{0t}) = \delta_{jt} = \boldsymbol{x}'_{jt}\boldsymbol{\beta}_t - \alpha p_{jt} + \xi_{jt}. \tag{3.2}$$

Therefore, viewing ξ_{jt} as error terms, this study can estimate this model using OLS. However, this study suspect a correlation between p_{jt} and ξ_{jt}, because if consumers appreciate unobserved product characteristics, ξ_{jt}, then the firm must charge higher prices.

Though this class of logit models enables us to identify the parameters of interest—how consumers evaluate the characteristics of the automobiles—it is known that this study cannot have realistic substitution patterns, as the property called independence of irrelevant alternatives (IIA) is not satisfied. Thus, to solve this issue, this study also estimate a nested logit model, assuming that each consumer first chooses the type of automobile, which is defined as the size of the automobile, and then chooses one of the automobiles from one of the subsets. More specifically, this study categorizes the automobiles into three mutually exclusive groups and assume that the outside option, $j = 0$, is the only member of the group 0. Instead of equation (3.1), this study now assume the following indirect utility function

$$u_{ijt} = \boldsymbol{x}'_{jt}\boldsymbol{\beta}_t - \alpha p_{jt} + \xi_{jt} + \zeta_{ig} + (1 - \sigma)\epsilon_{ijt}, \tag{3.3}$$

where ζ_{ig} is the additional utility derived from group g for consumer i and σ is a parameter that changes the variance of the error term, which is supposed to be in the interval $[0, 1]$. The distributions of ζ_{ig} and ϵ_{ijt} are standard to the nested logit model: they have a unique distribution such that ζ_{ig}, $(1-\sigma)\epsilon_{ijt}$ and $\zeta_{ig}+(1-\sigma)\epsilon_{ijt}$ follow the extreme value distribution. Similar to the previous derivation, this study can derive the following equation:

$$\ln(s_{jt}) - \ln(s_{0t}) = \boldsymbol{x}'_{jt}\boldsymbol{\beta}_t - \alpha p_{jt} + \sigma \ln(s_{j/g}) + \xi_{jt}, \tag{3.4}$$

where $s_{j/g}$ is the share of product j in group g, which can be easily calculated from the data. Estimating this equation via OLS might yield biased estimates for σ due to potential endogeneity between the LHS variable and $\ln(s_{j/g})$. Thus, this study takes an instrumental variable approach to solve this issue.

For the instrumental variables, the price of automobile j may be correlated with an unobserved product attribute ξ_j, as previously mentioned. This is because firms that produce automobile j can increase its price if consumers appreciate its unobserved attributes. Thus, ignoring such a firm's profit-maximizing behavior leads to bias in α. Furthermore, when constructing a within-market share variable, $\ln(s_{j/g})$ in equation (3.4), it is natural that endogeneity is introduced due to simultaneity, as both the LHS and RHS variables include the market share of product j. To cope with such endogeneity issues, following the literature, this study uses an instrumental variable (IV) approach. Inspired by S. Berry, Levinsohn, and Pakes, 1995, this study uses typical instruments: (i) the product characteristics themselves and (ii) the average characteristics of the product attribute (e.g., length, weight, and fuel economy) produced by other firms. The moment condition that this study exploits here is therefore $E[\xi|z] = 0$, where z is a vector of the aforementioned instruments for each product, j, and the parameters are estimated using two-stage least squares. For the identification of $\ln(s_{j/g})$, this study also use the characteristics of other products within the same nest.

3.1.4 Japanese Demand Estimation Results

Table 3.1 reports the estimation results for seven specifications—estimates of the plain ordinary least squares (OLS) and IV for the logit and nested logit demand models, with and without the interaction of fuel economy with years. The difference between OLS and IV, which is indicated in the second row is whether or not the automobile price is treated as an endogenous variable; whereas the difference between the logit and nested logit, which is also indicated in the second row, is which demand model this study use. All the specifications include the model-fixed effects, whether the Model appeared more than once in the data, yearly fixed effects and company fixed effects. As indicated in the bottom of the table, this study also includes some interaction terms between a year and ln(Horsepower/weight) for Models (vi) through (vii) for further checking the robustness of the results.[2] The difference between Models (i), (iii), and (v) and Models (ii), (iv), (vi), and (vii) is whether this study include the interaction terms of fuel economy with years. In Models (i), (iii), and (v), this study do not include them, assuming that consumer preferences for fuel economy do not change over time, whereas this study does include them in Models (ii), (iv), (vi), and (vii), attempting to capture the changes in consumer preferences for fuel efficiency.

First, as is typically found in the literature, a comparison of the price coefficients among the eight specifications reveal that the price coefficient could be overestimated because of endogeneity, i.e., the magnitude of the price coefficients derived from the OLS models are substantially different from the coefficients derived from the IV models, in particular, Models (iii) and (vi). For example, the comparison between Models (i) and (iii) or between Models (ii) and (vi) enables us to see that, without using IVs, this study is likely to overestimate the price coefficients.

Next, this study examines the coefficients related to fuel efficiency. In Models (i), (iii), and (v), this study estimates only one coefficient for fuel economy (labeled "Fuel Economy" in the table), assuming that consumer preferences do not change over time; whereas in Models (ii), (iv), (vi), and (vii), this study assumes that consumer preferences may vary over time and list the changes compared with the base year, which is 2010. Notice that this study drop an interaction term of the fuel efficiency and the year dummy in 2010. In doing so, this study can interpret the coefficient on "Fuel Economy" in the second row as how consumers in 2010 evaluated fuel efficiency, and other coefficients related to fuel efficiency as the changes from 2010. For example, based on Model (ii), the coefficient on fuel efficiency in 2006 should

[2] These estimates are, however, omitted from this table due to limited space. The results are upon request.

be $3.242 + (-1.296) = 1.946$. Regardless of the Model, this study finds two trends in fuel economy preferences: a relatively stable phase between 2006 and 2010, and a decreasing phase after 2010.

As for the former trend, a relatively stable phase between 2006 and 2010, one may think that consumers between 2006 and 2009 had less appreciation for fuel efficiency, because Models (ii), (iv), and (vi) exhibit negative coefficients for many of these years. However, when this study include many covariates with the nested logit specification, as in Model (vii), these negative coefficients mostly disappear, except for 2007. By omitting the nest share, this study may overestimate these coefficients, as compact cars sell well in the Japanese market and Models (ii), and (iv) merely capture such a pattern. However, Model (vii) tells that, once this study control for the subcategories of automobiles, this study can no longer find such a pattern. Thus, this study concludes that consumer preferences were stable between 2006 and 2010.

On the other hand, this study finds that preferences for fuel economy continuously decreased since 2010, confirmed by the results in Models (ii), (iv), (vi), and (vii), which consistently show negative coefficients on "Fuel Economy: 2011," "Fuel Economy: 2012," and so on, and these values decreased over time. These results imply that, compared with consumers in 2010, consumers from 2010 to 2016 had less appreciation for fuel economy. This decreased appreciation for fuel economy may contradict the observation in Panel (A) of Figure 3.1, which shows a steeper increase in sales-weighted fuel economy levels during 2009 and 2012. However, many financial incentives were given to consumers during that period and thus the increase in sales-weighted fuel economy level may be driven by such financial incentives, rather than by a greater appreciation for fuel-efficiency. Further, though there was a 24.5% improvement in fuel economy from 2010 to 2016, as shown in Table 3.4, consumers have less appreciation for fuel economy over time and thus, they derive lower utility from it. Multiplying average fuel economy by the fuel economy coefficients for each year, these

Table 3.1 Estimation Results

	Model (i) OLS/Logit	Model (ii) OLS/Logit	Model (iii) IV/Logit	Model (iv) IV/Logit	Model (v) IV/Nested	Model (vi) IV/Nested	Model (vii) IV/Nested
ln(Automobile Price)	-1.360***	-1.111***	-4.294***	-4.152***	-0.976**	-0.753*	-0.891**
	(.314)	(.315)	(1.410)	(1.428)	(.393)	(.391)	(.394)
Fuel Economy (km/l)	2.243***	3.242***	2.245***	3.069***	0.606***	0.693***	0.799***
	(.215)	(.308)	(.220)	(.326)	(.097)	(.139)	(.149)
Fuel Economy: 2006		-1.296***		-0.970***		0.030	-0.217*
		(.292)		(.321)		(.094)	(.111)
Fuel Economy: 2007		-1.113***		-1.037***		0.027	-0.110
		(.294)		(.303)		(.091)	(.109)
Fuel Economy: 2008		-1.026***		-0.824***		0.0910	-0.0274
		(.291)		(.312)		(.089)	(.107)
Fuel Economy: 2009		-0.207		-0.280		0.203***	0.0844
		(.287)		(.297)		(.078)	(.105)
Fuel Economy: 2011		-0.561*		-0.363		-0.015	-0.098
		(.291)		(.311)		(.080)	(.105)
Fuel Economy: 2012		-0.820***		-0.792***		-0.0944	-0.267***
		(.281)		(.289)		(.079)	(.103)
Fuel Economy: 2013		-1.202***		-1.002***		-0.127	-0.256**
		(.282)		(.303)		(.086)	(.106)
Fuel Economy: 2014		-0.915***		-0.713**		-0.0391	-0.172*
		(.281)		(.302)		(.082)	(.104)
Fuel Economy: 2015		-1.028***		-0.826***		-0.113	-0.223**
		(.281)		(.302)		(.082)	(.109)
Fuel Economy: 2016		-1.051***		-0.856***		-0.206*	-0.277**
		(.281)		(.302)		(.082)	(.109)
ln(Size)	4.887***	4.597***	7.485***	7.327***	1.708***	1.373***	1.450***
	(.835)	(.837)	(1.486)	(1.516)	(.469)	(.470)	(.469)
ln(Displacement)	-0.581	-0.667*	0.701	0.640	0.128	0.107	0.151
	(.391)	(.395)	(.721)	(.722)	(.185)	(.182)	(.186)
ln(Horsepower/weight)	1.656***	1.598***	2.619***	2.597***	0.262	0.157	0.431**
	(.382)	(.380)	(.597)	(.601)	(.190)	(.189)	(.188)
ln(Riding Capacity)	0.603**	0.661**	0.325	0.361	-0.417***	-0.350***	-0.357***
	(.269)	(.270)	(.305)	(.309)	(.085)	(.084)	(.083)
Nest parameter (σ)					0.806***	0.809***	0.813***
					(.039)	(.039)	(.039)
Constant	-115.3***	-109.2***	-165.2***	-161.7***	-40.57***	-33.87***	-34.83***
	(17.51)	(17.55)	(29.44)	(30.01)	(9.596)	(9.594)	(9.613)
Fixed Effects							
Year FE	✓	✓	✓	✓	✓	✓	✓
Company FE	✓	✓	✓	✓	✓	✓	✓
Model FE	✓	✓	✓	✓	✓	✓	✓
Interaction with ln(Horsepower/weight)							✓
N	1,806	1,806	1,806	1,806	1,806	1,806	1,806
R^2	0.804	0.809	0.795	0.799	0.987	0.987	0.988

Note: Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

numbers decreased substantially, implying that utility from fuel economy decreased during this period, completely offsetting the effects of technological improvement.[3]

These trends are also in agreement with some industry experts. The consumer demand for fuel efficiency has been somewhat satiated around 2010 and since then, consumers have put more weight on different car attributes rather than fuel efficiency. Therefore, this study believe that the estimates indeed reflect how consumers evaluate fuel efficiency.

As for the rest of the parameters, as expected and consistent with the previous study by Konishi and M. Zhao, 2015, other vehicle attributes such as size, horsepower/weight, and engine displacement exhibit positive coefficients, implying that consumers value these characteristics. Moreover, the nest parameter σ is estimated to be around 0.8, confirming that the nested logit specification indeed captures how consumers choose automobiles.

3.1.5 Counterfactual Simulations: Japanese Consumers

Based on the estimated demand parameters, this study perform a series of counterfactual simulations to decompose the reduction in CO_2 emissions from the new car market over time into changes in consumer preferences and technological advancement. As shown in Panel (C) in Figure 3.1, in tandem with the sales-weighted fuel economy improvements, CO_2 emissions continuously decreased after 2006. In particular, the CO_2 emission reduction accelerated between 2009 and 2012, whereas it decelerated after 2013. The demand parameters, however, show that consumer preferences for fuel economy declined over that period, posing a question of whether or not emission reduction is mainly driven by financial incentives. These observations, therefore, motivate us to further investigate this discrepancy between consumer preferences and CO_2 emissions.

To this end, based on the demand estimates, this study allows environmentally cautious consumers to choose cars produced in a year in which consumers were less environmentally

[3]For example, Model (vi) provides 1.88 ($= \ln(15.09) * 0.693$) in 2010 and 1.43 ($= \ln(18.79) * (0.693 - 0.206)$) in 2016, whereas Model (iv) provides 2.17 in 2010 and 1.53 in 2016.

cautious and vice versa. More specifically, to assess the effects of technological "advancement" on sales and CO_2 emissions, this study hypothetically provide a choice set of cars available in 2016 to households in 2010 (Scenario 1), and a choice set of cars available in 2010 to households in 2006 (Scenario 4). By contrast, to assess the effects of technological "retrogression" on sales and CO_2 emissions, this study hypothetically provide a choice set of cars available in 2010 to households in 2016 (Scenario 2), and a choice set of cars available in 2006 to households in 2010 (Scenario 3).

Through these four simulations, this study expect to observe some differences between Scenarios 1 and 4 and between Scenarios 2 and 3. For example, though both Scenarios 1 and 4 provide consumers with technologically advanced choice sets, how consumers evaluate fuel efficiency is different. Consumers in 2010 were more environmentally cautious than consumers in 2016, whereas consumers in 2006 were similar to consumers in 2010. Thus, by comparing the counterfactual sales in these analyses, this study can extract how technological progress affects sales, given consumer preferences and financial incentives. Similarly, even though both Scenarios 2 and 3 provide consumers with technologically retrogressive choice sets, again, how consumers evaluate fuel efficiency is different. Consumers in 2016 were less environmentally cautious than consumers in 2010, whereas consumers in 2010 were similar to consumers in 2006. Thus, by comparing the counterfactual sales in these analyses, this study can extract how technological retrogression affects sales, given consumer preferences and financial incentives.

Although including every year in the simulations would be ideal, this study chose 2006, 2010, and 2016 as the simulation years for two reasons. First, it is difficult to demonstrate all results due to limited space.Second and more importantly, the estimates of the model fixed effects would not be valid for a long time. For example, a model of a car in 2006 would not be produced in 2016 and, even if the model survived for 10 years, it would be completely redesigned. Hence, the car fixed effects could not capture such a change. Thus, the model fixed effects capturing model-specific preferences would not arise if this study set a long period as the simulation benchmark. Therefore, this study chose these three years for the simulations.

Counterfactual Simulation Results: Japan

The results in Table 3.2 have six panels: Panels (A1) and (A2) present annual sales, Panels (B1) and (B2) present sales-weighted fuel economy, and Panels (C1) and (C2) present the emissions consequences from the new car market. In each panel, there is a matrix—preference is indicated in the row, whereas technology is indicated in the column— showing which year's consumers and technology are used to conduct the simulation. For example, in Panel (A1), the units sold in the top-right cell correspond to Scenario 1, where this study use 2010 consumers (preference) and 2016 automobiles (technology). In other words, this study simulates the results by bringing 2010 consumers (preference) to 2016 and allowing them make their purchase decisions. Similarly, the units sold in the bottom-left in Panel (A1) correspond to Scenario 2, where 2016 consumers purchased automobiles available in 2016. The line labeled *Differences* refers to the percentage of changes from the data to the simulated results.

Automobile Sales Panels (A1) and (A2) of Table 3.2 present automobile sales. First, under Scenario 1, sales would have increased by 24.30%, which is calculated as $(4,946,740 - 3,979,588)/3,979,588$, implying that 2010 consumers would have purchased more automobiles if they were faced with 2016 automobiles.[4] On the contrary, under Scenario 2, sales would decrease by 14.65% in the simulations, implying that 2016 consumers would have purchased less automobiles if faced with 2010 automobiles. To further understand how these consumers change their purchasing patterns, this study also calculates the changes by fuel

[4]To calculate the percentage difference; this study subtracted the simulated result from the year's data that this study took technology from, and divided this difference by the data that this study took technology from. this study uses this approach to calculate the difference of other simulation results hereafter.

Table 3.2 Simulation Results

Panel (A1): Automobile Sales		Technology	
		2010	2016
Preference	2010	(Data) 4,000,227	(Scenario 1) 4,946,740
	2016	(Scenario 2) 3,413,885	(Data) 3,979,588

Panel (A2): Automobile Sales		Technology	
		2006	2010
Preference	2006	(Data) 4,326,053	(Scenario 4) 5,441,146
	2010	(Scenario 3) 3,486,398	(Data) 4,000,227

Panel (B1): Fuel Economy (km/l)		Technology	
		2010	2016
Preference	2010	(Data) 18.94	(Scenario 1) 24.32
	2016	(Scenario 2) 18.60	(Data) 23.71

Panel (B2): Fuel Economy (km/l)		Technology	
		2006	2010
Preference	2006	(Data) 17.80	(Scenario 4) 18.81
	2010	(Scenario 3) 17.22	(Data) 18.94

Panel (C1): CO_2 Emissions (million tons)		Technology	
		2010	2016
Preference	2010	(Data) 4.45	(Scenario 1) 4.28
	2016	(Scenario 2) 3.85	(Data) 3.54

Panel (C2): CO_2 Emissions (million tons)		Technology	
		2006	2010
Preference	2006	(Data) 5.27	(Scenario 4) 6.06
	2010	(Scenario 3) 4.24	(Data) 4.45

economy level category in Table 3.3. In this table, based on fuel economy, this study categorizes automobiles in each year into four groups, based on quartiles: Group 1 is the lowest quartile, having low fuel efficiency, Group 2 is the next quartile, having mildly low fuel efficiency, and so on. As expected, in Scenario 1, because consumers from 2010 were more environmentally cautious, more consumers would have purchased highly fuel efficient automobiles, i.e., those belonging to Group 4. On the other hand, less consumers would have purchased cars with low fuel efficiency, i.e., those belonging to other groups. However, such a decrease would not be completely offset by the increase in sales for the top quartile, and total sales would therefore increase. In Scenario 2, because 2016 consumers were less environmentally cautious, they were less averse to purchasing fuel-inefficient automobiles than 2010 consumers. As shown in Table 3.3, many consumers would purchase fuel-inefficient cars, particularly those belonging to Groups 1, 2 and 3, and thus the average fuel economy would have decreased, as discussed in the next paragraph.

In Scenario 3, as one can see from Panel (A2) of Table 3.2, the total number of sales would have decreased by 19.41%. Given that the fuel economy preference level did not change significantly from 2006 to 2010, 2010 consumers would not have been willing to purchase 2006 cars that are less fuel-efficient than 2010 cars. The results in Scenario 4 show a 36.03% increase in total sales, indicating that many 2006 consumers if faced with fuel-efficient cars, would have been willing to purchase them. Looking at Table 3.3, unlike Scenarios 1 and 2, this study finds that the number of sales decreased evenly in Scenario 3 and increased evenly in Scenario 4, regardless of the fuel economy groups. This result indicates that if there are no significant changes in preferences, consumers would not have been likely to substitute for another fuel economy group. For example, a 2006 consumer purchasing a car in fuel economy group 1 would not have chosen a car in fuel economy group 4 if he/she was faced with a 2010 car.

Fuel Economy Panels (B1) and (B2) of Table 3.2 present the results for average fuel economy weighted by sales under the counterfactual scenarios. In Scenario 1, this study finds that average fuel economy would have increased by 2.58%. This indicates that average fuel economy would have increased if the more environmentally cautious consumers of 2010 were brought to 2016, as 2010 consumers were more willing to purchase cars with lower fuel economy than 2016 consumers. On the contrary, the result in Scenario 2 shows that fuel economy would have decreased by 1.76%. This result implies that the number of fuel-efficient automobiles sold decreased, which is consistent with the results from the demand estimation and the counterfactual results of automobile sales. In summary, offering environmentally cautious 2010 consumers a technologically advanced choice set from 2016, as in Scenario 1, would have resulted in an increase in sales and average fuel economy. On the contrary, this study confirms that if 2016 consumers—who were less environmentally cautious—were provided with a technologically "retrogressed" choice set from 2010, as in Scenario 2, there would have been lower car sales, and the purchased cars would have been of lower average

Table 3.3 Automobile Sales by Fuel Economy Level

	Data	Simulation	Difference (%)
Panel (A): Scenario 1			
Fuel Economy Group 1 (1st quartile)	304,736	322,126	5.70%
Fuel Economy Group 2 (2nd quartile)	708,493	807,131	13.92%
Fuel Economy Group 3 (3rd quartile)	901,980	1,103,833	22.38%
Fuel Economy Group 4 (4st quartile)	2,064,379	2,713,650	31.45%
Total	3,979,588	4,946,740	24.30 %
Panel (B): Scenario 2			
Fuel Economy Group 1 (1st quartile)	131,766	128,705	-2.32%
Fuel Economy Group 2 (2nd quartile)	832,459	763,039	-8.34%
Fuel Economy Group 3 (3rd quartile)	815,342	706,564	-13.34%
Fuel Economy Group 4 (4st quartile)	2,220,660	1,815,577	-18.24%
Total	4,000,227	3,413,885	-14.66 %
Panel (C): Scenario 3			
Fuel Economy Group 1 (1st quartile)	347,695	268,506	-22.78%
Fuel Economy Group 2 (2nd quartile)	789,365	644,428	-18.36%
Fuel Economy Group 3 (3rd quartile)	1,040,199	838,019	-19.44%
Fuel Economy Group 4 (4st quartile)	2,148,794	1,735,445	-19.23%
Total	4,326,053	3,486,398	-19.41%
Panel (D): Scenario 4			
Fuel Economy Group 1 (1st quartile)	131,766	184,483	40.00%
Fuel Economy Group 2 (2nd quartile)	832,459	1,147,596	37.86%
Fuel Economy Group 3 (3rd quartile)	815,342	1,119,267	37.28%
Fuel Economy Group 4 (4st quartile)	2,220,660	2,989,800	34.63%
Total	4,000,227	5,441,146	36.02%

fuel economy.

On the other hand, when consumer preferences did not change, the results indicate that the average level of fuel economy would have only increased by 0.2% in Scenario 3 and would have decreased by 0.7% in Scenario 4. This result is consistent with the results in Table 3.3, in which this study did not find evidence that consumers would substitute to different fuel economy groups.

Consequences for Emissions Using Panels (A1), (A2), (B1), and (B2) in Table 3.2, this study finally calculate the emissions consequences. While Jacobson, Colella, and Golden, 2005 concludes that fuel usage and emissions would decrease following the introduction of financial incentives, this study expect emissions to rise because of increased sales under Scenario 1 and decreased fuel economy under Scenario 2. Following Clerides and Zachariadis, 2008, let $FU_{j,t}$ denote the fuel usage of automobile j in year t. this study take the inverse value of fuel economy (km/l) to approximate the amount of fuel used for the unit distance (l/km) as

$$FU_{j,t} = \frac{1}{E_{j,t}},$$

where $E_{j,t}$ denotes the fuel economy of automobile j in year t. Then, this study calculate aggregate emissions TE_t from the new vehicles sold in year t. This procedure can be expressed for each automobile as a function of sales, $Q_{j,t}$, driving distance, $D_{j,t}$, and fuel usage, $FU_{j,t}$. this study define total emissions as

$$TE_t = \sum_j FU_{j,t} \cdot D_{j,t} \cdot Q_{j,t} \cdot A,$$

where A represents the emissions calculation factor of fuel and $D_{j,t}$ is the driving distance of automobile J in year t. Although it would be ideal to have model-level (or even consumer-level) driving distance data, this study lack access to driving distance information, $D_{j,t}$. Thus, instead of using the model-level driving distance, this study uses the automobile type-level travel distance that is published by the Japanese Ministry of Land, Infrastructure, Transport and Tourism. In these data, automobiles are categorized into regular cars, hybrid cars, and minivans, and this study can observe the average driving distances of these three types.

Panels (C1) and (C2) of Table 3.2 present the results. this study finds that, in Scenario 1, total emissions would have increased to 4.276 from 3.543, whereas emissions would have decreased from 4.453 to 3.849 in Scenario 2. Specifically, emissions in Scenario 1 (4.276) show a 20.70% increase from the simulated emissions (3.543), mainly because of the increase in the number of automobiles sold— the increase in automobiles sold in Panel (A), 19.55%, prevents an overall reduction in emissions because of the fuel economy improvement of 2.58% in Panel (B). On the contrary, emissions in Scenario 2 (3.849) are lower than the emissions in 2016 (4.453) by 13.56% even though the fuel economy level declines by 1.76%, because the automobile sales decrease of 17.175%.

When consumer preferences do not change, but if technology retrogresses (Scenario 3), this study found that emissions would decrease by 19.44%, most likely because the total number of automobiles would decrease. On the other hand, if technology improves and consumer preferences do not change, this study finds that emissions would decrease by 36.12%, due to the increase in the total number of automobiles sold.

3.1.6 Conclusion of Japanese Consumer Behaviors

Important policy implications can be drawn from the results. Consumer preferences are an essential factor for lowering emissions. Environmentally cautious consumers purchase fuel-efficient cars, which prevents increases in emissions caused by either increased automobile sales or low fuel economy. However, the implications do not imply that improving fuel economy is a futile endeavor. Without improvements in fuel economy, emissions would increase, as average fuel economy falls. As alternatives, one option is to support manufacturers with financial incentives and therefore reduce their marginal cost of producing fuel-efficient automobiles. By doing so, consumer preferences and average fuel economy levels would both increase simultaneously, allowing larger reductions in emissions than only directing financial incentives toward consumers. Altering fuel taxes could be another option, as these can indirectly control the travel distances of consumers and thus lower emissions.

In sum, by illuminating the importance of both technological advancement and consumer preferences for reducing CO_2 emissions, the results suggest that the Japanese Government should continue to encourage manufacturers to produce fuel-efficient vehicles as well as entice consumers to purchase fuel-efficient automobiles by increasing environmental awareness. Doing so could continue to decrease emissions in the future.

3.2 Korean Consumer Behaviors

3.2.1 Policy Background on Korean Transportation Sector

In the late 2000s, the Korean government tried to reduce emissions from the transportation sector by promoting the purchase and usage of diesel cars. To do so, the government announced on May 21, 2009, the provision of tax incentives to designated "Clean Diesel" cars that satisfied Euro 5 Standards, with the policy's implementation by 2010. With the Clean Diesel policy, diesel car owners were also exempt from parking fees and congestion charges.

By the early 2010s, sales of diesel vehicles in Korea had increased significantly; the proportion of diesel automobiles sales to total automobile sales rose from 36.3% in 2011 to 39.4% in 2014. Meanwhile, the stock of diesel cars reached 9.58 million out of 22.53 million vehicles nationwide in 2017. With this policy, foreign car manufacturers, such as Volkswagen and BMW, included 2,000cc diesel engines in their Korean market products. In turn, the penetration rate of diesel cars in Korea had significantly increased.

However, this changed with the "Dieselgate" scandal starting from 2015, when the US Environmental Protection Agency found that the Volkswagen Group had manipulated the emissions test results for diesel automobiles by installing illegal software into their products. As a result, many Europeans started to criticize all internal combustion engines. France and Britain plan to ban the sale of new cars that only have internal combustion engines by 2040. Dieselgate also resulted in Korean consumers losing trust in diesel automobiles.

In light of the Korean citizens' distrust toward diesel automobiles, the Korean government abolished the Clean Diesel policy and introduced a bill to abolish diesel-powered cars. The bill was announced on September 26, 2017, as an effort toward curbing particulate matter

(PM) emissions and was enacted on November 8, 2018. The plan called for the removal of the criteria for "low-pollution diesel cars" and the financial incentives for 950,000 diesel cars that had been deemed as low-polluting in the past, such as reduced parking fees and congestion charges. In particular, the public sector set the goal of eliminating its diesel car stock by 2030.

However, there was another concurrent and contrasting change to Korean energy policy. Citing soaring fuel costs and the need for stimulating the economy and securing jobs, the Korean government announced to lower fuel taxes on November 6, 2018, lowering oil taxes on gasoline, diesel, and LPG by 10%. During the second week of October 2018, the average gasoline price at gas stations nationwide in the second week of October 2018 was KRW 1,674.9/liter, up by KRW 15.4 from the previous week. The price of diesel for automobiles also rose by KRW 16.5 to KRW 1,477.9/liter (Korea National Oil Corporation), whereas crude oil, which South Korea mostly imports, stood at USD 82.00 per barrel. The Deputy Prime Minister of Korea argued that since oil prices had exceeded USD 80 per barrel, this could put pressure on small business owners and working-class people, and a cut in oil taxes would help the economy by addressing their difficulties and increasing disposable income.

Thus, gasoline taxes changed from KRW 745.89/liter to KRW 643.50/liter, diesel taxes from KRW 528.75 to KRW 449.79/liter, and LPG taxes from KRW 528.75 to KRW 449.79/liter (www.opinet.co.kr). It was the first reduction in fuel taxes in 10 years, with the previous cuts being when international oil prices were as high as USD 140 per barrel. Other related fuels and automobile taxes were decreased as well, bringing to an overall reduction in taxes of approximately 15%. These tax cuts were a six-month temporary measure in response to the spike in crude oil prices. They intended to alleviate the economic effects of high oil prices on Korean households and businesses.

The Clean Diesel policy was abolished to improve the Korean automobile market's response to the environmentally damaging prospects of diesel fuel, and ultimately to reduce

Carbon Dioxide (henceforth CO_2), Nitrogen Oxide (henceforth NOx) and Particulate Matter (henceforth PM) emissions. Therefore, as regards to updating environmental policies, the decrease in fuel taxes, and the resulting increase in the demand for fuel seem to be contrasting elements.

The problem with the policy instruments is that the policy objective of the Korean government is unclear. Although the government announced that the gradual reduction in the number of diesel vehicles was the ultimate objective, if diesel and other fuel costs decrease, consumers will be induced to purchase more automobiles. In this sense, because the increased financial incentives enable consumers to replace their cars or buy a car for the first time, these incentives can eventually increase the number of car sales and counteract the abolition of the "Clean Diesel" policy, increasing emissions in the end.

Figure 3.2 supports the research motivation by providing clues that automobile demand and fuel cost move together. Figure 3.2 shows the trend in the cost of diesel and gasoline by dividing the time axis in Panel (A) according to the phases in Panel (B), which shows the sales of diesel cars. In Panel (A), this study divides the policy period into three phases: Phase 1 includes the period until September 2017, where no policy changes occurred. Phase 2 is from September 2017 to October 2018, when the increase in diesel car prices took place. Phase 3 starts in October 2018, when the government decreased diesel prices (this study henceforth refers to diesel fuel prices and diesel car prices separately, with "diesel prices" indicating diesel fuel prices). First, diesel prices tend to fluctuate more than those of gasoline and LPG, increased rapidly with the start of Phase 2, and quickly decreased at the end of Phase 2[5]. Second, the diesel price decreased again in Phase 3. Although diesel prices show a significant fluctuation, the raw price of diesel was always lower than that of gasoline or LPG.

Panel (B) of Figure 3.2 shows the number of diesel cars sold according to the policy

[5]This rapid fall in diesel prices is mainly due to the International Diesel Price Shock [OilPrice.com (2018.6.29), "Global Energy Advisory June 29, 2018"].

changes. This study observes that the number of diesel cars decreased significantly around Phase 2, and increased again around Phase 3. While in Phase 1, changes in a diesel car demand seem to fluctuate, there are visible differences between Phase 1 and Phase 2, and again between Phase 2 and Phase 3. From this casual view on the data alone, this study believes that Korean energy policy may have affected the demand for diesel cars. Thus in this paper, this study aims to examine the demand for such automobiles. Even though fuel prices started to fall in October 2018, the policy was announced in 2018Q2. Thus, this study expects that consumers made purchase decisions before the actual policy change.

Another point this study want to highlight is, looking into Phase 3, this study confirm that fuel cost decreased and the number of newly-bought cars increased significantly than in Phase 2, and these are likely to increase aggregate emissions, as this study does not see a decreasing trend in travel distances from 2017 to 2018.[6] If not investigated, Korean policies may induce more emissions, which is why the policies need to be examined on their impacts towards consumer preferences, automobile demands, and emissions.

[6] Referring to Korean Transportation Statistics (2019) published in Ministry of Land, Infrastructure, and Transport, travel distance of Korea has increased steadily from 2014 and increased 2.3% in 2018 compared to 2017.

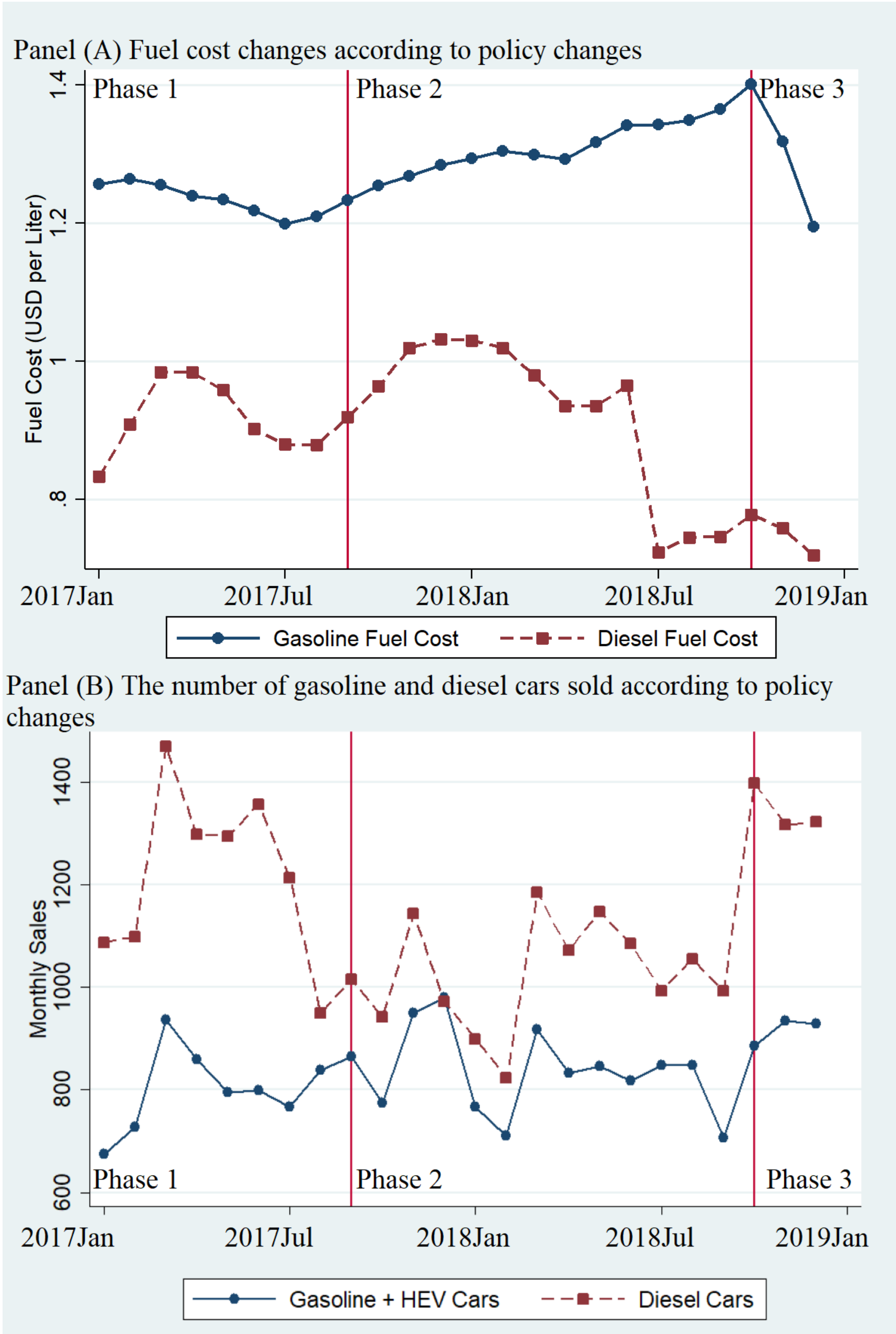

Figure 3.2 Timely Changes in Fuel Costs According to Policy Changes

3.2.2 Data and Demand Estimation of Korean Consumers

Data

This study first collects monthly data on new car sales, vehicle attributes, and fuel costs. The data are obtained from a Korean website, auto.danawa.com, which provides information on vehicle attributes such as horsepower, displacement, weight, fuel type, and fuel economy for all domestic manufacturer brands (Hyundai, Kia, GM, Samsung, and Ssangyong). In total, this study collects data on 3,320 vehicle models sold between January 2017 and December 2018. this study should note that by " model," this study refers to all specifications within the same model as well; for instance, the data include at least 20 specifications for the Hyundai Sonata, a flagship product of the Hyundai Motor Company. These specifications differ in fuel type and vehicle attributes (i.e., displacement, fuel economy, weight, size, and riding capacity). Considering all these different specifications leads to 3,320 vehicle models or specifications in the data (this study uses the terms interchangeably for the rest of the paper).

One distinctive characteristic of the Korean automobile market is that the Korea Energy Agency website provides information on the "CO_2 emissions" of each specification, namely, the car's amount of CO_2 per kilometer. This amount is the product of the emissions factor and the fuel source (Korea Energy Agency). Table 3.4 displays the descriptive statistics of the variables. Approximately 130 car models were available for each month in the sample period. In Table 3.4, the data indicate the differences in the vehicle attributes by automobile type. First, gasoline and diesel cars account for more than 80% of the market share. Second, surprisingly, although hybrid cars have a higher level of average fuel economy (17.484km/l), the data show that gasoline cars have the highest maximum fuel efficiency level. This is because hybrid vehicles are generally heavier than gasoline cars. As hybrid vehicles are more expensive than gasoline cars on average, this study anticipates that consumers who want to purchase a fuel-efficient vehicle would choose gasoline cars rather than HEVs. This study also did not find any significant differences in other vehicle attributes such as weight and length. Although the table shows the raw data for each variable, when estimating the model, this study takes the logarithm of all variables so that this study can interpret the results better. This study also includes a dummy variable for 'Minivans,' a car with a displacement of less than 1,000cc, a length lower than 3,600mm, a width lower than 1,600mm, and height lower than 2,000mm. This study also added 'Small cars' dummy variable. Small car in Korea refers to a vehicle slightly larger than Minivans but smaller than regular vehicles; that is, a car has a displacement less than 1,600 ccs but higher than 1,000 ccs, and a vehicle with a length lower than 4,6700 mm, width smaller than 1,700 mm, and height lower than 2,000 mm.

Table 3.4 Descriptive Statistics

	N	Mean	Std. Dev.	Min.	Max.
Gasoline Cars					
Market Share	1,692	49.52%			
Automobile Price (in KRW Million)	1,692	31.70	20.20	9.45	119.0
Units sold	1,692	877	2182.735	1	73,674
Fuel Efficiency (km/l)	1,692	11.712	2.665	7.3	22.4
Weight (kg)	1,692	1,504.352	319.018	890	2,225
Length (mm)	1,692	4,659.324	430.790	3,595	5,205
Riding Capacity	1,692	4.75	.88	2	8
Fuel Cost (KRW)	1,692	1,536.524	64.7120	1,433.13	1,681.12
Diesel Cars					
Market Share	1,008	37.81%			
Automobile Price (in KRW Million)	1,008	26.00	6.455	8.38	119.0
Units sold	1,008	1,123.651	1,772.983	1	10,064
Fuel Efficiency (km/l)	1,008	13.931	2.680	8	19.1
Weight (kg)	1,008	1,651.964	266.424	1,180	2,320
Length (mm)	1,008	4,674.653	289.911	4,060	5,150
Riding Capacity	1,008	5.09	0.88	3	9
Fuel Cost (KRW)	1,008	1338.6	65.906	1,229.81	1,485.02
LPG Cars					
Market Share	314	7.69%			
Automobile Price (in KRW Million)	314	18.50	6.798	8.380	31.90
Units sold	314	733.176	945.513	1	5,241
Fuel Efficiency (km/l)	314	8.821	1.014	6.5	10.6
Weight (kg)	314	1,322.118	306.334	735	1,690
Length (mm)	314	4,430.446	666.325	3,235	5,115
Riding Capacity	314	4.61	1.27	2	7
Fuel Cost (KRW)	314	1082.449	120.744	863.35	1238.37
HEVs					
Market Share	179	3.67%			
Automobile Price (in KRW Million)	179	32.30	4.609	23.50	39.40
Units sold	179	614.832	772.439	1	3,040
Fuel Efficiency (km/l)	179	17.484	1.354	11.3	19.5
Weight (kg)	179	1,605.084	84.452	1,425	1,725
Length (mm)	179	4,751.536	231.684	4,355	4,970
Riding Capacity	179	5	0	5	5
Fuel Cost (KRW)	179	1,536.524	64.7120	1,433.13	1,681.12
EVs					
Market Share	109	1.30%			
Automobile Price (in KRW Million)	109	38.00	10.00	15.00	47.80
Units sold	109	357.560	491.664	1	2,906
Fuel Efficiency (kw/h)	109	10.003	7.296	4.4	22.4
Weight (kg)	109	1,360.945	415.072	175	1,755
Length (mm)	109	4,046.266	781.361	2,338	4,750
Riding Capacity	109	4.26	1.30	2	5
Fuel Cost (KRW)	109	86.9	0	86.9	86.9

Random Coefficients and Driving Cost

Basically, the same set of methodology was used as in Japan, but a yearly-changing fuel costs were employed. Therefore, this study assumes that consumers have heterogeneous preferences toward automobile prices, and the preferences toward driving cost change over time. Driving cost is calculated as:

$$DC_{j,a,t} = FC_{a,t} * (1/E_{j,t}) \tag{3.5}$$

where $DC_{j,a,t}$ is a driving cost of automobile j of fuel type a in time t, $FC_{a,t}$ is a fuel cost of car type a of time t, and E is a fuel economy level of automobile j at time t. The inverse value of fuel economy ($(1/E_{j,t})$) would represent fuel usages per unit driving distance, which has also been used in Yoo et al., 2019a.

3.2.3 Korean Demand Estimation Result

Table 3.5 shows the estimation results for six model specifications. Models (1) and (2) are logistic ordinary least squares regressions. In Models (3) and (4), this study run IV regressions with automobile prices as the IV. Finally, in Models (5) to (8), this study use random coefficients for distance costs. In Models (1), (3), and (5), this study assume that consumer preferences change annually. On the other hand, in Models (2), (4), and (6), this study assume that consumer preferences regarding driving costs change every quarter. Finally, Models (7) and (8) include the lagged price terms of automobile price and unit distance cost. Model (7) includes monthly interaction terms, whereas Model (8) does not include monthly interaction terms.

The first result from the estimation results for Models (2), (4), and (6) in Table 3.1 is that the preferences regarding driving costs in Korea increased until 2017Q4, but keeps decreasing from 2018. For example, the driving cost coefficient in 2017Q3 in Model (6) would be the summation of base year driving cost coefficient and a driving cost coefficient in 2017Q3, which is $(-5.059) + (0.088)$. Similarly, the driving cost coefficient of 2018Q2 is $(-5.059) + (-1.059)$. The higher number would indicate consumer preferences towards fuel economy levels of cars increased, or that consumers become less sensitive to fuel costs, and vice versa. However, given that the data has a relatively short period of time and insignificant fuel economy improvements, this study assume that the changes in distance cost preferences are mostly induced by fuel cost changes. Therefore, this study suppose lower driving cost preferences would indicate higher fuel cost sensitivity, and vice versa. This implies that consumers' preferences in 2018Q4 were more affected by driving costs compared to those of consumers in 2017Q1 and 2017Q2. For instance, from Model (6), the log driving cost in 2017Q2 is $(-5.059)+(0.088)$ (base driving cost coefficient + 2017Q2 driving cost coefficient). Similarly, the driving cost coefficient of 2018Q2 is $(-5.059)+(-1.059)$. This result indicates that consumers have become more sensitive to their driving costs. Second, the random coefficient results in Models (5) and (6) indicate that there is a statistically significant level of heterogeneity in automobile prices and driving costs, with the random coefficient of driving cost being larger than that of automobile prices in both Models. Previous research typically finds heterogeneity among price coefficients (K. E. Tran and Winston, 2007). Given that the random coefficients are statistically significant, and that these parameters help alleviate the well-known problem of independence of irrelevant alternatives (IIA) exhibited by traditional logit models, the random coefficients play a critical role in defining the substitution patterns as in Xing, Benjamin, and Shajun Li, 2018.

Third, Models (7) and (8) show that the results are qualitatively similar even after including lagged price terms, namely 1 quarter-lagged automobile prices and 1 quarter-lagged unit distance costs. this study thus show that these results are robust even after the inclusion of past price and cost terms. this study also find that lagged automobile price yields a negative coefficient and lagged unit distance cost exhibits a positive coefficient, showing that consumers are more sensitive to the automobile prices in the last quarter than to fuel costs.

As expected, the other vehicle attributes, such as weight and car length, and minivan status, have positive and mostly statistically significant coefficients, implying that Korean consumers value these characteristics in their demand for automobiles.

This study conjecture that the change in driving cost preferences is correlated to policies and fuel price changes. Price changes during the 2017Q1–2018Q4 period, unfavorable to diesel fuel and diesel vehicles and more favorable toward gasoline- or LPG-fueled vehicles, could be correlated to consumers' choices on gasoline- or LPG-fueled automobiles instead of diesel-fueled ones. Note that fuel economy levels did not evolve much during the 2017–2018 period. The increasing trend of the unit distance cost coefficient in 2017 indicates that Korean consumers are becoming less sensitive towards increasing fuel prices. This increasing trend starts to decrease from 2017Q4, which is when the Clean Diesel policy is abolished, and therefore when fewer incentives are given to the consumers to purchase diesel cars. Given that diesel cars have a lower fuel economy than gasoline and HEVs, the increase in the average fuel economy level is likely to decrease the distance cost coefficient. this study also confirm that the distance cost preference decreases the most at 2018Q4, which is when the diesel fuel price is increased due to the governmental policy.

In summary, the demand estimation shows the importance of considering consumer preferences regarding fuel costs. However, if the Korean government adjusts fuel costs through policy instruments, will the demand for automobiles change? More specifically, would the fuel cost adjustments and consumer preferences affect consumers' choice of automobile fuel types and fuel economy levels? this study answer these questions via a scenario analysis and by calculating the emissions of each hypothetical scenario in the following section.

Table 3.5 Demand Estimation Results

	Model (1) OLS Logit	Model (2) OLS Logit	Model (3) IV Logit	Model (4) IV Logit	Model (5) IV RC Logit	Model (6) IV RC Logit	Model (7) IV RC Logit	Model (8) IV RC Logit
ln(Automobile Price)	-2.096***	-2.093***	-4.160***	-4.133***	-9.851***	-10.16***	-9.767***	-9.833****
	(.117)	(.117)	(1.058)	(1.069)	(1.067)	(1.118)	(1.115)	(1.540)
ln(Driving Cost: Base)	-.618***	-.579***	-.681***	-.639***	-4.049***	-3.857***	-3.835***	-3.821***
	(.111)	(.110)	(.121)	(.119)	(.122)	(.120)	(.129)	(.126)
ln(Driving Cost: 2018)	.120		-.130		-.728***		-.873***	
	(.133)		(.190)		(.191)		(.191)	
ln(Driving Cost: 2017Q2)		.049*		.056*		.202***		.347***
		(.028)		(.030)		(.030)		(.042)
ln(Driving Cost: 2017Q3)		.027		.030		.076**		.030
		(.028)		(.030)		(.030)		(.034)
ln(Driving Cost: 2017Q4)		.066**		.067**		.115***		.058*
		(.028)		(.029)		(.030)		(.034)
ln(Driving Cost: 2018Q1)		.147		-.106		-.872***		-.669***
		(.135)		(.191)		(.193)		(.194)
ln(Driving Cost: 2018Q2)		.159		-.094		-.725***		-.551***
		(.135)		(.191)		(.193)		(.193)
ln(Driving Cost: 2018Q3)		.145		-.107		-.859***		-.788***
		(.135)		(.191)		(.192)		(.193)
ln(Driving Cost: 2018Q4)		.189		-.060		-.654***		-.577***
		(.136)		(.190)		(.192)		(.192)
Minivans	2.092***	2.085***	2.204***	2.196***	1.359***	1.376***	1.420***	1.386***
	(.299)	(.300)	(.318)	(.318)	(.320)	(.320)	(.331)	(.330)
Small Cars	-2.538***	-2.568***	-1.206	-1.254	-2.034**	-2.086**	-1.683*	-1.907*
	(.645)	(.646)	(.957)	(.956)	(.965)	(.962)	(.987)	(.984)
Riding Capacity	.172	.168	.168	.164	.994***	1.033***	.947***	.949***
	(.247)	(.247)	(.258)	(.258)	(.259)	(.259)	(.270)	(.270)
Weight (kg)	3.884***	3.904***	7.635***	7.611***	10.22***	10.34***	10.17***	10.25***
	(.362)	(.362)	(1.947)	(1.946)	(1.967)	(1.963)	(2.043)	(2.039)
Car Length (mm)	2.714***	2.659***	2.708***	2.652***	-1.814**	-1.906**	-1.506*	-1.596*
	(.773)	(.773)	(.808)	(.808)	(.813)	(.811)	(.844)	(.842)
Random Coeff. of Automobile Price					1.794***	1.881***	1.750***	1.762***
					(.413)	(.583)	(.421)	(.562)
Random Coeff. of Driving Cost					3.420***	3.419***	3.222***	3.311***
					(.927)	(.902)	(.915)	(.898)
Lagged Automobile Price							-.599***	-.102
(Lag: 1 quarter)							(.126)	(.103)
Lagged Unit Distance Cost							1.945***	.521**
(Lag: 1 quarter)							(.214)	(.155)
Constant	-24.58***	-24.70***	-35.81***	-35.88**	-35.69***	-35.16***	-35.13***	-35.13***
	(1.839)	(1.840)	(6.048)	(6.091)	(7.007)	(6.979)	(7.302)	(7.668)
Fixed Effects (FE)								
Brand FE	√	√	√	√	√	√	√	√
Year FE	√	√	√	√	√	√	√	√
N	3,302	3,302	3,302	3,302	3,302	3,302	3,302	3,302
R^2	.145	.143	.064	.064	.683	.670	.671	.666

Note: Standard errors are shown in parentheses. + p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

3.2.4 Robustness Checks of Korean Demand Estimation

Before the counterfactual simulations, this study conducts multiple robustness checks to make sure that the estimates and implications are robust.

This study re-estimate some of the models above, allowing quarter-specific preferences regarding prices and vehicle weights, after excluding quarter-specific preferences regarding unit distance costs. If there is a decreasing trend in the vehicle weights, the main result likely correlates to the other vehicle attributes; for example, high vehicle weights are likely to be correlated to lower fuel economy levels. This study tries three different specifications. In Model (1), this study uses the logit specification. In Model (2), this study applies logit with IVs, and in Model (3), this study adds random coefficients of automobile price and unit distance cost from Model (2). As the main Model in Table 3.1 is a model with random coefficients, this study also focuses on Model (3) here. As shown in Table 3.6, this study mostly do not find statistical significance except for Model (1), which is a logit specification. Thus, this study can conclude that the findings are robust, as this study confirms the consumer preference towards vehicle weights did not change over time. This confirms the findings in Table 3.1.

Table 3.6 Robustness Test Results

	Model (1)	Model (2) IV	Model (3) IV
	Logit	Logit	RC Logit
ln(Automobile Price)	-2.308***	-.507	-12.17***
	(.310)	(2.855)	(2.953)
ln(Driving Cost: Base)	-.488***	-.479***	-1.076***
	(.077)	(.079)	(.079)
Weight	7.757***	3.918***	-1.533
	(3.677)	(1.085)	(20.75)
Weight : 2017Q2	.281	2.030	1.500
	(.444)	(2.793)	(2.888)
Weight : 2017Q3	.357	2.107	1.524
	(.446)	(2.793)	(2.888)
Weight : 2017Q4	.448	2.211	1.490
	(.454)	(2.816)	(2.911)
Weight : 2018Q1	-.564	1.764	.596
	(.627)	(3.721)	(3.848)
Weight : 2018Q2	-1.346**	.994	-.054
	(.623)	(3.721)	(3.867)
Weight : 2018Q3	-.961	1.380	.649
	(.624)	(3.741)	(3.868)
Weight : 2018Q4	-1.431**	.915	.198
	(.599)	(3.745)	(3.872)
Minivans	2.099***	2.024***	1.657***
	(.299)	(.323)	(.327)
Small Cars	-2.308***	-.507	-2.587***
	(.310)	(2.855)	(.972)
Riding Capacity	.146	.135	1.041***
	(.246)	(.248)	(.250)
Car Length (mm)	2.707***	2.621***	1.140
	(.775)	(.790)	(.797)
Random Coeff. of Automobile Price			3.674
			(24.88)
Random Coeff. of Driving Cost			2.712
			(3.323)
Constant	-29.68**	-26.26***	-20.63***
	(2.205)	(5.823)	(6.002)
Fixed Effects (FE)			
Brand FE	√	√	√
Year FE	√	√	√
Price Interaction	√	√	√
N	3,302	3,302	3,302
R^2	0.149	0.140	0.884

Note: Standard errors are shown in parentheses. + p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

Second, this study verifies the fit of the demand model by simulating the situation for each quarter. In this situation, consumers choose their cars in that quarter again, to make sure that the demand model can replicate consumers' behavior and allow us to proceed with counterfactual simulations. Table 3.7 shows the results of the fitness test of each quarter and year. In Table 3.7, "Data" refers to the actual value of the number of sales in the data, and "Simulation" shows the simulation results. In the "% Difference" column, this study also calculates the difference between the actual data and the simulation values as a percentage. The results show that the difference is approximately less than 10%. However, as this study does not find any visible trend in the differences, this study believes this difference is driven mainly by the random coefficient of automobile price in Table 3.5. The difference between the data and simulation values vacillates between positive and negative values, indicating that there is randomness in the bootstrap simulations. Also, as this study find that the fit works both in quarters and years, for the counterfactual simulations and the implications, this study pick years instead of quarters, as results with years would provide connections with a more extended period.

Table 3.7 Fit of the Model

Quarter	Data	Simulation	% Difference	Bootstrap p value	95% Confidence Interval
2017Q1	341,757	352,039	3.01%	0.000***	321,605.2 – 361,908.8
2017Q2	385,923	353,476	-8.41%	0.000***	322,327.6 – 449,518.4
2017Q3	355,362	352,493	-0.81%	0.000***	349,739.5 – 360,984.5
2017Q4	363,866	352,695	-3.07%	0.000***	341,971.9 – 385,760.1
2018Q1	343,326	357,619	4.16%	0.000***	315,311.6 – 371,340.4
2018Q2	385,676	358,851	6.96%	0.000***	333,099.6 – 438,252.4
2018Q3	352,306	357,824	1.64%	0.000***	341,491.3 – 363,120.7
2018Q4	394,514	359,076	-0.90%	0.000***	325,057.2 – 463,970.8
Year	**Data**	**Simulation**	**% Difference**	**Bootstrap p value**	**95% Confidence Interval**
2017	1,446,908	1,410,703	-2.50%	0.000***	1,375,948 – 1,517,868
2018	1,475,552	1,433,370	-2.86%	0.000***	1,392,877 – 1,558,227

Note: The fourth column, % Difference, is calculated as 100*(Data - Simulation)/Data.

3.2.5 Policy Simulations: Korean Consumers

Policy Simulation Settings to Reduce Emissions

Based on the demand estimation results, this study found that automobile price, fuel cost, and time-varying driving cost preferences are all crucial in determining automobile demand. In this section, through counterfactual simulations, this study quantitatively analyzes and decompose the impact of consumer preferences, fuel costs, and automobile prices on the number of automobiles sold and emissions. The efficiency of policy measures critically depends on consumer preferences. For example, if consumers are highly sensitive to fuel costs, consumers would not purchase less fuel-efficient cars, regardless of the financial incentives. Conversely, if consumers are not highly sensitive to fuel costs, financial incentives would not be necessary.

On the other hand, if the policy is significantly related to the automobile demands than consumer preferences, then the Korean government can design policies regardless of consumer preferences.

This study set hypothetical scenarios that incorporate both the periods when consumers are less sensitive towards fuel costs and when they are highly sensitive towards fuel costs. Through these scenarios, this study investigates how policies change consumers' car choices. The implications of this scenario exercise would provide policy insights that are applicable regardless of consumers' fuel costs preferences.

This study further examines whether consumers are more sensitive to automobile prices or fuel costs, as both exhibit heterogeneity based on their random coefficients.

Because the Korean government seeks to reduce emissions by controlling diesel prices and diesel car demand, this study set policy scenarios to evaluate whether these measures are effective in controlling diesel car demand and diesel car emissions.

Though contrasting, two policies of Korea have different purposes. The abolition of the Clean diesel act was to decrease emissions from diesel cars, whereas the reduction in diesel prices is for boosting employments. If the Korean government can't abolish one of two, it is necessary to find out which additional policy measures would be needed in terms of emissions reductions. As fuel tax and automobile subsidies are well-known policy instruments for emissions reductions, this study creates hypothetical scenarios by adding two policy instruments to the current Korean policies. Furthermore, given that the Korean government implemented two different policies at roughly the same time, this study tries to separate the effects of fuel tax changes and car price changes by simulating from these scenarios.

To this end, this study set the two following main scenarios: In Scenario 1, this study hypothetically takes consumers from 2018Q4 and give them the vehicle choice set from 2017Q1. In Scenario 2, this study hypothetically provides consumers from 2017Q1 the choice set of automobiles available in 2018Q4. To determine the policy implications, this study simulates using two additional scenarios for each of these two main scenarios. In Scenarios 1-a and 2-a, this study tested the impact of an "additional" 10% diesel fuel tax. In Scenarios 1-b and 2-b, this study examines the effect of additionally increasing the price of diesel automobiles by 10%.

Table 3.8 summarizes the scenario exercises. In the upper panel, this study describes the scenarios, and in the lower panel, this study marks each scenario's main objective. Given that consumers in 2018Q4 are facing both the abolition of diesel price subsidies and diesel car subsidies, this study marks them as 'contrasting policies.' The results of both scenarios would show whether emissions change after contrasting policies after shifting consumer preferences. For Scenarios 1-a and 2-a, as this study is changing the fuel tax rate in addition to Scenario 1, this study marked it with 'Fuel Tax Change' with 'Contrasting Policies.' Similarly, as this study is increasing the diesel car price and the different policies in Scenario 1-b and 2-b, this study marked in 'Automobile Price Change' and 'Contrasting Policies.'

One important note regarding this simulation is that this study does not take technological advancement into account, as this study covers a relatively short period of two years. Therefore, the simulation results should allow us to disentangle the impact of consumer preferences and policies. The results of these simulations can be meaningful to policymakers in the following two ways: First, as rapid technological advancement is not expected to have occurred in such a short period, the simulation results will provide evidence on whether consumer preferences are more critical than policy in controlling emissions. Second, as the marginal amount of technological advancement decreases over time—or costs increase—consumer preferences or policies will become increasingly important factors affecting emissions.

Table 3.8 Scenario Descriptions

Year	**Descriptions**
Scenario 1	Hypothetically Take People from 2018Q4 to 2017Q1
Scenario 1-a	Scenario 1 + 10% Increase in Diesel Fuel Tax
Scenario 1-b	Scenario 1 + 10% Increase in Diesel Car Prices
Scenario 2	Hypothetically Take People from 2017Q1 to 2018Q4
Scenario 2-a	Scenario 2 + 10% Increase in Diesel Fuel Tax
Scenario 2-b	Scenario 2 + 10% Increase in Diesel Car Prices

Scenario	**Contrasting Policies**	**Fuel Tax Change**	**Automobile Price Change**
Scenario 1	O	X	X
Scenario 1-a	O	O	X
Scenario 1-b	O	X	O
Scenario 2	O	X	X
Scenario 2-a	O	O	X
Scenario 2-b	O	X	O

To focus on the changes in consumer preferences in a relatively long period, this study looks at yearly differences instead of quarterly differences. Quarterly differences may be more prone to seasonal or stochastic changes in consumer preferences, if any, exist. In contrast, this study believes that using the yearly differences clearly shows the differences in preferences over time. Furthermore, when interpreting the results, this study mainly focuses on diesel automobile sales, as this study is evaluating policies that directly influence diesel car sales and diesel car emissions.

First, when this study takes fuel price-sensitive consumers strongly from 2018Q4 and presents them with automobile choices from 2017Q1 (Scenario 1), this study observes that the number of sales decreases by 3.04%. This result occurs mainly because consumers in 2018Q4 are more fuel price-sensitive; thus, they do not buy cars in 2017Q1 because fuel costs in this quarter are higher than those in 2018Q4.

Second, when this study takes less fuel price-sensitive consumers from 2017Q1 to 2018Q4 (Scenario 2), the total sales increase by 3.20% because consumers in 2017Q1 are not as fuel price-sensitive. Therefore, consumers from 2017Q1 are willing to purchase a new car or replace their existing ones with new ones, as fuel costs in 2018Q4 are cheaper than those in 2017Q1.

Specifically, in Panel A in Table 3.9, if this study increases the diesel fuel tax by 10% (Scenario 1-a), the automobile sales decrease slightly by 4.86%. Rising diesel car prices by 10% decrease in automobile sales by 6.48%. Compared to Scenario 1, Scenarios 1-a and 1-b result in a reduced number of automobiles being sold, indicating that fuel cost-sensitive consumers can amplify the policy effects. this study also finds that increasing automobile prices is more effective in reducing vehicle sales than increasing diesel prices.

Increasing the price of automobiles decreases total sales, but if consumers are not sensitive to fuel costs, higher automobile prices alone cannot reduce the number of cars sold. This study confirms that automobile sales increase by 2.13% if this study increases the diesel fuel tax by 10% (Scenario 2-a), which is a smaller increase than in Scenario 2. this study also finds that if this study increase diesel prices by 10%, this study see that automobile sales still increase but only by 0.54%, indicating that compared to Scenarios 2 and 2-a, increasing diesel car prices decreases total sales. However, consumers are more willing to purchase cars when fuel prices are lower.

Panel (B) shows the sales-weighted average fuel economy levels according to each scenario.

Compared to Panel (A), this study does not find significant changes in fuel economy levels except for in Scenario 2. This result indicates that Korean consumers are more likely to choose cars not on fuel economy levels, but more on the fuel costs.

To further understand how these consumers change their purchasing patterns, this study also calculates the changes by car fuel type. In panels (C) and (D), this study focus on gasoline and hybrid cars in Panel (C), and diesel cars in panel (D), respectively.[7] this study calculates the difference of the obtained numbers from the data and compute the market share of each type.

First, this study finds that both increasing the cost of diesel or diesel car prices would incentivize people to prefer gasoline and hybrid cars over diesel cars. Mainly, this study confirms that increasing diesel cars price would have a substantial impact on diesel car demands. For example, both in Scenario 1-b and 2-b, this study sees that gasoline and HEV cars have increased substantially while the market share of diesel cars decreased significantly.

Second, this study also notes that increasing diesel price would encourage consumers to choose diesel cars over gasoline and HEV, while the magnitude was smaller than that of the diesel cars. This study finds this result consistent with the findings in demand estimations, as the price coefficient was lower than the driving cost coefficient.

This study adds that relative to Scenario 1, the market share for gasoline and HEV cars is smaller in Scenario 1-a and more significant in Scenario 1-b. As for the market share for diesel cars, it increases in Scenario 1, due to diesel-fueled automobiles being less expensive than gasoline automobiles, which attracts more consumers towards diesel cars. In converse, the market share for diesel cars relative to Scenario 1 is higher in Scenario 1-a and smaller in Scenario 1-b.

On the other hand, the results suggest that when consumers are less fuel cost-sensitive

[7] this study also acknowledges that the demand for LPG cars and EVs change, but this study did not find significant substitution patterns for these two types of automobiles. Specifically, the number of EVs and LPG cars sold decreases in Scenarios 1, 1-a, and 1-b and increases in Scenarios 2, 2-a, and 2-b.

(Scenario 2), they replace diesel cars with gasoline and hybrid vehicles. Scenarios 2, 2-a, and 2-b show that the market shares of gasoline and hybrid vehicles increase, whereas that of diesel cars decreases. This study also adds that relative to Scenario 2, the combined market share for gasoline and HEV cars is higher in Scenarios 2-a and 2-b. In contrast, the market share for diesel cars is smaller in both scenarios.

This study concludes that controlling the demand for diesel cars would rely on the consumers' preferences, particularly on automobile price and fuel costs. That is, Korean consumers are not likely to purchase vehicles according to the fuel economy levels but would prioritize fuel costs and automobile prices. When fuel cost is more expensive, and consumers are less fuel-cost sensitive, consumers are instead more likely to substitute gasoline and hybrid cars for diesel cars. It is worth noting that diesel cars' fuel cost is the cheapest, while diesel's fuel economy is the lowest.

Table 3.9 Simulation Results

	Preference	Fuel Cost	Data	Simulation	Difference
(A): Automobile Sales					
Data	2017Q1	2017Q1	1,446,908		
Scenario 1	2018Q4	2017Q1		1,402,869	-3.04%
Scenario 1-a	2018Q4	2017Q1		1,376,540	-4.86%
Scenario 1-b	2018Q4	2017Q1		1,353,158	-6.48%
Data	2018Q4	2018Q4	1,475,552		
Scenario 2	2017Q1	2018Q4		1,522,754	3.20%
Scenario 2-a	2017Q1	2018Q4		1,506,971	2.13%
Scenario 2-b	2017Q1	2018Q4		1,483,576	0.54%
(B): Fuel Economy (km/l)					
Data	2017Q1	2017Q1	12.35		
Scenario 1	2018Q4	2017Q1		12.22	-1.07%
Scenario 1-a	2018Q4	2017Q1		12.28	-0.06%
Scenario 1-b	2018Q4	2017Q1		12.12	-1.92%
Data	2018Q4	2018Q4	12.21		
Scenario 2	2017Q1	2018Q4		11.20	-8.20%
Scenario 2-a	2017Q1	2018Q4		12.24	-0.32%
Scenario 2-b	2017Q1	2018Q4		12.47	0.31%

(C): Gasoline + HEV cars sold			
		Difference	Market Share
Data	747,012		51.63%
Fitted Value	732,255	-16.18%	50.60%
Scenario 1	722,683	-17.96%	51.51%
Scenario 1-a	778,515	-12.53%	56.55%
Scenario 1-b	943,884	26.35%	69.75%
Data	773,617		52.43%
Fitted Value	763,382	-1.32%	51.74%
Scenario 2	830,113	7.30%	54.51%
Scenario 2-a	872,891	12.83%	57.92%
Scenario 2-b	1,045,307	35.12%	70.45%

(D): Diesel cars sold			
		Difference	Market Share
Data	564,756		39.03%
Fitted Value	552,195	-2.23%	38.16%
Scenario 1	560,786	-0.70%	39.97%
Scenario 1-a	471,899	-16.44%	34.28%
Scenario 1-b	263,068	-53.42%	19.44%
Data	567,884		38.48%
Fitted Value	563,369	-0.80%	33.23%
Scenario 2	583,304	2.72%	38.31%
Scenario 2-a	512,876	-9.69%	34.03%
Scenario 2-b	288,866	-49.13%	19.47%

Emissions Consequences Based on the results in Table 3.9, this study calculates the CO_2 emissions of the car market result of each scenario. Note that the calculated emissions here are emissions of the resulting car market rather than the overall emissions from vehicles. To calculate for emissions, this study let the fuel usage of automobile j in year t be equal to the inverse of the fuel economy value, in liters per kilometer, following Yoo, Wakamori, and Yoshida, 2019 . The emissions for a given time t, TE_t, can be calculated by multiplying the total number of sales, $Q_{j,t}$, with driving distance, $D_{j,t}$, and fuel usage, $FU_{j,t}$. Therefore, the aggregate emissions can be calculated as:

$$TE_t = \sum_j FU_{j,t} \cdot D_{j,t} \cdot Q_{j,t} \cdot A,$$

where A denotes the emissions calculation factor and $D_{j,t}$ denotes the driving distance of automobile j in year t. A differs by automobile fuel type, that is, gasoline (including that for hybrid vehicles), diesel, LPG, and electricity (for EVs). In regards to CO_2 emissions, diesel emits the largest amount (2.6kg/l), followed by gasoline (2.4kg/l) and LPG (1.7kg/l). In terms of NOx emissions, diesel emits the largest amount (0.8g/l), followed by gasoline (0.5g/l) and LPG (0.16g/l)[8]. Particulate Matter (PM) was calculated only for diesel cars (3.8mg/l). Thus, the emissions amount primarily reflects the car type substitutions.

Table 3.10 provides the results from emissions simulations. Each panel represents CO_2, NOx, and PM emissions (Million tons eq), 'Preference' refers to the time of consumer preference this study takes as a benchmark, and 'Fuel Costs' shows the time of fuel cost this study takes as a benchmark. For example, The first column of Panel (A) would refer to the preference level in 2018Q4 and fuel costs Q4). 'Data' refers to the original data, and 'Simulation' shows the projected emissions. 'Difference' shows the differences between simulated emissions and the data.

[8]this study acknowledge that NOx emission depends on engine type. Thus, this study uses the average NOx emission factor of average passenger cars, referring to a material published in National Institute for Land and Infrastructure Management, Japan.

Emissions in Panel (A), (B) and (C) generally shows a decreasing trend. Compared to CO_2 and NOx, which hinges on gasoline, LPG, and diesel cars, PM emissions rely solely on diesel cars. First, this study finds that emissions would decrease in Scenario 1, 1-a, and 1-b, and it will decrease the most in Scenario 1-b, regardless of the emission types. This is fuel-cost sensitive people of 2018Q4 are not likely to purchase cars in 2017Q1, and the magnitude would become higher if the fuel cost increases (Scenario 1-a), and diesel car price increase (Scenario 1-b).

Second, unlike Scenario 1, emissions would increase in Scenario 2, as people in 2017Q1 are sensitive to fuel costs and will purchase cars in 2018Q4 due to the cheaper fuel costs. However, the emissions would decrease compared to Scenario 2 if diesel price is penalized (Scenario 2-a) and diesel car price is increased (Scenario 2-b). PM emissions show the largest decline over CO_2 and NOx, and this is because PM emissions solely depend on the number of diesel cars sold, and the number of diesel cars sold decreased as in Panel (C) and (D) in the Table 3.9.

Table 3.10 Emissions Simulation Results

	Preference	Fuel Costs	Data	Simulation	Difference
(A): CO_2 Emissions (Million tons eq)					
Data	2017Q1	2017Q1	4.17		
Fitted Value	2017Q1	2017Q1	4.12	-1.22%	
Scenario 1	2018Q4	2017Q1		4.10	-1.79%
Scenario 1-a	2018Q4	2017Q1		3.89	-6.70%
Scenario 1-b	2018Q4	2017Q1		3.62	-13.08%
Data	2018Q4	2018Q4	4.22		
Fitted Value	2017Q1	2018Q4	4.19	-0.55%	
Scenario 2	2017Q1	2018Q4		4.52	7.16%
Scenario 2-a	2017Q1	2018Q4		4.27	1.19%
Scenario 2-b	2017Q1	2018Q4		3.81	-9.52%
(B): NOx Emissions (Thousands kg eq)					
Data	2017Q1	2017Q1	1,035.19		
Fitted Value	2017Q1	2017Q1	1,019.08	-1.55%	
Scenario 1	2018Q4	2017Q1		1,017.33	-1.72%
Scenario 1-a	2018Q4	2017Q1		937.96	-9.39%
Scenario 1-b	2018Q4	2017Q1		897.82	-13.31%
Data	2018Q4	2018Q4	1,054.96		
Fitted Value	2017Q1	2018Q4	1,047.33	-0.07%	
Scenario 2	2017Q1	2018Q4		1,125.99	6.73%
Scenario 2-a	2017Q1	2018Q4		1,038.99	-1.51%
Scenario 2-b	2017Q1	2018Q4		948.22	-10.12%
(C): Particulate Matter (Thousands kg eq)					
Data	2017Q1	2017Q1	3.17		
Fitted Value	2017Q1	2017Q1	3.10	-2.20%	
Scenario 1	2018Q4	2017Q1		3.11	-1.90%
Scenario 1-a	2018Q4	2017Q1		2.61	-17.84%
Scenario 1-b	2018Q4	2017Q1		1.47	-53.84%
Data	2018Q4	2018Q4	3.23		
Fitted Value	2017Q1	2018Q4	3.19	-1.12%	
Scenario 2	2017Q1	2018Q4		3.38	4.59%
Scenario 2-a	2017Q1	2018Q4		2.92	-9.51%
Scenario 2-b	2017Q1	2018Q4		1.64	-49.35%

To derive more implications from the emissions, this study looks into the different fuel types and their emissions in Table 3.11. Panel (A) of Table 3.11 refers to the emissions from gasoline and hybrids cars, and Panel (B) shows emissions from diesel cars. While this study finds mostly similar implications in Table 3.10, two points are worth highlighting. First, overall, this study finds diesel cars have more emissions than gasoline and hybrids regardless of emissions types, and this is mainly due to the low fuel economy level of diesel cars. Second, the result implies that adjusting diesel car prices may not lead to emissions reductions. This study finds that increasing diesel cars price (scenario 1-b and 2-b) may lead to an increase in gasoline car emissions. For example, CO_2 and NOx emissions in Scenario 1-b are higher than Scenario 1 and 1-a. Similarly, emissions result in Scenario 2-b does not show significant reductions compared to Scenario 2 or 2-a. This result indicates that the people may substitute diesel to gasoline cars, increasing the market share of gasoline and hybrid cars.

Table 3.11 Emissions from Different Fuel Type Cars

(A): Emissions from Gasoline + HEV cars			
	CO_2	NOx	PM
Data	1.59	332.34	0
Scenario 1	1.58	328.56	0
Scenario 1-a	1.69	352.81	0
Scenario 1-b	2.13	443.89	0
Data	1.66	346.13	0
Scenario 2	1.85	384.68	0
Scenario 2-a	1.87	389.62	0
Scenario 2-b	2.20	458.25	0
(B): Emissions From Diesel cars			
	CO_2	NOx	PM
Data	2.16	663.16	3.15
Scenario 1	2.11	650.54	3.11
Scenario 1-a	1.77	544.84	2.61
Scenario 1-b	1.00	306.08	1.47
Data	2.19	674.87	3.18
Scenario 2	2.29	705.86	3.38
Scenario 2-a	1.98	610.69	2.92
Scenario 2-b	1.11	341.79	1.64

Note: All results are in the same unit as in Table 3.10.

3.2.6 Comparisons between Scenarios

This study finds that the current contrasting set of Korean policies may lead to unexpected outcomes. Particularly, in Scenario 2, show an increase of CO_2 emissions due to a rise in automobile sales. Scenario 1 also shows less emissions reduction compared to Scenario 1-a and 1-b.

This study also sees a proportional change between Scenario 1, 1-a and 1-b, and Scenario 2, 2-a, and 2-b. That is, increasing diesel prices (Scenario 1-a and Scenario 2-a) would reduce the number of diesel cars sold and emissions from diesel cars, compared to no-policy scenarios (Scenario 1 and 2). When the diesel car price is increased (Scenario 1-b and 2-b), then the number of diesel cars sold and emissions from diesel cars would decrease more than in Scenario 1-a and 2-a. This is because consumers are more sensitive towards automobile prices than fuel costs, as displayed in the demand estimation model in Table **??**, where estimated coefficients suggest that consumers are more than twice as sensitive towards automobile prices than fuel costs. However, this result does not indicate that policies focused on fuel costs are a futile endeavor, as raising fuel tax would increase governmental budget while achieving emissions reductions. For instance, Scenario 1-a and 2-a always show reduced emissions and automobile sales, and increased fuel economy levels, compared to Scenario 1 and 2.

This study notes that the policies can achieve more emissions reduction when faced with fuel-cost sensitive consumers that are not sensitive. This study sees a more substantial amount of automobile sales and emissions reduction in Scenario 1, 1-a and 1-b, compared to Scenario 2, 2-a and 2-b, in the same setting. For example, if a diesel price increases by 10%, Scenario 1-a shows a 6.70% of CO_2 emissions reduction due to the automobile sales reduction of 4.86% and fuel economy levels reduction of 0.06%, Scenario 2-a shows an increase of CO_2 emissions of 1.19% followed by an automobile sales increase of 2.13% and fuel economy levels decrease of 0.32%.

Given that, this study concludes that the Korean government to prioritize the policy objectives and choose policies accordingly. If the Korean government wants to achieve emissions reduction through reducing ‘the number of automobiles sold,’ then increasing the diesel car price would be the best option. On the other hand, if a Korean government wants to achieve emissions reductions while keeping the number of diesel cars, increasing fuel tax would be the better option.

In sum, the results highlight that consumer preferences and policies are highly correlated to automobile demands and emissions. This study also confirms that to reduce emissions from diesel cars; it would be more useful to increase diesel car prices than to increase diesel fuel costs.

3.3 Cross-country Implications on Consumer Preference and Transportation Sector

The difference between Japan and Korean consumers is that Japanese consumers do not prefer fuel-efficient cars as time goes by, where Korean consumers do not show such a trend; instead, it shows an increasing trend. The difference can be explained by the different circumstances between the two countries. While the Japanese government tried to improve fuel economy levels through various policies promoting technological developments, the Korean government attempted to discourage diesel cars regardless of their fuel economy levels. As a result, Japanese cars have achieved a drastic fuel economy improvement, but also the automobile price has been increased, discouraging consumers from purchasing a fuel-efficient vehicle in 2016, compared to 2006. Hence, in Korea, because Korean consumers are sensitive towards fuel costs and diesel cars on average have a higher level of fuel economy, consumers are still willing to purchase fuel-efficient vehicles, even though it is a diesel car. Both results highlight the potential of fuel tax. For both countries, taxing the fuel would indirectly induce consumers to drive less, eventually reducing emissions from vehicles.

First, for Japan, this study finds both technological advancement and consumer preference are essential. Consumer preferences are a crucial factor in lowering emissions. Environmentally cautious consumers will purchase fuel-efficient cars, which prevents the emission increases caused by either increased automobile sales or low fuel economy. However, the implications do not mean that improving fuel economy is a futile endeavor. Without fuel economy improvements, emissions would increase, as the average fuel economy falls. As alternatives, supporting manufacturers with financial incentives and therefore reducing their marginal cost of producing fuel-efficient automobiles is one option. By doing so, consumer preferences and average fuel economy levels both increase simultaneously, allowing more emissions reductions than only directing financial incentives toward consumers. Altering fuel taxes could be another option, as these can indirectly control the travel distances of consumers and thus lower emissions.

Second, for Korea, when there is not a significant level of technological advancement, the results indicate that fuel cost sensitivity of consumers is the essential factor for automobile demand and further emissions. This is because if consumers are more sensitive to fuel prices, regardless of fuel tax or price, emissions would decrease, indicating that the Korean government does not have to make a costly decision on reducing fuel costs.

Chapter Four

Travel Distances of Japan

4.1 Importance of Investigating Travel Distance

Technological advancements such as fuel economy improvements are a promising solution for reducing carbon dioxide and fuel consumption in the transportation sector. Furthermore, if combined with behavioral changes such as people being gradually encouraged to travel less, emissions and fuel usage would be reduced more effectively in the long term.

Japan, the sixth-highest emitter in 2015, has also attempted to reduce emissions by implementing fuel economy standards for vehicles. As a result, fuel economy levels have improved by 23% from 2006 to 2016 (Japan Automobile Manufacturer Association). On the other hand, only a 4% decrease in CO_2 emissions from the transportation sector has been observed from 2007 to 2016 (EIA, 2016), creating a discrepancy between the expected and the actual decrease. Understanding travel behavior would explain this discrepancy between the expected reduction in CO_2 emissions due to the fuel economy improvement and the actual reduction because the improvement in fuel economy mainly reflects the technological advancement of the industry. In contrast, the latter reflects mostly people's behaviors. Therefore, explaining the discrepancy and providing policy suggestions to resolve it is necessary for designing policies to reduce emissions effectively[1].

[1] This study acknowledges that the impact of macroeconomic variables would affect the CO_2 emissions

The first contribution of this study is that it examines whether demographic factors influence travel distances. Previous studies reached mixed conclusions about the relationship between socio-demographic variables and travel distances. Goodwin, Dargay, and Hanly, 2003 stated that traffic volumes would decrease with a 10% increase in real income. On the other hand, Stapleton, Sorrell, and Schwanen, 2017b found that income does not have a significant impact on travel distances in the United Kingdom, and Ding et al., 2017 mentioned that high income and the number of children in the family are positively correlated with vehicle miles traveled. Therefore, previous studies mostly focus on the impact of income, whereas there are many other factors to consider. In light of this, this study contributes to the travel distance literature by investigating diverse variables (gender, education, car ownership, vehicle attributes, and region). From this perspective, this study follows Yang, C. Wang, and Wenling Liu, 2018, who found that gender, income, car usage intensity, car ownership, and age are highly correlated with being a high emitter in terms of daily travel. They then calculated the emissions in China and examined what mode of transportation contributes to emissions the most. Expanding the work of Yang, C. Wang, and Wenling Liu, 2018, this study contributes to the literature by exploring the period from 2011 to 2015 in Japan and extensively investigating travel behavior in this extended period, focusing on private vehicles. Furthermore, the investigation is focused on what affects personal driving distances, rather than on a mode shift. This study also considers travel purposes as defined by Luo et al., 2017, who mentioned that work patterns are vital for taxi drivers' travel distances.

The second contribution of this study is that it calculates the direct rebound effects in travel distance and explicitly investigates their relation to demographic features, hybrid

from the transportation sector. However, in the case of Japan, population, the spatial distribution of urban centers, GDP, characteristics of the industrial sectors, logistic demands, design of roads and highways have not changed significantly compared to 2006 to 2016. In contrast, the fuel economy level of Japanese cars skyrocketed 23% in a simple average, and 40% in a weighted average. Therefore, in this study, this study focus on vehicle fuel economy levels.

interest, and ownership. As mentioned in Spielmann, P. d. Haan, and W.Scholz, 2008, although a car is highly fuel-economical, a rebound occurs because a lower fuel cost induces higher fuel usage. Small and Dender, 2007 used US panel data from 1961 to 2001 to estimate that the long-run rebound effect of fuel costs in the US transportation sector was 22%. D. L. Greene, 2012 examined the rebound effect of fuel costs during the same period and obtained an almost identical rebound effect of 23%. Borger, Mulalic, and Rouwendal., 2016 estimated a rebound effect of 7.5–10% in Denmark's transportation sector due to fuel prices. Weisheng Liu, Y. Liu, and Lin, 2018 also evaluated the rebound effect on travel distances for passenger transportation in China to be approximately 65%. As the size of the rebound effect varies by study, calculating the size of this effect would contribute to the rebound effect literature. Furthermore, as previous studies focus on the rebounds due to the macro-economic scale (i.e., the impact of financial incentives for reducing fuel consumption), this study further contributes by introducing travel distance into the rebound literature and by investigating micro-level rebounds through conducting a survey.

Specifically, this study used a survey to estimate factors affecting travel distances to understand travel behavior and derive policy implications. This study conducted surveys in Tokyo in 2011, 2013, and 2015. this study acquired data on socio-demographic factors (age, gender, and income), travel purpose (commute, leisure, and vacation), vehicle type (light-duty vehicle vs. hybrid), and hybrid interest.

4.2 Motivation of Investigating Travel Distances

Over the past two decades, the fuel efficiency of automobiles has improved significantly due to the development of new technologies such as hybrid engines.

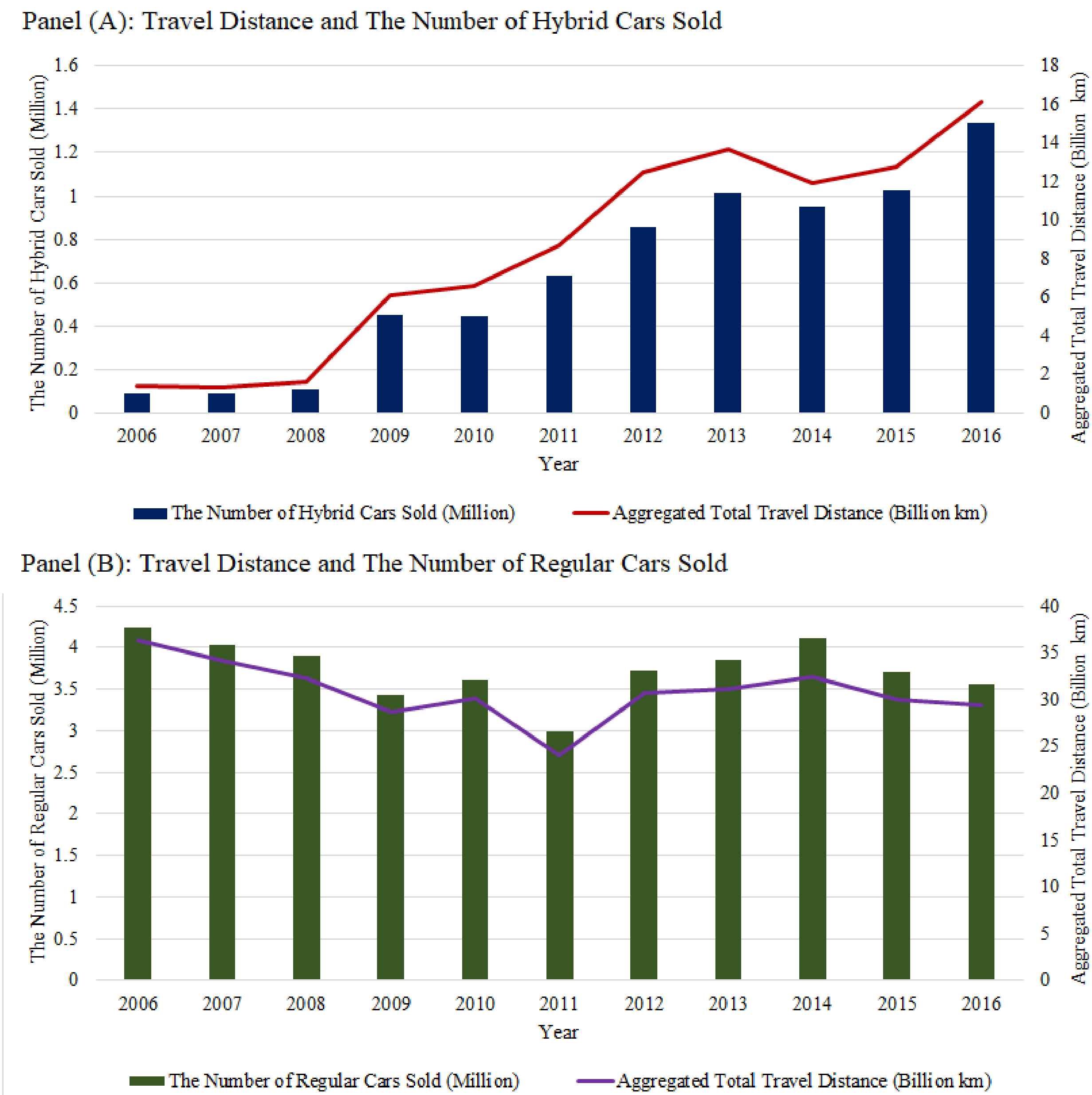

Figure 4.1 The Number of Hybrid and Regular Cars Sold and Aggregated Travel Distances

Data Source: Average fuel economy data are from the Japan Automobile Manufacturer Association, and travel distance data and travel distance inequality data are from the Japanese Ministry of Land, Infrastructure, Transport, and Tourism.

Figure 4.1 shows the relationship between the number of hybrid passenger cars and regular cars sold in Japan and the aggregate total travel distances.[2] Compared to regular cars,

[2]To obtain aggregate total travel distance, this study multiplies the number of cars sold by the annual

hybrid vehicles show a rapidly increasing trend from 2006 to 2016. Figure 4.1 further indicates that travel distance did not decrease in tandem with fuel economy improvements from the year 2006 to 2016 in Japan, because hybrid cars, which show an average fuel economy level of approximately 30-40 km/l, show more considerable travel distances than regular vehicles, which have an average fuel economy level of approximately 16 km/l[3]. Although the fuel economy level increases, if the travel distance does not stay constant or decrease, fuel consumption would not fundamentally decrease. Therefore, this study expects the proliferation of hybrid vehicles to be one of the factors causing the increase in travel distances.

This observation also indicates that fuel economy improvements alone cannot guarantee a reduction in fuel usage; instead, factors other than fuel economy affect travel distances, and this study seeks to explain travel patterns through individual characteristics (income level, age, gender, travel purposes, and hybrid interest). Furthermore, this study adds hybrid interest in the model, expecting that a high level of hybrid interest decreases individuals' travel distances. The trend suggests that to explore ways to prevent rebounds, this study should investigate factors affecting travel distances other than mere fuel economy improvements.

Fuel Economy Standards

The Japanese government allowed cars with high fuel efficiency to be exempted from taxation to promote fuel-efficient cars. Furthermore, the government implemented a subsidy program in 2009 for cars with high fuel efficiency levels, lighter weights, and small displacements. [4]

travel distance. Hybrid vehicles refer to cars that do not belong to the light-duty vehicle category and are equipped with a hybrid engine. On the other hand, regular cars in Japan relates to cars other than hybrid vehicles, which do not belong to the light-duty vehicle category.

[3]Both of fuel economy are from 2006 to 2016, in Japan

[4]Subsidy amounts are determined by how much the fuel economy level exceeds the fuel economy standards of the target year. For example, if a car has a fuel economy level that is 40% higher than the 2020 fuel economy standard, a consumer purchasing the vehicle would obtain a full tax exemption. If a car's fuel economy level is 30% higher than the 2020 fuel economy standards, the vehicle would be eligible to receive an 80% reduction in car tax. Further, if a car has a fuel economy level equal to the 2020 fuel economy standard, the consumer will obtain a 20% car tax reduction.

As a result, hybrids and light-duty vehicles[5] are more likely to receive financial subsidies than regular vehicles. As a result, hybrid and light-duty vehicles have been gaining popularity in the Japanese automobile markets. For example, the total number of hybrid vehicles sold in Japan has continuously increased from 74,183 in 2002 to 6,568,960 in 2017, according to the Japanese Ministry of Land, Infrastructure, and Transport, and the share of light-duty vehicles in Japan is approaching almost 40% of the new car market.

Fuel Tax in Japan

The Japanese government implemented a fuel tax (gasoline tax) based on the analysis that reducing travel distances would be an essential way to reduce the transportation sector's dependency on gasoline and the sector's emissions. The Japanese government expected the fuel tax to indirectly decrease travel distance by increasing the drivers' financial burdens. However, some previous studies indicated that improved fuel efficiency would increase the number of car owners as well as travel distances. Vivanco, Freire-González, et al., 2014 argued that the environmental rebound effect of electric cars could outweigh the environmental benefit the technology provides. Other researchers explained that the use of hybrid vehicles would increase fuel usage (Kagawa et al., 2013, W. Li and Kamargianni, 2018, Hamamoto, 2019) and even the number of automobiles might increase, as consumers are induced to replace their cars with a Prius (P. d. Haan, G.Mueller, and Peters., 2006).

If the rebound effect persists in the Japanese transportation sector, this study can expect smaller reductions in fuel consumption and traveled distances from the transportation sector. Furthermore, to achieve a more aggressive impact on the transportation sector, a combination of vehicle-related subsidies and fuel taxes is required (Tanishita, Kashima, and Hayes, 2003, Bjertnæs, 2019). Taxation is also one of the policy pathways (Vivanco, Kemp, and Voet,

[5]Light-duty vehicles refer to small-sized cars with a displacement level of 660 cubic centimeters or less. Light-duty vehicles have approximately 34.75% lighter weights on average than regular cars (Ministry of Land, Infrastructure, Transport, and Tourism, Japan)

2016) beyond behavior adjustment and eco-innovation. The current Japanese gasoline tax rate is JPY 53.8 per liter. As this study has observed increasing travel distances and a stagnant fuel tax after the introduction of hybrid vehicles, this study assumes that taxes may affect traveled distances, as increasing the fuel tax would increase the price of fuel, resulting in reduced fuel consumption and smaller traveled distances.

4.3 Data and Methodology

4.3.1 Survey on Travel Distances

This study used a "repeated cross-sectional" dataset, which contains information on each respondent for three years: 2011, 2013, and 2015. The analysis focuses on Japan, which consists of 47 different prefectures with different demographics. This study uses three survey data sets in this study. The first main data set is from a 2011 Internet questionnaire survey, conducted from November 18th to November 22nd, 2011 (East Japan), and from December 7th to December 16th, 2011 (West Japan) (Survey 1). The Survey for the second data set was conducted from November 26th to November 28th, 2013 (Survey 2). The third data set is from a 2015 survey (Survey 3) conducted from November 18th to November 19th, 2015, through an Internet questionnaire.

The Survey included questions on three categories. First, this study asked the weekly travel distances, dividing them into weekdays and weekends. After that, this study asked the respondents to state the main travel purposes of their weekday and weekend trips. Travel purposes consisted of commute, shopping, going to the hospital, leisure, taking family members to school or station, and others.

Before asking detailed travel distance questions, this study asked questions to screen out the respondents who were not eligible to participate in the Survey. In every Survey, this study first asked about the car ownership and excluded those without a car. Second, in Survey 2, this study excluded people who had not decided whether to buy a car. Third, in Survey 3, this study asked whether the respondent was fully aware of his/her annual travel distance and excluded those who could not provide accurate information about it. However, it is natural that ordinary people would not be aware of their precise annual travel distances. Therefore, for a more accurate estimation of annual travel distances regardless of the differences in the data collection methods of Surveys 1, 2, and 3, in Surveys 1 and 2, this study asked respondents about their weekday and weekend travel distances. Then, this study calculated annual travel distances by summing the results of the two products. The first product was the number of weekdays in a year multiplied by the weekday travel distances, and the second one was the number of weekends in a year multiplied by the weekend travel distances. This method increases the precision of the collected data. Examples of travel distance questions are provided in Appendix Figure A1.

Second, the respondents were required to provide demographic details, including their age, income, gender, jobs, and their prefecture of residence. Third, in 2011 and 2013, respondents were asked about their vehicle attributes and their hybrid interest. To assess this interest, this study directly asked respondents about their degree of interest in hybrid vehicles, on a scale of 1 to 6 in 2011, and a scale of 1 to 4 in 2013. For example, people rated their interest as "6" in 2011 had the highest interest in purchasing hybrid cars, and likewise for people rating their interest as "4" in 2013. this study created a "hybrid interest" dummy variable to represent the people who were highly interested in purchasing hybrid vehicles, for those choosing "5" or "6" in 2011 and "3" or "4" in 2013. this study does not have information about hybrid interest in Survey. Therefore, the analysis of hybrid interest uses the data between 2011 and 2013. However, as Survey 3 still contains detailed driver information, including demographics, travel purposes, and vehicle types, it can also provide meaningful implications.

Table 4.1 presents the list of main variables measured by the three surveys. For each

Table 4.1 Variable List

	Description	2011	2013	2015
Travel Distance per Year (km)	Yearly Travel Distances	√	√	√
Average Fuel Economy (km/l)	Fuel Economy Level	√	√	√
Total Fuel Usage	Travel Distance per Year*(1/Average Fuel Economy)	√	√	√
Travel Purpose	Main Travel Purposes	√	√	√
Gender	A Respondent's Gender	√	√	√
Age	A Respondent's Age	√	√	√
Job	A Respondent's Job	√	√	√
Region	Region that Respondents Reside	√	√	√
Hybrid Ownership	Hybrid Vehicle Ownership	√	√	√
Hybrid Interest	Interest towards Hybrid Cars	√	√	

Table 4.2 Descriptive Statistics

	N	Mean	Std. Dev.	Min.	Max.
Year 2011: Survey 1					
Travel Distance per Year (km)	9,373	7735.698	7529.646	1825	54,750
Yearly Income (10,000 JPY)	9,406	580.9909	344.835	100	2,250
Age	11,224	44.563	13.533	18	87
Gender (=1 if Female)	11,224	0.478	0.450	0	1
Year 2013: Survey 2					
Travel Distance per Year (km)	997	7,650.451	5,372.886	2,500	25,000
Yearly Income (10,000 JPY)	1,028	686.897	366.689	50	1,750
Age	1,028	48.901	11.285	22	82
Gender (=1 if Female)	1,028	0.235	0.424	0	1
Year 2015: Survey 3					
Travel Distance per Year (km)	993	9,493.454	6,299.818	1,000	35,000
Yearly Income (10,000 JPY)	1,000	742.699	396.6	0	1,625
Age	1,000	50.142	10.980	20	79
Gender (=1 if Female)	1,000	0.113	0.317	0	1

variable, this study indicates the survey years it appeared in. All the variables appear in all survey years, except for hybrid interest, which does not appear in 2015. Table 4.2 shows the descriptive statistics for travel distance and the demographic data obtained in the surveys. First, the data show that the portion of female respondents decreased from 2011 to 2015, as 47.8%, 23.5%, and 11.3% of the respondents were female in 2011,2013, and 2015, respectively[6]

[6] According to the Japanese Passenger Car Market Trend Survey (2015) conducted by the Ministry of Land, Transport, and Infrastructure, women exhibit the general trend of focusing on travel purposes rather than distances and prefer public transportation systems compared to men. This may be one of the reasons for the gender split.

This study also added a dummy variable for the rural area, as some previous studies have indicated that travel distances in rural areas are more significant than in cities (Polzin, Chu, and Godfrey, 2014) due to the lack of a public transportation system in the former (Kasraiana, Maat, and Wee, 2018, Ralph et al., 2016). Further, the relatively low level of congestion in rural areas compared to that in urban areas (Robert B Noland, 2011) eventually leads to the consumption of less gasoline (Wadud, Graham, and Robert B. Noland, 2010). This study regarded prefectures, whose primary industry is agriculture as rural areas, and 19 such prefectures were found. This was done considering that no clear classification of urban and rural areas exists. A detailed description of the rural areas is provided in Appendix Table A.1.

4.3.2 Limitation of Survey

Although the sample size of the surveys is large, and the samples contain useful information, the data have a limitation. this study acknowledges that the sample sizes of the data sets are unbalanced: the 2011 survey has over 10,000 observations, whereas other years have approximately 1,000 observations.

Hence, to provide reliable estimates, this study uses the year-fixed effects to control for the annual differences in variables and divided model into five categories according to the years. Furthermore, This study separately analyzes the results of the 2011 and 2013 surveys. If these results are consistent with the main results in Table 4.4, this study can infer that the results are consistent and reliable.

Another possible limitation of the survey is that this study merged the data from three different surveys. Therefore, their information might be inconsistent. However, although this study merged the data from three separate surveys, the questions and answer options were identical, except for hybrid interest. As the other relevant variables (i.e., demographics, travel distance, and vehicle attributes) are the same, this study believes the survey method is consistent and, thus, the estimates are reliable. Therefore, the estimation results can provide meaningful implications for policymakers aiming to design transportation-related policies.

4.3.3 Empirical Strategy of Investigating Factors Affecting Travel Distance

The objective of this study is to evaluate the statistical relationship between travel distances and income level, hybrid interest, travel purpose, demographic data, car ownership, and vehicle attributes. The identification strategy uses a log-log form of nonlinear regression. This study uses a repeated-cross sectional data on a multi-country sample and the following model as in equation 4.1

$$\ln TD_{it} = \alpha_0 + \boldsymbol{\beta_1} * \boldsymbol{D_{it}} + \beta_2 * I_{it} + \beta_3 * dOwnership_{it} \tag{4.1}$$
$$+\beta_4 * P_{it} + \beta_5 * dRural_{it} + \beta_6 * Gender_{it} + \boldsymbol{\beta_7} * \boldsymbol{Age_{it}} + \xi_i + \theta_t + \epsilon_{it}$$

where TD_{it} is the travel distance of respondent i in year t, $\boldsymbol{D_{it}}$ is a vector indicating a consumer's income, which is classified into two groups: high-income (people in the top 10% income group), and the low-income (people in the bottom 10% income group). I_{it} is a dummy variable for "hybrid interest," which equals 1 if a person is interested in hybrid vehicles. $dOwnership_{it}$ is a dummy variable that equals 1 if a person owns a hybrid vehicle. $\boldsymbol{P_{it}}$ is a travel purpose vector representing the following categories: commute, travel, and shopping. $dRural_{it}$ is a dummy variable that equals 1 if a prefecture is considered a rural area. $\boldsymbol{Age_{it}}$ is a vector for age group and $Gender_{it}$ is a dummy variable that equals 1 if a respondent is female. ξ_i represents the region fixed effects, θ_t denotes the year fixed effects, and ϵ_{it} is the error-term. This study includes region and year fixed effects to control for characteristics that can affect the estimates, because travel behaviors may differ according to the region and year. Particularly, region fixed effects can account for time-invariant factors that affect travel distance, for example, automobile ownership in the different regions of Japan. As this study has diverse interaction terms between the income, age, and region variables, summary lists of variables are shown in Table 4.3. Coefficients were estimated for 20 variables aggregated in five types: income level, hybrid interest, travel purpose, vehicle type, and demographics, as shown in Table 4.3. The variety of variable types that enter the model demonstrates that the factors affecting travel distance are nuanced—travel distance is not only influenced by income level but also by hybrid interest, travel purpose, vehicle type, and demographics.

Table 4.3 Variable Descriptions

Variable	Notation	Description
Income Level	$\boldsymbol{D_{it}}$	
Household Income		Income of a household (Million Yen)
Top Income Dummy		=1 if a person has the top 10% income level each year
Low Income Dummy		=1 if a person has the bottom 10% income level each year
Hybrid Interest	I_{it}	
Hybrid Interest		A degree that a person is interested in hybrid vehicle
Hybrid Interest with Ownership		=1 if a person is interested in hybrid vehicle, and owns a hybrid car
Hybrid Interest without Ownership		=1 if a person is interested in hybrid vehicle, and does not own a hybrid car
Hybrid Interest with Top Income		=1 if a person is interested in hybrid vehicle, and belongs to Top income group
Hybrid Interest with Low Income		=1 if a person is interested in hybrid vehicle, and belongs to low income group
Travel Purpose	$\boldsymbol{P_{it}}$	
Commute		=1 if a person commutes by the car
Shopping		=1 if a person goes shopping by the car
Leisure		=1 if a person goes trip/ leisure activity by the car
Vehicle Type		
Hybrid Ownership		=1 if a person have owned a hybrid car
Top Income & Hybrid Ownership		=1 if a person belongs to Top Income group and owns a hybrid car
Low Income & Hybrid Ownership		=1 if a person belongs to Low Income group and owns a hybrid car
Demographics		
Rural Area	$Rural_{it}$	=1 if Rural Area
Gender		=1 if female
Age		a respondent's age.
Age Under 30		=1 if a respondent's age is under 30.
Age Over 30 Under 60		=1 if a respondent's age is under 60 and over 30.
Age Over 60		=1 if a respondent's age is over 60.

‘Travel distance’ is set as a main dependent variable and ‘Total fuel usage’ as an alternative dependent variable and estimate factors affecting two dependent variables through regression models. These models are set to investigate not only the policy implications but also the impacts of diverse factors (i.e., income, hybrid interest, and hybrid vehicle ownership) towards travel distances.

4.4 Model Estimation Result of Factors Affecting Travel Distance

4.4.1 Estimation Result of Factors Affecting Travel Distance

Table 4.4 shows the estimation result. This study has five models for each result, and these five models are classified into different specifications and years. For example, as the surveys do not have information for hybrid interests in the year 2015, this study estimate Model (1), which only takes into account the income level and demographics to the estimation to investigate the whole year (2011, 2013 and 2015). From Model (2), this study focus estimating variables of the year 2011 and 2013, which adds variables related to vehicle type and demographics from Model (1), Model (3) includes hybrid interest to Model (2), and Model (4) adds travel purposes to Model (3). Model (5) is a full model. Every Model includes region fixed effects and year fixed effects. Regardless of specifications and data availability, this study finds the results are robust from Model (1) to Model (5). Therefore, this study focuses on Model (5), the full Model. Even though R-squared is low for the models, this is typical of repeated cross-sectional data as they usually are around 0.1.

Income Effect First, the results indicate the positive relationship between household income and travel distances, which means that the rich drive more than the poor. For example, model (5) shows a positive coefficient of 0.088 for a 1% increase in household income.

On the other hand, according to model (5), this study finds that people in the top 10% income group are negatively correlated to the travel distance by 2.3% compared to the people not in the top-income group. Although this study did not find a statistically significant result for low-income people, the results imply that the travel distances of Japanese people increase with income level while people in the top 10% of income levels may exhibit smaller travel distances than those who do not belong to the high-income group.

Hybrid interest The results provide evidence that the rebound effect exists, even if a person is interested in purchasing a hybrid. The results show that having an interest in, but not owning a hybrid car, has a negative relationship with travel distance, with a coefficient of approximately -0.15. This suggests that people purchasing hybrids are mainly doing so due to the hybrids' fuel-saving function, which allows them to drive more. Further, this means that rather than improving hybrid interest, focusing on increasing hybrid ownership would decrease travel distances, because the results indicate that the travel distance depends more on actual hybrid ownership than on having an interest in hybrid vehicles.

Vehicle Type The estimated coefficients provide clear evidence that hybrid ownership is positively correlated with travel distances. The estimate is approximately 0.198 in model (5), which this study believes is likely because of the fuel cost-saving function of hybrid cars. The results also show that hybrid ownership in the low-income group is positively correlated to travel distances, with the corresponding estimates ranging from 0.471 to 0.575 between model (1) and model (5). This shows that there are differences in the purposes of purchasing hybrid vehicles by income group, as people in the low-income group are likely to purchase hybrid cars to save on fuel costs, which encourages them to drive more.

Demographics and Travel Purpose The results imply that older people (people older than 60) show lower coefficient than younger people, and gender differences in travel distance as estimates suggest that males drive more than females. For travel purposes, this study also finds that the average Japanese person, regardless of income level or region, drives more for commute and leisure than for shopping.

4.4.2 Consistency of the Survey Data

As the data set is consisted of different numbers of observations, one might think the results would change if the number of observations changes, for example, if the number of observations in the year 2013[7] and 2015 were the same as the year 2011 or vice versa[8]. Therefore, this study checks the consistency of the results; that is, this study seeks to confirm that the result would not change according to the year settings. Models of the year 2011 and the 2013 data were individually analyzed, and compared with overall results. If the estimates are close the Table 4.4, the findings are consistent.

Table 4.5 shows estimates of equation 4.1, only after taking observations of year 2011. Results in Table 4.5 are consistent to the results in Table 4.4. Similarly, Table 4.6 provide the consistent results as in Table 4.4.

Table 4.4 Estimation Result

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Income Level (D_{it})					
ln (Income)	0.100*	0.092*	0.091*	0.088*	0.088*
	(.026)	(.028)	(.028)	(.028)	(.028)
Top Income Dummy * ln(Income)	0.0003	0.001	-0.001	-0.020*	-0.023*
	(.004)	(.005)	(.006)	(.008)	(.009)
Low Income Dummy * ln(Income)	0.004	0.002	0.001	-0.016	-0.016
	(.011)	(.012)	(.015)	(.021)	(.023)

[7] For people in 2013, hybrid interest has been omitted out due to its collinearity with I_{it} *No Ownership

[8] This study does not include analysis dealing with the year 2015 in this Subsection, as the survey data do not have many control variables as in the data.

Hybrid Interest (I_{it})				
I_{it}		0.129	0.143+	0.132
		(.084)	(.082)	(.083)
I_{it} *No Ownership		-0.146+	-0.156+	-0.152+
		(0.084)	(0.083)	(0.083)
I_{it} * Top Income		0.028		0.034
		(.043)		(.043)
I_{it} * Low Income		0.010		0.04
		(.070)		(.070)
Travel Purpose (P_{it})				
Top Income* Commute			0.290*	0.290*
			(.040)	(.040)
Top Income* Shopping			-0.151*	-0.151*
			(.046)	(.046)
Top Income* Leisure			0.290*	0.290*
			(.040)	(.040)
Low Income* Commute			0.293*	0.293*
			(.067)	(.067)
Low Income* Shopping			-0.197*	-0.198*
			(0.083)	(.083)
Low Income* Leisure			0.248*	0.248*
			(.070)	(.070)
Vehicle Type				
Top Income* Hybrid Ownership	0.011	-0.006	-0.044	-0.044
	(.090)	(.090)	(.090)	(.091)
Low Income* Hybrid Ownership	0.575*	0.570*	0.472*	0.471*
	(.216)	(.216)	(.217)	(.217)
Hybrid Ownership	0.248*	0.182*	0.197*	0.198*
	(.052)	(.064)	(.067)	(.067)
Rural Area* Hybrid Ownership			-0.080	-0.081
			(.104)	(.104)

Demographics					
Rural Area	-0.017	0.084	0.085	0.091	0.090
	(.149)	(.187)	(.187)	(.186)	(.186)
Gender	-0.172*	-0.170*	-0.170*	-0.162*	-0.162*
	(.018)	(.018)	(.018)	(.018)	(.018)
ln (Age)	0.028	0.048	0.048	0.069	0.069
	(.052)	(.055)	(.055)	(.055)	(.055)
Age Under 30	0.025	0.015	0.017	0.004	0.005
	(.079)	(.085)	(.085)	(.084)	(.084)
Age Over 30 Under 60	-0.058	-0.075	-0.074	-0.072	-0.071
	(.063)	(.069)	(.069)	(.068)	(.068)
Age Over 60	-0.126+	-0.151+	-0.149+	-0.147*	-0.145*
	(.064)	(.070)	(.070)	(.069)	(.069)
Constant	8.483*	8.308*	8.361*	8.274*	8.279*
	(.291)	(.319)	(.321)	(.319)	(.319)
Fixed Effects					
Region FE	√	√	√	√	√
Year FE	√	√	√	√	√
N	9,727	8,852	8,852	8,852	8,852
R^2	0.049	0.042	0.042	0.058	0.058

Note: Standard errors in the parentheses. + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Table 4.5 Estimation Result: Year 2011

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Income Level (D_{it})					
ln (Income)	0.095*	0.087*	0.086*	0.085*	0.084*
	(.031)	(.031)	(.031)	(.031)	(.031)
Top Income Dummy * ln(Income)	0.001	0.001	-0.001	-0.020*	-0.021*
	(.004)	(.005)	(.006)	(.008)	(.009)
Low Income Dummy * ln(Income)	0.004	0.002	0.002	-0.018	-0.017
	(.013)	(.013)	(.016)	(.022)	(.025)

Hybrid Interest (I_{it})				
I_{it}		0.151	0.155	0.148
		(.104)	(.102)	(.103)
I_{it} *No Ownership		-0.157	-0.158	-0.155
		(0.104)	(0.104)	(0.104)
I_{it} * Top Income		0.027		0.024
		(.048)		(.048)
I_{it} * Low Income		-0.001		-0.006
		(.074)		(.074)
Travel Purpose (P_{it})				
Top Income* Commute			0.289*	0.289*
			(.044)	(.044)
Top Income* Shopping			-0.138*	-0.138*
			(.048)	(.048)
Top Income* Leisure			0.289*	0.289*
			(.044)	(.044)
Low Income* Commute			0.300*	0.299*
			(.071)	(.071)
Low Income* Shopping			-0.198*	-0.199*
			(0.086)	(.086)
Low Income* Leisure			0.229*	0.230*
			(.074)	(.074)
Vehicle Type				
Top Income* Hybrid Ownership	-0.036	-0.060	-0.083	-0.086
	(.106)	(.107)	(.107)	(.107)
Low Income* Hybrid Ownership	0.463+	0.460+	0.389	0.388
	(.256)	(.256)	(.258)	(.258)
Hybrid Ownership	0.284*	0.187*	0.196*	0.198*
	(.062)	(.089)	(.095)	(.091)
Rural Area* Hybrid Ownership			-0.044	-0.045
			(.119)	(.119)

Demographics					
Rural Area	0.226	0.229	0.228	0.236	0.235
	(.169)	(.168)	(.168)	(.167)	(.167)
Gender	-0.162*	-0.161*	-0.161*	-0.154*	-0.1542*
	(.019)	(.019)	(.019)	(.019)	(.019)
ln (Age)	0.106+	0.099+	0.99+	0.118*	0.118*
	(.059)	(.059)	(.059)	(.059)	(.059)
Age Under 30	0.065	0.067	0.068	0.052	0.053
	(.091)	(.091)	(.091)	(.090)	(.090)
Age Over 30 Under 60	-0.055	-0.049	-0.048	-0.049	-0.048
	(.074)	(.073)	(.073)	(.073)	(.073)
Age Over 60	-0.126+	-0.127+	-0.128+	-0.125+	-0.125+
	(.075)	(.074)	(.074)	(.074)	(.074)
Constant	7.865*	7.934*	7.938*	7.863*	7.866*
	(.326)	(.325)	(.326)	(.323)	(.324)
Fixed Effects					
Region FE	√	√	√	√	√
N	7,919	7,919	7,919	7,919	7,919
R^2	0.033	0.037	0.038	0.052	0.052

Note: Standard errors in the parentheses. + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Table 4.6 Estimation Result: Year 2013

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Income Level (D_{it})					
ln (Income)	0.117+	0.124+	0.103	0.077*	0.074*
	(.069)	(.069)	(.069)	(.069)	(.069)
Top Income Dummy * ln(Income)	0.008	0.003	0.001	-0.0248	-0.030
	(.011)	(.012)	(.012)	(.033)	(.033)
Low Income Dummy * ln(Income)	0.063+	0.050	0.020	0.055	0.016
	(.036)	(.036)	(.044)	(.0108)	(.119)
Hybrid Interest (I_{it})					

I_{it} *No Ownership			-0.190*	-0.161*	-0.200*
			(0.057)	(0.055)	(0.064)
I_{it} * Top Income			0.122		0.128
			(.133)		(.131)
I_{it} * Low Income			0.312		0.226
			(.268)		(.278)
Travel Purpose (P_{it})					
Top Income* Commute				0.268*	0.266*
				(.092)	(.092)
Top Income* Shopping				-0.313	-0.307
				(.206)	(.206)
Top Income* Leisure				0.514*	0.517*
				(.108)	(.108)
Low Income* Commute				0.435	0.378
				(.287)	(.299)
Low Income* Shopping				-0.441	-0.346
				(0.493)	(.510)
Low Income* Leisure				0.459+	0.480+
				(.250)	(.251)
Vehicle Type					
Top Income* Hybrid Ownership		0.159	0.197	0.085	0.120
		(.159)	(.162)	(.157)	(.161)
Low Income* Hybrid Ownership		0.821*	0.903*	0.476	0.599
		(.378)	(.389)	(.413)	(.443)
Hybrid Ownership		0.189*	0.133	0.189*	0.176+
		(.085)	(.087)	(.090)	(.090)
Rural Area* Hybrid Ownership				-0.306	-0.308
				(.216)	(.216)
Demographics					
Rural Area	0.267	0.368	0.543	0.567	0.598
	(.847)	(.841)	(.841)	(.822)	(.823)

Gender	-0.286*	-0.286*	-0.281*	-0.260*	-0.257*
	(.058)	(.058)	(.057)	(.056)	(.056)
ln (Age)	-0.441*	-0.434*	-0.433*	-0.393*	-0.388*
	(.160)	(.158)	(.158)	(.155)	(.155)
Age Under 30	-0.273	-0.298	-0.296	-0.286	-0.264
	(.258)	(.255)	(.255)	(.249)	(.250)
Age Over 30 Under 60	-0.263	-0.286	-0.257	-0.276	-0.255
	(.200)	(.199)	(.198)	(.194)	(.195)
Age Over 60	-0.287	-0.340+	-0.303	-0.348+	-0.321
	(.200)	(.199)	(.199)	(.194)	(.196)
Constant	10.86*	10.73*	10.83*	10.80*	10.78*
	(.912)	(.907)	(.905)	(.892)	(.893)
Fixed Effects					
Region FE	√	√	√	√	√
N	933	933	933	933	933
R^2	0.129	0.148	0.157	0.198	0.199

Note: Standard errors in the parentheses. + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

4.4.3 Alternative Specifications on Fuel Usages

In this subsection, this study takes an alternative variable, "TFU", as a dependent variable, and estimate the same model as in equation 1. As TFU would move together with emissions and total fuel costs, investigating whether factors increasing travel distances also increase TFU is necessary. If factors increasing travel distance (i.e., hybrid vehicles) also increase TFU, this would provide evidence for a negative environmental externality affecting travel distances, which, in turn, offsets the potential positive environmental externalities of fuel economy improvements. Therefore, following (Clerides and Zachariadis, 2008 and Yoo et al., 2019b), this study calculates TFU from driving and use it as an alternative variable, defined as

$$TFU_{it} = TD_{it} * (1/E_i) \tag{4.2}$$

where TD_{it} is the travel distance of respondent i at year t, and E_i represents the fuel economy of the automobile owned by respondent i. Table 4.7 presents the estimation results when TFU is used as a dependent variable. For 2011, this study use vehicle displacement data as a proxy for fuel economy data. This study refers to a previous Japanese study, a survey conducted by Iwaki, Ishiyama, and Yamashita, 2015, which discovers that the average fuel economy level varies according to the displacement level. However, as it is necessary to prove that travel distances might increase the TFU, this study calculates the overall fuel usage according to the estimated fuel economy level and add it as an alternative specification.

Evidence and Size of Rebounds Similar to the results given in Table 4, this study finds several pieces of evidence supporting the existence of fuel usage rebounds. First, the results indicate that income level is positively related to TFU: high-income people drive less, which results in lower fuel usage. The results indicate that a 1% increase in income is positively correlated to the increase in fuel usage by 20.2%. Hence, according to model (5), high-income people show the negative coefficient of -0.018.

Second, this study finds that hybrid vehicle owners in the low-income group may exhibit a higher level of fuel usage. This proves that the increase in hybrid owners' travel distances would nullify the effect of the improved fuel economy and, in the end, result in more fuel being used. On the other hand, this study finds that hybrid owners other than those in the low-income group use less fuel, which shows that hybrid vehicles' better fuel economy reduces the TFU. The results suggest that hybrid car drivers belonging to the low-income group use 83.3% (a coefficient of 0.606) more fuel than those who are not hybrid vehicle owners and do not belong to the low-income group, as the coefficient's values range from 0.606 to 0.701.

However, this study also finds that hybrid owners use 30.0% (a coefficient of -0.262) less fuel than people who do not own hybrid cars, according to model (5). Most of the results are the same as in the case of travel distance estimation, except that hybrid ownership shows the opposite results. Third, this study finds that the TFU increases when people commute and take trips rather than when they go shopping, regardless of the income group. As regards to the demographic variables, this study finds that females exhibit 20.804% lower fuel usage than males (a coefficient of -0.189), and people older than 60 years old have 36.615% lower fuel usage than people who are younger than the age of 60 (a coefficient of -0.312).

Table 4.7 Alternative Specification Result

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Income Level D_{it}					
ln (Income)	0.292*	0.207*	0.206*	0.202*	0.202*
	(.028)	(.030)	(.030)	(.030)	(.030)
Top Income Dummy * ln(Income)	-0.002	-0.001	-0.003	-0.016*	-0.018*
	(.005)	(.005)	(.006)	(.008)	(.009)
Low Income Dummy * ln(Income)	0.015	0.019	0.019	0.003	0.004
	(.011)	(.013)	(.016)	(.022)	(.025)
Hybrid Interest (I_{it})					
I_{it}			0.101	0.113	0.104
			(.087)	(.088)	(.107)
I_{it} *No Ownership			-0.089	-0.099	-0.096
			(0.889)	(0.881)	(0.883)
I_t * Top Income			0.023		0.028
			(.046)		(.046)
I_{it} * Low Income			0.003		-0.006
			(0.074)		(.074)
Travel Purpose (P_{it})					
Top Income* Commute				0.279*	0.280*
				(.043)	(.043)

Top Income* Shopping				-0.217*	-0.216*
				(.049)	(.049)
Top Income* Leisure				0.279*	0.280*
				(.049)	(.049)
Low Income* Commute				0.277*	0.277*
				(.071)	(.071)
Low Income* Shopping				-0.196+	-0.197+
				(0.088)	(.088)
Low Income* Leisure				0.230*	0.231*
				(.075)	(.075)
Vehicle Type					
Top Income* Hybrid Ownership		-0.045	-0.058	-0.093	-0.093
		(.095)	(.096)	(.096)	(.096)
Low Income* Hybrid Ownership		0.701*	0.699*	0.607*	0.606*
		(.229)	(.229)	(.230)	(.230)
Hybrid Ownership		-0.225*	-0.265*	-0.263*	-0.262*
		(.055)	(.068)	(.072)	(.072)
Rural Area* Hybrid Ownership				-0.028	-0.029
				(.111)	(.111)
Demographics					
Rural Area	-0.073	-0.021	-0.018	-0.028	-0.028
	(.158)	(.166)	(.166)	(.165)	(.165)
Gender	-0.205*	-0.198*	-0.198*	-0.189*	-0.189*
	(.019)	(.019)	(.019)	(.019)	(.019)
ln (Age)	-0.014	-0.012	0.012	0.032	0.032
	(.056)	(.058)	(.058)	(.058)	(.052)
Age Under 30	-0.035	-0.087	-0.085	-0.084	-0.083
	(.067)	(.073)	(.073)	(.072)	(.072)
Age Over 30 Under 60	-0.035	-0.087	-0.085	-0.084	-0.083
	(.067)	(.073)	(.073)	(.072)	(.072)
Age Over 60	-0.104	-0.136+	-0.136+	-0.133+	-0.312+

	(.068)	(.074)	(.074)	(.073)	(.073)
Constant	5.351*	5.199*	5.207*	5.120*	5.124*
	(.305)	(.324)	(.324)	(.322)	(.322)
Fixed Effects					
Region FE	√	√	√	√	√
Year FE	√	√	√	√	√
N	9,635	8,772	8,772	8,772	8,772
R^2	0.119	0.080	0.081	0.095	0.095

Note: Standard errors in the parentheses. + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

4.4.4 Correlation Analysis

The independent variables in the model might be correlated, as high-income people are more likely to be able to afford the expensive prices of hybrid vehicles than people from low-income groups. Therefore, this study test the sensitivities of the independent variables with respect to the dependent variable, excluding the interaction terms.

Table 4.8 Results of Pairwise Correlations: Sensitivity Analysis of Main Dependent and Independent Variables

	TFU	*TD*	*E*	*D*	*Age*	*Gender*	*Ownership*	*I*	*Rural*
TFU	1.0000								
TD	0.9339	1.0000							
E	−0.3849	−0.0293	1.0000						
D	0.1049	0.0865	−0.0553	1.0000					
Age	0.0486	0.0288	−0.0642	0.1263	1.0000				
Gender	−0.1496	−0.1251	0.0866	−0.1046	−0.2760	1.0000			
Ownership	0.2759	0.2695	−0.0598	0.0247	0.0423	−0.0359	1.0000		
I	−0.0138	0.0285	0.1145	0.0391	0.0152	−0.0012	0.0250	1.0000	
Rural	0.0536	0.0542	−0.0077	−0.0635	−0.0197	0.0172	−0.0001	−0.018	1.0000

Table 4.8 reports the results of the correlation analysis, providing the pairwise correlation coefficients, where TD is travel distance, E is fuel economy level, D refers to income, and I is hybrid interest. As mentioned above, this study finds that TFU and travel distance are closely related, which shows that the impact of travel distances on TFU is larger than that of fuel economy. As regards the independent variables, the results show that they are

not correlated with each other substantially enough to affect the estimation results. For example, the correlation between income and hybrid ownership was 0.0247, which would not produce a biased result. Consistent with the results, hybrid ownership shows the highest correlation with travel distance among all the variables, followed by income level. The correlations among the other variables were not significant, other than their correlations with TFU and TD. Hence, the results show two important correlation values for the relationships between independent variables. First, hybrid ownership is not highly correlated with hybrid interest. This might indicate the awareness–choice gap: having a high level of interest is not necessarily correlated to choosing hybrid ownership. Second, although the correlation is not high or significant, this study finds that hybrid interest is positively correlated with fuel efficiency.

4.5 Discussion on Factors Affecting Travel Distances

4.5.1 Overall Discussion

This study reveals multifaceted implications for future environmental policy. This study does not find a significant difference in the factors affecting travel distance in 2011, 2013, and 2015. Additionally, the results of this study provide evidence for rebound effects and the impact of various socio-demographic factors on travel distances.

The estimation results confirm the following findings: First, the results provide evidence of a direct rebound. Hybrid vehicle ownership is positively correlated to increased travel distances, regardless of hybrid interest and income level, which is a form the "green paradox." Furthermore, the results show the negative correlation between the people who are interested in purchasing a hybrid vehicle but ultimately do not purchase one and travel distances. The results also suggest that hybrid owners in the low-income group drive more than hybrid owners outside the low-income group. This result is related to the fuel-cost saving function of hybrid vehicles, which allows people in the low-income group to make the costly decision to purchase hybrids. Such results demonstrate that the ownership of a hybrid vehicle plays a more significant role in altering travel distances than hybrid interest.

Second, this study generally finds that household income is positively related to travel distances. Meanwhile, this study also finds that, compared to the average person, people in the high-income group (top 10%) show negative coefficients towards travel distances. The results also reveal the general trend of Japanese people's travel behavior: commuting and leisure activities are positively correlated while shopping is negatively correlated to travel distances.

This study also finds that females and people over the age of 60 may drive less than those in the other age groups, as these were negatively correlated to travel distance.

The findings also confirm that the same factors that are positively correlated with travel distances also display a positive coefficient for fuel usage, except for hybrid ownership. The increase in travel distances by itself may not imply the existence of a negative environmental externality because fuel efficiency could vary among cars. This is indicated by the fact that hybrid ownership exhibits a positive coefficient in the model with travel distance but a negative coefficient in the model with TFU, possibly due to the high level of fuel efficiency of hybrid vehicles. In the alternative specification where the dependent variable is TFU, this study finds that although hybrid ownership generally shows negative coefficients for fuel usage, people in the low-income group show positive coefficient for fuel usage. Such results imply the need for implementing policies tailored to individual's socio-demographical identities and the type of vehicles owned.

4.5.2 Policy Implications

The Japanese government promotes hybrids to the public by using tax cuts and subsidies. The government expects to reduce the average fuel consumption as a result of the high fuel economy level promised by the hybrid technology. Hybrid vehicles can indeed contribute to emission reduction, holding other factors, such as travel distances, constant. An increase in travel distances, especially related to hybrid interest and vehicle type, jeopardizes the fuel consumption reduction resulting from the hybrid technology. This is indicated by the reduction in the emission rate from transportation (Eco-Mo Foundation 2019) and the minuscule change in the gasoline consumption amounts in several years.

People's intention to purchase hybrid vehicles is leaning towards saving fuel costs, which may lead to more traveling and not reducing fuel consumption as expected, for a given driving distance. Tanishita, Kashima, and Hayes, 2003 and Bjertnæs, 2019 suggested that introducing a tax in addition to the subsidy and tax cuts may help reduce the environmental rebound effect that electric vehicles have introduced. Increasing fuel tax can influence the alternative-fuel vehicle adoption rate (Hardman et al., 2017) but on the other hand, it can also influence travel patterns as in Zhuge et al., 2020.

Additionally, raising the awareness of rebound effects would prevent a possible rebound. Hybrid owners in the low-income group drive more than people who are not hybrid owners. This result does not indicate that having a hybrid vehicle is not an advantage for the low-income group. Hybrid cars do allow people in the low-income group to drive more than regular cars, given the same amount of fuel costs. However, the results imply that the cost-saving function of hybrid cars may create a more significant psychological appeal for people to drive more, which may lead to rebound effects and an increase in the fuel costs regardless of income group. Such an implication suggests that what is essential in future environment policy is to prioritize and prompt behavioral changes in hybrid vehicle owners.

The differences among the income groups and the unusual travel behavior in the high- and low-income groups imply that a one-size-fits-all emission reduction policy for the transportation sector may be less effective. Instead, it indicates that the emission reduction policy should account for micro factors such as income level, to realize a travel distance reduction in addition to improving fuel economy.

4.5.3 Theoretical Implications

The results of the study provide links to two existing theories: Theory of rebound and wealth effect. First, this study finds a form of ”Green Paradox" and confirm the Rebound Theory. Starting from William Stanley Jevons in 1865, economists have studied the relationship between energy efficiency improvements and fuel consumption. They have found rebound effects, where efficiency improvements, micro economically enable people to consume more fuel due to lower private marginal costs of fuel and leads to higher levels of energy consumption at the macroeconomic level. (Munyon, Bowen, and Holcombe, 2018). This study finds that hybrid ownership is one of the main factors increasing travel distances. Taking the hybrid interest constant, people who own hybrid cars drove significantly more than people who do not. This implies that people's interest in hybrid cars may be due to their fuel cost saving function, which allows people to drive farther at a lower cost.

Second, the results exhibit the wealth effect, where people spend more if their income (wealth) increases. This study finds that travel distances generally increase with income, implying that more affluent people can afford to pay more for fuel costs. The positive relationship between the income level and the driving distance shows that emission inequality holds for the general public. Interestingly, this study also finds evidence for a reverse-wealth effect. The results find unusual driving behaviors in the high-income groups, counter to the findings for the general public: people in the high-income group drive less than the general public.

4.5.4 Conclusion

Compared to the significant improvement of 23% in the fuel efficiency level from 2006 to 2016, the reduction rate of gasoline consumption has stagnated. The purpose of this study was to discover if there is an increase in travel distances, which offsets fuel economy improvements, resulting in rebound effects. This study also aimed to investigate if any other factors increase travel distance so as to identify factors that reduce fuel consumption. This study explored factors that may influence travel distances in Japan, such as income, hybrid interest, vehicle type, travel purpose, region, age, and gender. Using three data sets obtained by surveys in Japan in 2011, 2013, and 2015, this study was able to derive the impacts of diverse factors on travel distances. This study suggests some directions for future research. One possible direction is to investigate whether the model and implications can be extended to other countries, particularly developing countries. Addressing the issues of oil dependency and on-road emissions is crucial not only for developed countries but also for developing countries. Therefore, investigating travel behavior using the study as a reference will provide meaningful policy implications for achieving emissions and oil usage reductions. Another possible extension of this study would be to investigate the correlation and dynamics between the independent variables. For example, investigating how the socio-demographic variables, including gender, income, and region, are related to travel distances may also be a promising future research topic. In the sample, the portion of top high-income people is concentrated in metropolitan cities. For example, in the dataset, 86% of respondents in Tokyo belong to the high-income group, and approximately 80% of respondents residing in cities around Tokyo belong to the high-income group. Cities around Tokyo also show a large portion of high-income people (around 80%). Tokyo and cities around Tokyo have a well-developed public transportation system. It provides a convenient environment for residents to maneuver around the city without driving much. Another possible explanation from the dataset is that the main travel purpose of top income people is commuting, rather than shopping and leisure. Commuting within the metropolitan cities would not extend travel distance. Therefore, top income people's travel distances are likely to be lower than those who are not in the top income group. Explaining the behavior of specific income groups (i.e., high-income group) would also be a meaningful future research.

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Chapter Five

Factors Affecting Bike-Sharing Demands in Shanghai and Tokyo

5.1 Bike-Sharing and Environmental Awareness

Bike-sharing is considered as one of the promising options in decreasing on-road carbon emissions in the transportation sector because bike-sharing is a transport mode with 'zero-emission,' can be encouraged by the government level by various policy measures, and does not require an individual to purchase a bike. Therefore, many countries introduced various policies to encourage bike-sharing, which can be categorized into two types. First, countries tried to increase the number of bikes and bike-sharing stations installed, by financially supporting the installation costs of bike-sharing programs, through the government incentives. Consequently, by 2014, the number of cities operating bike-sharing programs increased to 855 from 13 in 2004, with a total number of 946,000 bicycles in operation (Fishman, 2016). The rapid expansion of bike-sharing programs proves that financial incentives were effective in promoting bike-sharing installations.

Another approach is to raise environmental awareness to increase Bike-sharing usages. To do so, many countries have aimed to raise public environmental awareness with various policies through, for example, information campaigns, the free exchange of ideas, and energy-saving campaigns. However, the question of whether raising environmental awareness is crucial in generating bike-sharing demands remains unanswered. Furthermore, what kind of environmental awareness (i.e., fear towards disasters and respect towards natural environment) affect the bike-sharing demands the most is not investigated, and lack of investigation could lead to less effective policies. For example, encouraging people to make pro-environmental choices because conserving natural environment is a good deed, would not be effective if people are more likely to change behaviors because they fear the adverse outcomes of natural disasters or environmental pollution. This example further implies that the concept of environmental awareness is broad and needs to be categorized and sophisticatedly examined. As mentioned earlier, because bike-sharing can be facilitated at the government level, will be useful to consider which type of environmental awareness leads to more usages. If these are not answered, the bike demand will fall, leading to the failure of the bike-sharing policy.

Because bike-sharing is a relatively new means of transportation, previous researches on bike-sharing demands are limited. This study mainly has three contributions resolving three research gaps in the previous works.

First, the contribution is that this study considers the different types of environmental awareness in the analysis. As mentioned earlier, the term "environmental awareness" is broad, general, and includes diverse aspects. One possible problem which can be induced due to this broadness is that this study might overlook the fact that environmental awareness is not a "homogenous" concept that everyone has the same idea. Instead, it is a heterogeneous concept, indicating that people can have different opinions and solutions to challenge environmental pollution. For example, some people might regard environmental pollution should be resolved first, while other people would think natural conservation should come first. Thus, incorporating environmental awareness as one broad concept in the analysis might lead to misleading policy implications. This is why the previous works which treated environmental awareness as one big concept have come up with a mixed conclusion: some authors argue that environmental awareness is positively correlated to the bike demands (Campbell et al., 2016), or the public transportation demands (M. V. Johansson, Heldt, and P. Johansson, 2006, Cheng and S.-Y. Chen, 2015, Nordfjærn et al., 2019). On the contrary, the other strands of authors mention that environmental awareness does not predict mode choices (D. Liu et al., 2017, and Hopkins, 2016). To cope with this problem, this study categorizes environmental awareness into three types: those who prioritize the environment because they fear potential natural disasters, those who express respect to the environment or nature, and those who do not care about the environment. Categorizing it can potentially explain what makes individuals choose bike-sharing over other means of transportation.

Second, the research contributes by comparing factors affecting bike-sharing demands through exploring different travel purposes (i.e., commute, leisure, and going shopping). While it is natural to think that the factors affecting bike-sharing demands would be different according to the travel purposes, most papers focus on mode choices that depend on the static situation (Bamberg, Ajzen, and Schmidt, 2013 and Heath and Gifford, 2002). All travel purposes have different expected outcomes: for example, whether a user can arrive on time would be the best essential factor when deciding a mode. On the other hand, whether a mode can carry a family member would be the most critical factor when going on vacation. In that sense, the choice is likely to change according to travel purposes. Therefore, not considering such a travel purpose would result in unreliable policy implications.

Third, many types of research are focused on western countries, while bike-sharing is also growing in cities in Asia. While studies have investigated factors motivating the use of bike-sharing in various regions Frade and Riberio, 2014, T. D. Tran, Ovtracht, and d'Arcier, 2015, Regue and Recker, 2014, Faghih-Imani et al., 2017, there remain research gaps: Researches up to date are disproportionately focused on Western countries. Mateo-Babiano, Sameer-aKumar, and AlvinMejiab, 2017 suggests that the failure of the numerous pilot projects in

East Asia modeling western examples do not adequately align with the distinct local cultural, economic, and social contexts. Therefore, Mateo-Babiano, SameeraKumar, and AlvinMejiab, 2017 suggests that the failure of the numerous pilot models in East Asia adopting western examples calls for rigorous analysis on people's preferences and demands in each country to overcome the dependence on research on other regions. In this research, this study sought to understand bike-sharing in Asia as Asia is the world's fastest-growing bike-sharing market (Shaheen, Guzman, and H. Zhang, 2010). So far, previous research in Asia is focused on Beijing; Campbell et al., 2016 argued that trip distance, temperature, precipitation, and poor air quality are significant factors influencing the bike-sharing demand. Other than Beijing, there is very little research that deals with bike-sharing in other Asian countries.

5.2 Background of Bike-Sharing in Shanghai and Tokyo

5.2.1 Background of Bike-sharing

Bike-sharing is a short-term bicycle sharing service offered by companies to users on campuses, at subway and bus stations, and in residential and commercial areas. To use a bike-sharing, a person must pay a deposit and a fee to use the bicycles for a given duration, after reserving through a smartphone application. Even though the bike-sharing system based on a smartphone application is new, the history of bike-sharing goes back to 1965, according to Shaheen, Guzman, and H. Zhang, 2010, which explains the development of bike-sharing systems by generation. The development of bike-sharing systems has gone through several stages since the launch of the first-generation model in Amsterdam in 1965 (Shaheen, Guzman, and H. Zhang, 2010).

The first generation of bike-sharing emerged in Amsterdam in 1965, Midgley, 2011, Parkes et al., 2013, but was not successful for the first time. At this time, a citizen can borrow free bicycles provided from the cities and return from any location, and there were no incentives to return bicycles in good condition. Many of the bikes were ended up being stolen and damaged. To prevent the vandalism towards bike-sharing, as the second generation, the "bicycle lending library "was opened in Copenhagen with a membership to prevent theft, resulting in the much fewer numbers of damaged bikes (*Bike Share Program Investigation-Best Practices Investigation* 2009). Starting from the second generation, with the introduction of information technology (IT) systems, bike-sharing began to flourish. The third and fourth generations equipped with smartcard technology, smartphone applications, and Internet-based reservation systems and were not only adopted worldwide but also advanced with developments in information technology.

5.2.2 Bike-Sharing in Shanghai and Tokyo

Despite its limited experience compared to the United States and Europe, Asia has recently become the fastest-growing market for bike-sharing (Shaheen, Guzman, and H. Zhang, 2010). Starting from the 2010s, the Chinese and Japanese governments; second and sixth emitters in the world, introduced a bike-sharing system based on smartphone applications on top of the existing bike-sharing system, expecting an increase in the number of people using bike-sharing, and eventually, a reduction in emissions, like other countries. The increase of bike-sharing of these two countries does contribute to the global growth rate for bike-sharing to reach 37% (Meddin, 2013).

For China to reinstate the deteriorated cycling environment due to the rapid urbanization and motorization, the Chinese government actively promoted the use of bike-sharing. To do so, the Chinese government introduced European bike-sharing systems to increase demand for green transport by raising public awareness that using bike-sharing can alleviate urban traffic problems. Within a few years, Hangzhou, Wuhan, Shanghai, Zhuzhou have built scaled urban bike-sharing systems, and mainland China has become the largest bike-sharing market in the world (Tang, Pan, and Fei, 2017). Furthermore, the new generation of dock-less bike-sharing programs (e.g., ofo and Mobike) emerged in Chinese cities with the development of mobile internet. This new bike-sharing program integrates mobile payments and GPS tracking with big data and is considered the fifth generation of bike-sharing Si et al., 2019, and was successful in encouraging Chinese people to use bike-sharing; more than 13% of total commuters used bike-sharing services during peak hours in Shanghai (Y. Zhang and Mi, 2018).

According to statistics, as of May 2013, mainland China has a total of 105 bike-sharing systems in service, 13,317 public bike stations, and 398,181 bike-sharing for use. Up to July 2015, it has rapidly grown to more than 300 systems in service, 1 million shared bikes for use (Tang, Pan, and Fei, 2017). On the other hand, in Tokyo, to address the environmental problems, the Japanese government introduced bike-sharing within Tokyo City, promoting the dependency on motor vehicles. The Japanese government also announced policies, including the establishment of the bike-sharing system and increasing the on-road bike lanes in 2016. Bike-sharing in Tokyo have multiple cycle ports installed within a given area, where people can rent and return from the ports. Additionally, the Tokyo metropolitan government is also increasing the number of services and parking areas to boost user convenience.

Connected with private companies; the Japanese government is also actively promoting the proliferation of bike-sharing. Starting from 2011, bike-sharing services are extended from Yokohama, Koto, Sendai, Chiyoda, and Minato, reaching more than 5,600 bicycles nationwide at the year 2017, with the 250,000 memberships and 521 ports[1].

[1] Data source: https://www.japantimes.co.jp/life/2017/10/21/lifestyle/pedal-power-bike-sharing-services-expand-in-japan

5.3 Methodology: Survey and Stated-Preference Analysis

Consistent with existing works (Paulssen et al., 2014, Daziano and Bolduc, 2013, Hess et al., 2012), this study adopts a logit approach to investigate the factors affecting the demand for bike-sharing. The following subsections introduce the survey data and the scenarios assumed in this study.

5.3.1 Scenarios Description

This study sets scenarios to investigate if circumstances and purpose of travel influence respondents' choice of transportation, as well as environmental awareness. In Scenario 1, this study assumes that the respondents are commuting (single trip) to the nearest subway station. In Scenario 2, this study assumes that the respondents are traveling to a shopping mall on a weekend afternoon. this study set an additional Scenario 3, which assumes that the respondents would carry a shopping bag on their return journey from the shopping mall. In all scenarios, this study set the distance to be 2km, and the weather to be cloudy. The respondents are given five modes of transportation to choose from: private car, bus, taxi, car sharing, and bike-sharing.

this study expect the different types of environmental awareness to have different/respective impact on bike-sharing choice. Commuting (Scenario 1) is a daily, regular, and individual routine. Therefore, choosing an environmentally friendly mode would indicate the willingness of people to choose that mode, despite some inconvenience in their daily lives. For example, choosing a bike-sharing requires a person to reserve a bike through smartphone applications, reach the bike-sharing station and return the bike at the station. Such a process would require much more energy and time compared to driving a car.

Furthermore, in Scenario 1, factors such as travel time, expenses, and car ownership would be more relevant than environmental or health considerations in the decision making process. Time would primarily be a more critical factor of consideration when commuting than shopping.

When returning from shopping (Scenario 3), a specific demographic feature (i.e., age) would be more critical, since a respondent should be able to take the shopped items back home.

5.3.2 A Stated-Preference Analysis

In March 2019, this study conducted an Internet survey on questionnaire based on a conjoint analysis in Tokyo and Shanghai. The data are used to develop a logit and multinomial logit choice model. The survey aims to identify the factors affecting citizens' choice of transportation mode based on their socio-demographic factors (i.e., age, gender, education level, frequency of workout, and expenditure), situational factors (travel time and expense) and different types of environmental awareness.

This study uses a stated preference approach, which is based on behavioral intentions and responses to hypothetical choice situations. Although it would be ideal for letting users choose modes without time and cost constraints (a.k.a revealed preferences), such a setting might not be consistent in reality. Therefore, this study instead set conditions to control for different expectations of people towards time and expenses according to a particular scenario. Without such constraints, it would not be straightforward to estimate the implicit process of evaluation in choosing transportation modes. Therefore, this study uses a conjoint analysis of a limited number of attributes to determine the most influential factor in the user's choices. In the study, the attributes include means of transportation, expense, and time consumption for the trip. Combinations of different levels of these attributes are alternatives.

This study divided the survey into two parts. In the first part, this study introduces hypothetical situations to control for respondents' heterogeneous reactions to travel time and cost, as in Table 5.1 to investigate the stated preferences. Every question in the first part contains five alternatives, and the respondents were asked to choose their favorite one for the given Scenario. In this survey, this study denoted expenses in the Chinese Yuan and Japanese Yen in their respective countries. Here, this study does not adopt the unified currency (i.e., USD) because the relative transportation price of China and Japan compared to the average expenses or income would be different. Therefore, this study indirectly considers the differences in price levels of two countries as well.

Table 5.1 Question Examples on: *Please choose your favorite alternative for the given scenario from the following question.*

Means	Expense (CNY)	Expense (JPY)	Time (Mins)
Bus	5 yuan	500 yen	15 mins
Private Car	1 yuan	50 yen	20 mins
Taxi	10 yuan	250 yen	25 mins
Shared Car	1 yuan	50 yen	25 mins
bike-sharing	3 yuan	150 yen	20 mins

The sample size is 246 people in Shanghai and 259 people in Tokyo. Since there are 12 different versions of questions, the total number of observations would be 6,216 in Shanghai (518*12) and 5,904 in Tokyo (492*12).

After the respondents answer the first part, this study then let the respondents answer the second part of the questions, which are mainly socio-demographic factors, frequency of workouts, and environmental awareness. Hence, the survey questions focus on participants' environmental awareness and emphasis on health.

Categorizing environmental awareness would facilitate the understandings of the results and implications by showing how the diverse aspects of environmental awareness interact with the choices of people. In that sense, the limited number of previous works also have emphasized the necessity to examine different aspects of environmental awareness. For the Japanese market, Hiratsuka, Perlaviciute, and Steg, 2018 show that the more people accept ecological values; the stronger they believe that car use has negative environmental impacts, the more they feel responsible for the problems caused by car use, and the more they feel personally obliged to reduce their car use. For another country, Nordlund, Jansson, and Westin, 2018 also mentioned that while environmentally-focused attitudinal factors (positive perspectives) are critical for Electric Vehicles (EV) demands, the personal norm towards the environment is the most crucial factor among all other factors. These researches show the necessity to investigate the different aspects of environmental awareness.

When asking questions on environmental awareness, this study classified environmental awareness into three types: "Respect," "Danger," and "Indifference". The classification is to investigate how the different categories of environmental awareness affect bike-sharing choices. People with a high "Danger" score would care for the environment because he/she is afraid of the aftermath of natural disasters that could be triggered by human activity. On the other hand, people with high "Respect" score would be cautious towards the environment because he/she respects nature and the environment. People with a high "Indifference" score would not express concerns about environmental problems.

To this end, this study set four criteria: first, a question would be labeled as "Danger" if it contains negative expressions. For example, Question 2 "When humans interfere with nature, they often have a tragic end." would be connected to "Danger" as it contains an expression of 'tragic end.' Second, a question would be labeled as "Danger" if it includes negative consequences of environmental degradation. Question 3 would be the best example, as it contains "deteriorated by human activity.", which explicitly mentions the negative result of human activity towards the environment.

Third, a question would be labeled as "Respect" if it has positive expressions, for example, as in Question 4, 'right to life.' Fourth, a question would be labeled as "Respect" if it describes admiration for nature, as in Question 9, 'The balance of nature is delicate,' and as in Question 6, "the laws of nature.". These expressions are used to point out Respect in nature. Therefore, this study classified questions containing such expressions as "Respect."

For the rest of the questions are marked as "Indifference, "as it does not express any concern about environmental pollution, degradation, or natural disasters. Instead, it indicates that people believe that the current environment does not have any problem, as in Questions 5 and 7. To this end, survey respondents were indicated to answer the questions in Table 2 on a five-point scale : (1) strongly disagree, (2) disagree, (3) not sure, (4) agree, and (5) strongly agree. As for the average value, this study finds both Shanghai and Tokyo people have a similar level of "Danger" perspective towards the environment, and the score of "Respect" and "Indifference" in Shanghai was higher than in Tokyo.

Survey respondents were indicated to answer the questions in Table 5.2 on a five-point scale[2]: (1) strongly disagree, (2) disagree, (3) not sure, (4) agree and (5) strongly agree. From the average value, this study finds both Shanghai and Tokyo people perceive a similar level of "Danger," and the score of "Respect" and "Indifference" in Shanghai was higher than in Tokyo. While the increase of scores in "Danger" and "Respect" would mean that a respondent would care for the environment, the higher value for the "Indifference" parameters would indicate that people would not care about the environment. this study takes this difference into account when interpreting estimation results.

I recognize that some of the questions in "Danger" and "Respect" categories could imply overlapping ideas. For example, Question 1, "The population of the earth is nearing its limit," would stimulate fear towards people but also make people express Respect towards the natural environment. In the same vein, Question 9, "The balance of nature is delicate and easy to change," would also imply both perspectives, leaving the difference between "Respect" and "Danger" vague and unclear. Therefore, deciding which perspectives the questions belong to without clear criteria would result in ambiguous result estimates, which will make the estimates and policy implications unreliable.

To address this issue, this study sets four criteria: first, a question would be labeled

[2]The question sets are constructed after referring to a New Ecological Paradigm scale and Clark, Kotchen, and Moore, 2003, to acquire direct answers on different perspectives of environments

as "Danger" if it contains negative expressions. For example, Question 2 "When humans interfere with nature, they often have a tragic end." would be connected to "Danger" as it contains an expression of 'tragic end.' Second, a question would be labeled as "Danger" if it includes negative consequences of environmental degradation. Question 3 would be the best example, as it contains "deteriorated by human activity.", which explicitly mentions the negative result of human activity towards the environment. Third, a question would be labeled as "Respect" if it has positive expressions, for example, as in Question 4, 'right to life.' Fourth, a question would be labeled as "Respect" if it describes admiration for nature, as in Question 9, 'The balance of nature is delicate,' and as in Question 6, "the laws of nature.". These expressions are used to point out respect in nature. Therefore, this study classified questions containing such expressions as "Respect." For the rest of the questions are marked as "Indifference "as it does not express any concern about environmental pollution, degradation, or natural disasters. Instead, it indicates that people believe that the current environment does not have any problem, as in Questions 5 and 7.

While the increase of scores in "Danger" and "Respect" would mean that a respondent would care for the environment, the high value for the "Indifference" parameters would indicate that people would not care about the environment. This study considers this difference when interpreting estimation results.

Table 5.3 presents the descriptive statistics for each city. this study finds the frequency of workout of Shanghai (3.30) is almost twice of Tokyo (1.68), where this study also find the frequency of sharing transportation in Shanghai (4.45) is higher than Tokyo (0.10). This study finds that expenditures are also different according to the cities, as Tokyo's average income (2.05) was higher than that of Shanghai (1.51). As an expenditure, frequency of workout, and the frequency of using shared transportation are decisive factors in bike-sharing demands; On the other hand, this study does not find significant differences in age, number of family members, daily commuting time, and environmental awareness between the two

Table 5.2 Survey Questions: Environmental Concerns

Type	No.	Descriptions	Avg. Score (Shanghai)	Avg. Score (Tokyo)
Danger	1	The population of the earth is nearing its limit.	3.465	3.266
Danger	2	When humans interfere with nature, they often have a tragic end.	3.732	3.723
Danger	3	The environment is seriously deteriorated by human activity.	3.685	3.849
Respect	4	Animals and plants have the right to life, like humans.	3.977	3.913
Indifference	5	Nature has sufficient capacity to deal with the effects of present industrial development.	3.006	2.822
Respect	6	Humans have special abilities, but they cannot go against the laws of nature.	3.836	3.911
Indifference	7	The “crisis of nature” that is said to be facing humanity is an exaggeration.	2.747	2.338
Danger	8	The earth is like a spaceship with very limited space and resources.	3.867	3.560
Respect	9	The balance of nature is delicate and easy to change.	3.923	3.607
Danger	10	At the present rate of human activity, this study will experience terrible natural disasters in the future.	3.882	3.814
Average Score				
Danger			3.72	3.71
Respect			3.92	3.69
Indifference			2.88	2.58

cities. To estimate the model, this study takes the logarithm for all variables, except the dummy and categorical variables, to facilitate a better interpretation of the results.

5.3.3 Perception towards Environment

As this study mentioned earlier, the perception of the Environment has various dimensions, and this study captures those by asking three categories of questions: respect, danger, and indifference. This study categorizes them according to the “reasons” that make people cautious about the environmental impacts.

While the idea that the Environment should be protected underlies in both ”Danger" and ”Respect" towards the Environment, they differ in the reason why it should be protected. Therefore, “Respect" type questions capture whether a person believes that the Environment should be protected because of the respect to it. “Danger" type questions capture whether a person believes that Environment must be protected because of the fear against the negative consequences which mismanagement would bring.

People with high “Indifference" score are those who are not environmentally cautious, and they do not care about the possible adverse impact of human activity on the Environment and nature. Therefore, "Indifference" type questions assess the perception towards the current environmental situation, whether it is negligible or problematic. Note that a lower score in this category reflects the perception that the current environmental situation is severe.

Table 5.4 Pairwise Correlations Results

Shanghai	*Danger*	*Respect*	*Indifference*
Danger	1.00		
Respect	0.80	1.00	
Indifference	0.12	0.18	1.00
Tokyo	*Danger*	*Respect*	*Indifference*
Danger	1.00		
Respect	0.72	1.00	
Indifference	−0.21	−0.25	1.00

Table 5.4 summarizes the pairwise correlation result between the average scores from each category of perception towards the environment. The result shows that the response to danger and respect categories is highly correlated in both Shanghai and Tokyo. However, the outcome from the indifference category has a weaker correlation with the other two category outcomes. In particular, while the correlation coefficients of indifference category against the other categories are positive in Shanghai, those are negative in Tokyo.[3] Motivated by this, this study utilizes the regional and categorical differences in the survey outcome for perception toward the environment in the regression analyses.

To estimate the utility level of people choosing bike-sharings, this study adopts logit (binary logit[4]) and Multinomial logit (MNL), as they are the most commonly used models in the literature.[5] Followed by B.-A. M. and B. M., 1999, the utility U_{ij} of individual i's

[3]While it is unclear why the trend in "Indifference" differs by region; this study hypothesizes that the gap between the frequency of natural disasters in each region may contribute to this difference. This study also attaches the histogram of the different types of environmental awareness in Appendix.

[4]Of course, 'logit' is a broad concept including nested logit, multinomial logit, categorical logit, and so on. However, in this paper, this study denotes binary logit to 'logit' in the result specification.

[5]See McFadden, 1977, B.-A. M. and B. M., 1999 and Cervero, 2002

choice on transport mode j is:

$$U_{ij} = \bar{U_{ij}} + e_{ij} = X_{ij}\beta_j + e_{ij} \tag{5.1}$$

where $\bar{U_{ij}}$ is the mean utility, e_{ij} is an error term, and X_{ij} is a vector of independent variables. β is a vector of coefficients, and is estimated through maximum likelihood estimation. The alternative with the highest utility is chosen. In the logit specification, the probability of choosing shared bike can be written as:

$$P(Y_i = j) = \frac{1}{1 + e^{\beta_j' x_i}} \tag{5.2}$$

where $P(Y_i = j)$ is the probability that the people would choose shared bikes (jth transportation mode choice), with characteristic of x_i. For the multinomial logit (MNL) regression model with five alternatives can be written as:

$$P(Y_i = j) = \frac{e^{\beta_j' x_i}}{\sum_{j=0}^{4} e^{\beta_j' x_i}}, j = 0, 1, 2, 3, 4. \tag{5.3}$$

Table 5.5 shows the list of variable notations and descriptions. This study includes the interaction term from travel cost and travel time of each modes, and control variables. The model using logit and multinomial logit was estimated. In addition to the variables mentioned in Table 5.5, dummy variables were added on respondent's job type, gender, and car ownership as control variables.

5.4 Bike-Sharing Demand Estimation Results

Tables 5.6, 5.7, and 5.8 report the estimation results of the bike-sharing demand model for logit and multinomial logit Models for Tokyo and Shanghai in Scenario 1, Scenario 2, and

Scenario 3. For all models, this study includes the same set of variables, mainly time and expense, demographic variables, environmental awareness, and job types. Model (1) and (3) are results for Shanghai, Model (2), and (4) are the results for Tokyo. Model (1) and (2) are estimated through the logit approach, whereas Model (3) and (4) are assessed through a multinomial logit approach.

Overall, results show that different types of environments, situational factors, and demographic factors show different correlations towards bike-sharing, according to scenarios and countries. First, this study explains how the different types of environmental awareness correlate with bike-sharing choices by scenarios and countries. Then this study briefly explains other factors, including situational factors demographical variables, frequency of workout, and job types regardless of the scenarios.

5.4.1 Impact of Environmental Awareness towards Bike-Sharing

Overall, this study finds that the impact of "Indifference" towards bike-sharing was not significant in Tokyo compared to Shanghai in most cases. Results also show that most, the estimated coefficients of "Respect" was higher than "Danger."

Scenario 1 Table 5.6 shows the bike-sharing demand estimation results after estimating the utility function in Equation 1. Regardless of the model specification, this study finds that various dimensions of environmental awareness show different types of correlations towards the demands for bike-sharing. However, this study also sees the correlation between "Respect" and bike-sharing is not dominant when commuting, in both countries. To be specific, in both countries, this study finds that "Respect" parameters are weak predictors, that only Model (3) shows a statistical significance, and the estimated coefficient was slightly weaker than that of "Indifference." "Indifference" was a dominant, influential parameter for Shanghai, and "Danger" was a weak predictor for both countries. Hence, the estimated coefficient value of "Indifference" was higher than "Danger" and "Respect" in Shanghai. For Tokyo, "Danger" shows the weak, but positive and statistically significant coefficient in Model (4), while other coefficients were statistically insignificant.

Scenarios 2 and 3 Table 5.7 presents the results for participants on a shopping trip (Scenario 2) and Table 5.8 shows the estimated coefficients for those returning from shopping (Scenario 3). In contrast to the case of commuting, this study finds that both cities, regardless of Scenario 2 and 3, "Respect" is now a statistically significant and influential parameter showing the substantial correlation towards choosing bike-sharing. Conversely to the results in Scenario 1, the coefficient value of "Respect" is higher than "Indifference" and "Danger." On the other hand, "Indifference" in Shanghai and "Danger" in Tokyo show negative coefficients in both scenarios, where the magnitude of the estimated coefficients of them was larger in Scenario 3 than in Scenario 2. Results further report that the impact of "Indifference" was statistically significant, and positive in Model (4) of Scenario 2, whereas in most cases, "Indifference" reports a statistically insignificant coefficient.

5.4.2 All Scenarios Results

Situational Factors: Time and Expense All the results show that situational factors, such as time and expense of the modes, are correlated towards bike-sharing choices in both countries regardless of scenarios and countries. In both countries, results indicate that the private car and taxi travel cost and time (α_2, α_3), show positive coefficients. Rideshare travel cost and time (α_4) and bike-sharing travel cost and time (α_4, α_5) demonstrates negative coefficients. Bus travel cost and time (α_1) presents a positive coefficient in Scenario 1 in both countries but shows negative coefficients in Scenario 2 and 3 in Tokyo. In contrast, it remains not statistically significant in Shanghai in Scenario 2 and 3.

Other Factors: Demographics, Frequency of Workout, and Jobs As expected, this study finds that demographic factors are correlated with bike-sharing choices. For example, in Shanghai, this study finds that age, income, education, and car ownership are correlated to bike-sharing choices. On the other hand, car ownership was not a significant factor in Tokyo, whereas commuting time is correlated to the bike-sharing choices of Tokyo. In both countries, the results indicate that demographic factors are correlated to bike-sharing choices. When going shopping (Scenario 2), this study did find that age in both countries and car ownership in Tokyo is negatively correlated to the bike-sharing choices. When returning from shopping (Scenario 3), the education level in Tokyo is positively correlated to bike-sharing choices.

For the frequency of workout, this study finds that in Shanghai, the frequency of workout is negatively correlated to the bike-sharing in Scenario 1. In contrast, in Tokyo, the personal frequency of workout does not show a statistically significant coefficient towards the demand for bike-sharing in Scenario 1. In Scenario 2, the frequency of workout was not a powerful predictor in bike-sharing in both countries, as it shows a negative coefficient in Shanghai, and not statistically significant in Tokyo. On the other hand, in Scenario 3, in Tokyo, the frequency of workout shows a positive coefficient.

As for the job parameters, this study finds no statistically significant variables related to job types in Shanghai, while this study finds job parameters of professionals, white collars and blue collars and public officers show positive coefficients towards bike-sharing in Tokyo.

5.5 Comparison with Other Modes

In this section, we take a closer look at how environmental awareness affects other means of transportation and compare them with the case of bike-sharing. Mainly, I investigate private cars and buses, representing modes of private means of transportation and public transportation.[6]

Table 5.9 shows the estimated result of Tokyo and Shanghai when commuting. In Shanghai, environmental awareness does not play a significant role in the bus, while lower environmental awareness is positively correlated to private car usage. On the other hand, the result indicates that environmental awareness plays a more significant role in Tokyo, as positive environmental awareness show a positive correlation with bus usages and lower level of environmental awareness would be negatively correlated to the private car usages.

Table 5.10 and 5.11 shows estimation results for Scenario 2 and Scenario 3[7]and generally, they share similar implications. In other words, for bus and private cars, I did not find the evidence that the factors affecting their demands change when they go or return from the shopping. Both in Shanghai and Tokyo, as indifference offsets the respect, people would not ride the bus. For private cars, as the coefficient of 'Indifferent' is the highest and the most statistically significant, people with lower environmental awareness would choose private vehicles.

The overall result shows the impact of environmental awareness on the mode choice. Generally, we find similar implications as this study did for the bike-sharing. A high level of environmental awareness is positively correlated to bike-sharing usage and negatively correlated to private car demand and bus demand. Given that private cars and public transportation use fuels and emits CO_2, this result re-confirms that promoting environmental awareness would facilitate people to use bike-sharing. Transferring into bike-sharing would decrease emissions both in the short-term and the long-term.

[6] I also have a data sample for both cities for taxi and car-share services, but I did not include them for the following reasons. First, It is unclear how to distinguish a taxi and shared car and a private car. As this study discussing the impact of environmental awareness on emissions, I thought adding them would call more confusion. On the other hand, buses and private cars are easy to understand. Second, I don't find a meaningful and original contribution of adding them, because using a taxi would probably not depend on environmental awareness. Third, Tokyo and Shanghai have a somewhat different definition of shared cars. For Tokyo its a car share but for Shanghai, it's more close to Carpool.

[7] I have omit out the variables related to job variations from the table. The results are available upon request.

5.6 Discussion and Policy Implications on Promoting Bike-Sharing Usages

This study contributes to the existing literature by providing evidence of how different types of environmental awareness predict environmentally friendly behavior, focusing on the transportation mode choice. Because commuting is a daily activity, in Scenario 1, the result can suggest whether different types of environmental awareness have different implications for changing regular and daily routines. Given that, in the case of Shanghai, this study finds that "Indifference" is a dominant parameter, which is negatively correlated to the bike-sharing usages, while other types of environmental awareness are either weak or statistically insignificant. On the other hand, "Danger" was the dominant significant factor in Tokyo with the highest positive estimated coefficient.

Contrary to commuting, going (Scenario 2) and returning from shopping (Scenario 3) is more likely to be a family event, and carrying heavy shopping bags may require additional considerations (i.e. age) in the decision-making process. Such factors could overrule environmental concerns. For example, younger people could find it easier to carry bags than elderly ones, which could lead them to use shared bikes. In this case, people who feels difficult carrying bags would not put environmental awareness as a priority. Interestingly, as for the shopping, the estimated coefficient of "Respect" was generally higher than "Danger" and "Indifference" both in Shanghai and Tokyo.

Throughout the results, this study finds a form of 'awareness-choice discrepancy' in Scenario 1: having a high level of environmental awareness is not necessarily correlated to the choice towards bike-sharing in both cities. In Scenario 1, even if it is the same people answering the survey between Scenario 1, 2, and 3, "Indifference" was the dominant factor with the highest estimated coefficient in bike-sharing choices (Shanghai), or presented statistical significance when people are concerned about the negative consequences of environmental deterioration (Tokyo). This result implies the existence of obstacles in using bike-sharing when commuting. Examples of such obstacles would include travel time because arriving on time is the most important for commuters, and travel costs because commuting is a daily behavior requiring a travel cost every day. On the other hand, this study does not find 'awareness-choice discrepancy' in Scenario 2 and 3 in both cities, implying that travel time, cost, and demographical requirements for carrying a bag were not worked as an obstacle to bike-sharing choice.

Another interesting point to mention is that, in most outcomes, the estimated coefficient of "Danger" was smaller than that of "Respect." It is natural to think that people with a high score of "Danger" wish to avoid the negative consequences of the environment (i.e., disasters). On the other hand, people with a high score of "Respect" are more likely to be active towards direct actions that can improve the environment or related to nature conservation. This suggests that people with a higher degree of "Respect," compared to those with a higher degree of "Danger," are more willing to choose bike-sharing as it would directly contribute to the environmental protection.

Lastly, the result shows a positive and statistically significant correlation between "Respect" and bike-sharing choices when shopping, in both countries. These results provide implications on the fact that situational factors are critical when people make pro-environmental decisions, not limited to commuting and shopping.

5.7 Conclusion of Factors Affecting Bike-Sharing Demands in Shanghai and Tokyo

This study explores and fills in the research gap of whether and how different types of environment awareness induce people to choose bike-sharing. Using the stated-preference approach through surveys conducted in Shanghai and Tokyo, the demand model shows that various kinds of environmental awareness are correlated to the bike-sharing demands, and the impact differs by region and travel purposes. The contribution of this paper will be that this study suggested how situational factors, countries, and different types of environmental awareness affected bike-sharing demands. Notably, this study finds that positive perspectives, such as conserving the natural environment are not correlated to bike-sharing choices when people are commuting. On the other hand, the results show that when people are going and returning from shopping, positive perspectives are highly correlated to the bike-sharing demands. the results, therefore, provide insights to policymakers that promoting bike-sharing would require considering diverse perspectives of environmental awareness, as well as situational factors and socio-demographic factors.

Table 5.3 Descriptive Statistics

	N	Mean	Std. Dev.	Min.	Max.
Shanghai					
Age (Year)	518	38.84	13.44	21	65
Monthly Income (1,000 USD)	516	1.51	0.72	0.21	2.85
Number of Family Members	518	2.94	0.95	1	6
Frequency of workout	518	3.30	1.75	0	7
Frequency using Sharing Transportation per Week	518	4.45	3.40	0	18
Daily Commuting Time	518	1.06	0.61	0	3.5
Environmental Awareness (Total)	518	36.12	47.12	10	50
Danger	518	18.60	4.22	5	25
Respect	518	11.77	2.52	3	15
Indifference	518	5.75	2.27	2	10
Tokyo					
Age (Year)	508	43.48	14.14	18	69
Monthly Income (1,000 USD)	392	2.05	1.14	0.41	5.48
Number of Family Members	508	2.58	1.40	1	6
Frequency of workout	508	1.68	2.15	0	7
Frequency using Sharing Transportation per Week	508	0.10	0.42	0	4
Daily Commuting Time	508	0.81	0.79	0	3.5
Environmental Awareness (Total)	508	34.79	4.99	12	50
Danger	508	18.56	3.38	5	25
Respect	508	11.07	2.12	3	15
Indifference	508	5.16	1.49	2	10

Note: I acknowledge that there are differences in the scale of scores. For example, the score of 'Danger' is the largest, while 'Indifference' is the smallest, implying that I might have to normalize the scores. However, estimating with/without such a normalization does not change the estimation results and implications. Therefore I proceed without normalization. The results with normalization are available upon request.

Table 5.5 Variable Descriptions

Notation	description
α_1	(log) Bus Travel Cost * Bus Travel Time
α_2	(log) Car Travel Cost * Car Travel Time
α_3	(log) Taxi Travel Cost * Taxi Travel Time
α_4	(log) Rideshare Travel Cost * Rideshare Travel Time
α_5	(log) bike-sharing Travel Cost * bike-sharing Travel Time
Commute Time	Commuting Time (Mins)
No Car	=1 If a Respondent Does Not Own a Car
Income	Monthly Income (1,000 USD)
Age	Age
Education	Education Level
Family	The Number of Family Members
Frequency of Workout	Frequency of Workout per a Week
Danger	"Danger" Environmental Perspective Score
Respect	"Respect" Environmental Perspective Score
Indifference	Indifferent Environmental Perspective

Table 5.6 Estimation Results of Scenario 1

	Model (1) Logit Shanghai	se	Model (2) Logit Tokyo	se	Model (3) MLogit Shanghai	se	Model (4) MLogit Tokyo	se
α_1	0.014	0.046	-0.009	0.037	0.421***	0.060	0.856***	0.066
α_2	0.185*	0.091	0.389***	0.081	-0.002	0.107	0.445***	0.102
α_3	0.379***	0.061	0.646***	0.058	0.120	0.075	0.358***	0.076
α_4	-0.192*	0.082	-0.268***	0.073	-0.192*	0.092	-0.264**	0.090
α_5	-0.561***	0.077	-0.827***	0.067	-0.730***	0.097	-1.114***	0.112
Commute Time	-0.003	0.002	-0.005**	0.001	0.003	0.003	-0.005*	0.002
Income	-0.011	0.044	0.000	0.023	0.144**	0.055	-0.065*	0.032
Age	-0.132***	0.037	-0.004	0.003	-0.212***	0.048	-0.009	0.005
Education	-0.138	0.122	-0.211**	0.078	-0.318*	0.159	-0.093	0.108
Female	-0.050	0.104	-0.058	0.093	-0.212	0.136	-0.009	0.129
No Car	0.101	0.165	0.442***	0.093	-0.535**	0.196	0.120	0.133
Family	0.102	0.063	0.175***	0.037	0.110	0.081	0.118*	0.053
Health	0.043	0.081	0.290***	0.041	-0.435***	0.106	0.232***	0.057
Danger	0.055*	0.022	0.078***	0.018	0.073**	0.027	0.113***	0.025
Respect	0.064	0.037	-0.033	0.029	0.117**	0.044	-0.062	0.040
Indifference	-0.122***	0.023	0.002	0.029	-0.118***	0.031	-0.007	0.043
Student	-1.019	0.536	-0.263	0.223	-0.315	0.622	-0.238	0.306
Professional	0.293	0.442	0.108	0.244	0.625	0.509	0.815*	0.364
Self-Employed	0.119	0.439	-0.185	0.178	0.545	0.505	-0.087	0.238
White Collar	-0.122	0.427	0.294*	0.129	0.344	0.479	0.558**	0.181
Blue Collar	-0.351	0.436	0.292*	0.137	0.498	0.495	0.846***	0.198
Public Officer	-0.045	0.463	1.065***	0.246	0.406	0.533	1.162***	0.344
Constant	-1.902	1.443	-3.983***	1.172	2.226	1.726	-4.191**	1.613
N	6,216		6,096		2,849		2,871	
Pseudo R^2	.085		.145		.110		.270	

Note: + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Table 5.7 Estimation Results of Scenario 2

	Model (1) Logit Shanghai	se	Model (2) Logit Tokyo	se	Model (3) MLogit Shanghai	se	Model (4) MLogit Tokyo	se
α_1	0.042	0.046	0.049	0.044	-0.037	0.062	-0.124*	0.063
α_2	0.144	0.084	0.277**	0.087	0.237*	0.111	0.551***	0.115
α_3	0.055	0.052	0.225***	0.057	-0.029	0.068	-0.060	0.073
α_4	-0.084	0.070	-0.271***	0.078	-0.155	0.091	-0.507***	0.097
α_5	-0.377***	0.069	-0.921***	0.073	-0.520***	0.092	-1.003***	0.099
Income	0.021	0.041	0.095***	0.026	-0.053	0.057	0.117**	0.037
Age	-0.143***	0.036	-0.001	0.004	-0.310***	0.052	-0.016**	0.006
Education	0.436***	0.126	0.371***	0.083	0.267	0.165	0.159	0.114
Female	-0.038	0.100	0.282**	0.100	-0.139	0.133	0.274	0.151
No Car	0.220	0.149	0.034	0.105	1.953***	0.283	1.639***	0.155
Family	-0.025	0.063	-0.035	0.042	-0.014	0.086	0.018	0.059
Health	-0.342***	0.080	-0.022	0.050	-0.249*	0.109	0.084	0.076
Danger	0.016	0.021	-0.055**	0.021	0.021	0.030	-0.055	0.031
Respect	0.184***	0.036	0.210***	0.034	0.255***	0.053	0.294***	0.050
Indifference	-0.154***	0.022	-0.046	0.032	-0.253***	0.029	0.135**	0.046
Student	2.089*	1.032	0.796***	0.240	1.206	1.100	0.835*	0.341
Professional	2.169*	1.019	1.249***	0.233	2.144*	1.079	4.155***	0.589
Self-Employed	1.753	1.021	0.666***	0.201	1.157	1.077	0.623*	0.272
White Collar	1.473	1.013	0.924***	0.138	1.306	1.067	1.241***	0.188
Blue Collar	1.420	1.016	0.773***	0.163	0.572	1.070	0.519*	0.223
Public Officer	1.665	1.028	-0.087	0.482	1.058	1.100	0.633	0.583
Constant	-3.626*	1.668	-0.323	1.346	-0.622	2.065	2.061	1.750
N	6,216		6,096		3,108		2,952	
Pseudo R^2	.081		.141		.097		.273	

Note: + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Table 5.8 Estimation Results of Scenario 3

	Model (1) Logit Shanghai	se	Model (2) Logit Tokyo	se	Model (3) MLogit Shanghai	se	Model (4) MLogit Tokyo	se
α_1	0.030	0.045	0.030	0.042	-0.045	0.066	-0.244***	0.072
α_2	0.174*	0.083	0.297***	0.086	0.293*	0.125	0.730***	0.122
α_3	0.058	0.052	0.229***	0.057	-0.087	0.078	0.855***	0.075
α_4	-0.059	0.071	-0.151	0.081	-0.039	0.104	-0.212*	0.105
α_5	-0.344***	0.069	-0.898***	0.074	-0.514***	0.103	-0.927***	0.100
Income	0.021	0.041	0.095***	0.026	0.060	0.063	0.076	0.039
Age	-0.143***	0.036	-0.001	0.004	-0.106	0.055	0.002	0.006
Education	0.436***	0.126	0.370***	0.083	0.233	0.184	0.348**	0.124
Female	-0.038	0.100	0.281**	0.100	0.038	0.145	0.231	0.154
No Car	0.220	0.149	0.034	0.105	2.236***	0.301	-0.406**	0.157
Family	-0.025	0.063	-0.035	0.042	0.134	0.095	-0.097	0.062
Health	-0.341***	0.080	-0.022	0.050	-0.082	0.120	0.170*	0.076
Danger	0.016	0.021	-0.055**	0.021	0.011	0.032	-0.086**	0.031
Respect	0.184***	0.036	0.209***	0.034	0.159**	0.056	0.237***	0.052
Indifference	-0.153***	0.022	-0.046	0.032	-0.169***	0.031	0.001	0.047
Student	2.087*	1.032	0.796***	0.240	14.142	732.863	0.823*	0.367
Professional	2.168*	1.019	1.248***	0.233	15.863	732.863	1.046**	0.367
Self-Employed	1.752	1.021	0.665***	0.201	14.363	732.863	0.642*	0.305
White Collar	1.473	1.013	0.923***	0.138	15.353	732.863	0.124	0.196
Blue Collar	1.420	1.016	0.772***	0.163	14.720	732.863	0.159	0.236
Public Officer	1.664	1.028	-0.087	0.482	15.192	732.863	0.208	0.619
Constant	-4.225*	1.647	-1.428	1.293	-17.228	732.865	-3.908*	1.800
N	6,216		6,096		3,108		2,952	
Pseudo R^2	.079		.138		.081		.256	

Note: + $p<0.1$,* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 5.9 Estimation Results of Scenario 1: Bus and Private Cars

	Model (1) MLogit Shanghai Bus	se	Model (2) MLogit Tokyo Bus	se	Model (3) MLogit Shanghai Private car	se	Model (4) MLogit Tokyo Private car	se
α_1	-0.677***	0.077	-1.585***	0.098	0.037	0.076	-0.003	0.110
α_2	0.054	0.092	-0.015	0.099	-0.014	0.092	-0.094	0.133
α_3	0.281***	0.056	0.474***	0.061	0.373***	0.054	0.884***	0.085
α_4	0.019	0.075	0.074	0.087	0.170*	0.074	0.598***	0.099
α_5	0.380**	0.117	0.503***	0.134	-0.612***	0.115	-0.761***	0.114
Commuting Time	-0.012***	0.002	0.003	0.002	-0.007***	0.002	-0.008**	0.003
Income	-0.150**	0.047	0.067*	0.034	0.082	0.048	0.033	0.041
Age	0.147***	0.039	0.010*	0.005	0.106**	0.040	-0.021***	0.006
Education	0.348**	0.132	0.024	0.110	0.194	0.139	-0.276*	0.138
Female	0.001	0.114	0.309*	0.134	-0.106	0.118	-0.415*	0.163
No Car	0.451**	0.159	0.368**	0.138	-1.176***	0.227	-0.696***	0.167
Family	-0.039	0.070	0.102	0.056	0.006	0.069	-0.038	0.067
Health	0.311***	0.089	0.064	0.061	0.031	0.094	-0.132	0.079
Danger	0.004	0.021	-0.044	0.025	-0.042*	0.020	-0.049	0.030
Respect	-0.037	0.035	0.121**	0.041	-0.133***	0.034	0.001	0.050
Indifference	-0.017	0.026	-0.131**	0.044	0.151***	0.028	0.128*	0.052
Constant	-1.098	1.401	2.548	1.545	-2.213	1.309	-7.934***	1.581
N	2,590		2,610		2,590		2,610	
Pseudo R^2	.113		.257		.113		.257	

Note: + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Table 5.10 Estimation Results of Scenario 2: Bus and Private Cars

	Model (1) MLogit Shanghai Bus	se	Model (2) MLogit Tokyo Bus	se	Model (3) MLogit Shanghai Private car	se	Model (4) MLogit Tokyo Private car	se
α_1	-0.208***	0.039	-0.682***	0.045	0.059	0.037	0.126**	0.044
α_2	0.030	0.069	0.088	0.085	-0.040	0.062	-0.181*	0.074
α_3	0.061	0.042	0.288***	0.057	0.125***	0.037	0.351***	0.043
α_4	0.152**	0.053	0.339***	0.062	-0.067	0.079	-0.210**	0.080
α_5	0.017	0.062	-0.074	0.082	0.098	0.053	0.074	0.066
Commuting Time	-0.013***	0.002	0.003	0.001	-0.001	0.001	-0.003	0.001
Income	-0.010	0.034	-0.117***	0.026	0.077*	0.032	-0.027	0.023
Age	0.055	0.028	0.010**	0.003	0.087**	0.026	0.004	0.003
Education	0.331**	0.101	0.176*	0.081	0.195*	0.091	0.296***	0.074
Female	-0.015	0.081	0.341***	0.098	0.142	0.075	0.014	0.095
No Car	-0.004	0.124	0.485***	0.103	-1.942***	0.231	-1.514***	0.104
Family	-0.237***	0.065	0.005	0.045	-0.085	0.047	-0.097*	0.038
Health	0.311***	0.089	0.064	0.061	0.031	0.094	-0.132	0.079
Danger	0.003	0.017	0.028	0.019	0.018	0.014	0.025	0.019
Respect	0.071**	0.028	-0.013	0.030	-0.044	0.024	-0.004	0.030
Indifference	-0.072***	0.018	-0.088**	0.03	-0.156***	0.025	-0.056	0.032
Constant	-1.924	1.068	-2.566	1.360	-1.779	1.504	-1.039	1.365
N	6,216		6,096		6,216		6,096	
Pseudo R^2	.074		.145		.074		.145	

Note: + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Table 5.11 Estimation Results of Scenario 3: Bus and Private Cars

	Model (1) MLogit Shanghai Bus	se	Model (2) MLogit Tokyo Bus	se	Model (3) MLogit Shanghai Private car	se	Model (4) MLogit Tokyo Private car	se
α_1	-0.211***	0.039	-0.733***	0.048	0.061	0.036	0.141**	0.044
α_2	0.036	0.068	0.167*	0.084	-0.043	0.061	-0.205**	0.073
α_3	0.061	0.042	0.280***	0.056	0.124***	0.037	0.352***	0.043
α_4	0.146**	0.055	0.236***	0.066	0.066	0.049	0.289***	0.056
α_5	0.034	0.065	0.191*	0.095	0.103	0.055	0.031	0.068
Commuting Time	-0.013***	0.002	0.003	0.001	-0.001	0.001	-0.003	0.001
Income	-0.010	0.034	-0.118***	0.026	0.077*	0.032	-0.027	0.023
Age	0.055	0.028	0.010**	0.003	0.087**	0.026	0.004	0.003
Education	0.331**	0.101	0.174*	0.082	0.195*	0.091	0.296***	0.074
Female	-0.015	0.081	0.340***	0.098	0.142	0.075	0.014	0.095
No Car	-0.004	0.124	0.485***	0.103	-1.942***	0.231	-1.512***	0.104
Family	0.007	0.052	-0.127**	0.042	-0.085	0.047	-0.097*	0.038
Health	-0.237***	0.065	0.005	0.045	-0.278***	0.062	-0.160***	0.046
Danger	0.003	0.017	0.028	0.019	0.018	0.014	0.025	0.019
Respect	0.071**	0.028	-0.013	0.030	-0.044	0.024	-0.004	0.030
Indifference	-0.072***	0.018	-0.088**	0.031	0.122***	0.017	-0.122***	0.031
Constant	-2.028	1.052	-4.032**	1.340	-2.079*	0.937	-4.159***	1.018
N	6,216		6,096		6,216		6,096	
Pseudo R^2	.073		.145		.073		.145	

Note: + p<0.1 ,* p<0.05, ** p<0.01, *** p<0.001.

Chapter Six

Conclusion, Limitations and Future Research Topics

6.1 Overall Conclusion

This study aims to investigate consumer behavior in the East Asian Transportation Sector, by examining how consumer choices affected mode choice and emissions, and investigating factors affecting consumers' travel behaviors. In that sense, this study provides a new way to reshape environmental policy by including consumer behaviors in the model and suggesting policy implications considering consumer behaviors.

Each chapter of this study evaluates and provides policy implications on consumer behaviors and emissions but from different perspectives. Thus, the scope/topic of the chapters is inter-related. Emissions and oil usages in the transportation sector are decided by whether people choose to drive rather than choosing public transportation and whether environmental awareness induces people not to drive (Chapter 5). For those who want to drive, it is essential to look at how people drive (Chapter 4) with how people choose cars (Chapter 3), whether the government is supporting environmentally-friendly vehicles with policies (Chapter 2), and finally, whether the policy instruments supporting environmentally-friendly vehicles (i.e., hybrid vehicles)

Governmental policies (Chapter 2) and consumer preferences (Chapter 3) are critical in automobile demands. With the analysis on how consumers drive (Chapter 4) and how consumers choose modes (Chapter 5), would provide implications that can reduce emissions and fuel usage would be reduced more effectively in the long term.

Thus, this study contributes by providing policy implications on how policies, consumer preference, travel patterns, and mode choices are correlated to the emissions and oil consumption, which are all important in reducing emissions and oil usages in the transportation sector.

Results in this study overall imply that the focus of Japanese environmental standards should change from inducing consumers to buy more fuel-efficient automobiles to influencing consumers to purchase and consume less fuel for transportation, as in Chapter 2,3, and 4. To be more specific, to reduce oil dependency, the Japanese government can change the focus of its energy policies from promoting energy-efficient vehicles to raising the marginal costs of fuel (or driving distance). The confirmation of the rebound effect in fuel usage would imply that drivers take advantage of the high fuel economy of their hybrid vehicles, leading to more driving and higher fuel usage. The consumer-level subsidies do not change the marginal cost of driving distance or fuel usage. On the other hand, fuel taxes can lower the driving distance and fuel usage for each vehicle, whereas policies have to induce the consumer to consume less fuel (OECD, 2010). Taxing the fuel can contribute to resolve the problem of the rebounds.

This study also highlights that considering the heterogeneity of consumers on policies is necessary. Because the results show the heterogeneity of consumers exist because consumers have different and time-varying preferences towards vehicle attributes (Chapter 3), consumers travel differently according to the socio-demographic factors (Chapter 4) and consumers have different perceptions towards environmental awareness (Chapter 5), this study also implies that different policies might result in different consequences. For example, highlighting that natural preservation is a good deed is not likely to promote the bike-sharing usages in Tokyo (Chapter 5), increasing diesel fuel price would not be effective to those who are not sensitive to fuel costs (Chapter 3), and different income group would result in different travel distances (Chapter 4). The results can inform policymakers about the existence of such differences.

6.1.1 Limitations and Future Research Topics by Chapters

Policy Implications, Limitations and Future Research Topics of Investigating Direct Rebound Effects from Japanese Transportation Sector,2006-2016

In the Chapter 2, this study explored direct rebound effects induced by consumer behavior and find out government policies encourage consumers to use more fuels, eventually resulting in direct rebounds. The results show that both total fuel usage and total fuel costs rose, and even that rapid increases in automobile sales canceled out the potential positive impacts of fuel economy improvement. This was caused mainly by the increased demands for light-duty and hybrid electric vehicles because of tax reductions and fuel economy standards, which encouraged consumers to purchase more cars and travel more, due to the improved fuel economy levels which were facilitated by the fuel economy standards and financial incentives.

Results of this study suggests the necessity of policy revisions considering the existence of rebounds, regardless of macroeconomic shocks. This is not to say that promoting environmentally-friendly vehicles is a futile endeavor; given a choice between a car with a low fuel economy and another with high fuel economy, this study as a society would prefer vehicles with high fuel economy on the roads rather than the alternate scenario. Therefore, there is still a need for policies that provide high fuel-efficient automobiles as a financially viable substitute for low fuel-efficient cars.

A second possible strategy is to shift financial incentives from the consumers to the producers, which has two foreseeable effects. The first is to stop the arbitrary rise in automobiles sales by lowering the financial incentives for consumers. The second is to raise the financial incentives for producers' research and development (OECD, 2010). Previous researches (Ahn, Jeong, and Y. Kim, 2008; Francis Sprei and Karlsson, 2013; MacKenzie and Ohndorf, 2012) shows that consumers regard fuel economy as a vital vehicle attribute, inducing automobile manufacturers to improve the fuel economy of their vehicles to gain market share.

For the future researches, demand estimation based on consumer information can be added to examine the impact of consumers' demographic factors on purchasing behavior, particularly when they are choosing hybrid electric vehicles. Because this study analyzed the given phenomenon rather than consumer demand, it is more focused on finding explanations other than consumer preferences or choices. Adding such factors would improve the explanatory power of the study.

Including macroeconomic variables to extend the scope of this research for cross-national comparisons may be one of the future researches. This study reflected the macroeconomic situations by adding the gasoline price to the dependent variable, and this can be developed through including other macroeconomic variables, such as GDP per capita, disposable income, and interest rates. This would provide essential implications if analyses in multiple countries were added. Answering those questions with consumer data would not only offer explanations to firm behaviors but also suggest strategies to stimulate firms to reduce total fuel usage while fulfilling consumers' needs.

From a methodology perspective, adding demographic data on consumers would improve the model by allowing the variables to be endogenously treated; for example, the driving distance would have more meaningful explanations if equipped with consumer data, since a driver does not directly change his or her travel distance according to the car type and fuel efficiency of the car he or she owns. These are left for the future research.

While this study provides significant advantages over the previous studies, this study also has some limitations to be addressed in further studies. First, for Chapter 2, the stable unit treatment value assumption (SUTVA) in the differences in difference method could be violated. Previous researches have pointed out that purchasing hybrid electric vehicles can be increased due to technology spillover effects from supply sides (Watanabe et al., 2004), and peer effects from demand sides as in Struben et al. (2017). Even though it cannot explicitly find out whether such effects exist in this study, the findings are still meaningful because the existence and size of rebounds are confirmed. Hence, analyzing whether such spillovers and contagions exist in Japan would be fruitful research in the future, because the existence of them would indicate that the energy rebound can increase, by increasing the number of fuel-efficient vehicles, light-duty vehicles, and hybrids.

Policy Implications, Limitations and Future Research Topics of "Automobile Demands and Rebounds"

In Chapter 3, the automobile demand for Japanese and Korean consumers was estimated. The model explicitly allows consumer preferences for fuel economy to evolve, and the estimation results confirm such a change. In Japan, consumer preferences towards fuel economy keep decreasing over time, mainly because the automobile price of fuel-efficient cars gets more and more expensive. Then the counterfactual simulation is conducted towards the consumer behavior. The results highlight that both technological improvement and consumer preferences are important for reducing CO_2 emissions. These results highlight the importance of both consumer preferences and technological advancement for reducing CO_2 emissions. If the government only implemented a policy that enhanced consumers' appreciation for fuel economy, consumers would purchase more cars, which would increase CO_2 emissions.

On the other hand, in Korea, in contrast to the Japanese case, the preference towards fuel economy improved over time, because Korean consumers are getting more and more sensitive towards fuel costs over time. After that, policy simulations were conducted to simulate which policy sets would decrease the emissions the most. Results show that to achieve different goals via environmental policy, governments should consider the relative weights for such purposes and implement the corresponding policy mix. While there is also the issue of informing consumers with accurate facts on automobile fuels and regaining the trust of the public towards greener automobiles and choices in general, this is a separate long-term goal that is not immediately affected by the policy proposals of this study.

Overall, this study shows that consumer behavior had a significant impact on emissions in the transportation sector. For the policy implication, first, results indicate the effective fuel taxation can contribute to emissions reductions. Hence, as initiating gasoline tax would incorporate challenges due to the complexities, for example, as shown in Chapter 3, consumers might have different preferences towards automobile price, gasoline price, and other vehicle attributes. For example, consumer heterogeneity should be considered when implementing the gasoline tax, because if owners of large, more-polluting cars are more sensitive towards fuel prices, then a gasoline tax will have a more significant impact on emissions since owners of less fuel-efficient cars would reduce miles by more than owners of high fuel-efficient cars. Tackling such a problem can also be a fruitful future research.

The results in Chapters 2 and 3 raise questions about proper regulation and policy tools as well as how taxes and subsidies have not led to the intended environmental outcomes. The existence of direct rebounds is confirmed, as increased automobile ownership exceeds the fuel efficiency improvements. Vehicle ownership is likely to rise because of the introduction of financial incentives: either consumer buys an additional car without disposing of an already owned car, or these incentives enable consumers to purchase a vehicle for the first time.

The results further indicate that policymakers should take account of consumer preferences toward fuel efficiency. Because consumers have become less encouraged to purchase fuel-efficient automobiles over time, incentivizing them would result in emissions rebounds due to the increase in less-fuel-efficient cars sold. Therefore, our result shows that if not appropriately designed, financial incentives would either increase total emissions or decrease average fuel efficiency (or both). This relates to the question on the future policy of Japan and Korea.

Both findings in Japan and Korea show that even if geographically close, consumer behaviors can vary according to the different situations. While Japanese consumers experienced rapid technological development, Korean consumers experience fuel cost fluctuations, and these differences induced consumers in both countries to behave differently, resulting in different emissions implications.

This study can also be extended: First, the model can be extended to include other essential vehicle characteristics other than consumer characteristics. For example, vehicle age is critical for emissions, because emissions standards have become increasingly stringent over time, and because technologies continuously improved to make cars more fuel-efficient and lighter. Therefore, consumer-oriented financial incentives that boost substitution to newer cars would also reduce emissions with less financial burden towards the governments. Such policies can be included in the study as an extension.

Unfortunately, this study only has access to aggregated data on the demand parameters. Having access to micro-level data such as household demographics and/or driving distance data would enable us to study why consumers change their preferences for fuel efficiency as well as model their driving behavior and choices of automobiles. This fruitful direction is left to future research.

Policy Implications, Limitations and Future Research Topics of "Travel Distance and Rebound"

In Chapter 4, the travel behavior of Japanese people was explored, and results indicate that the direct rebound effects towards travel distance or "Green Paradox" of hybrid cars and income exist. For example, hybrid ownership would increase travel distances regardless of income level and hybrid interest. Second, the income level has a positive relationship with travel distances. However, people from the top income group would drive less than the general public. Results also show that factors increasing travel distance would also increase fuel usage except for hybrid ownership: which is a form of "Green Paradox." The results of Chapter 4 indicate the importance of exploring travel distances of consumers, as factors positively correlated to travel distance are also positively related to the on-road emissions. Furthermore, results urge the need for implementing policies according to the socio-demographical identity and vehicle ownership of individuals.

Raising the awareness of rebound effects would prevent a possible rebound. Hybrid owners in the low-income group drive more than people who are not hybrid owners. This result does not indicate that having a hybrid vehicle is not an advantage for low-income groups. Hybrid cars do allow low-income group people more than the regular cars, given the same amount of fuel costs. However, our results imply that the cost-saving function of hybrid cars may have a more significant psychological appeal on people to drive more, that may lead to rebound effects and increase in the fuel costs regardless of the income group. Such implication suggest that what is essential in the future environment policy is to prioritize and prompt behavioral changes of the hybrid vehicle owners.

The differences within the income spectrum and the unusual travel behavior in the top and the lowest income group imply that the one-size-fits-all emission reduction policy in the transportation sector may be less effective. Instead, it poses that the emission reduction policy should account for micro factors such as income level, to realize the travel distance reduction along with the development of the fuel economy level. This study suggests future researches. One possible future research is testing whether the model and implications can be extended to other countries, particularly developing countries. As tackling the oil dependency and on-road emissions are crucial not only for developed countries but also to developing countries, investigating travel behavior using our study as a reference will provide meaningful policy implications to achieve emissions and oil usage reductions successfully.

Another possible extension of this paper would be, investigating the correlation and dynamics between the independent variables. For example, investigating how the socio-demographic variables, including gender split, income difference and region is related to travel distance, would also be the fruitful future research.

Policy Implications, Limitations and Future Research Topics of "Environmental Awareness and Bike-Share Demands"

In Chapter 5, factors affecting bike-sharing in Shanghai and Japan are investigated, and results indicate that different kinds of environment awareness affect differently towards the mode choice. Such a difference indicates the importance of carefully positioning bike-sharing systems, considering the characteristics of the two cities. Results suggested how situational factors, countries, and different types of environmental awareness affected bike-sharing demands in Shanghai and Tokyo. Notably, the results find that positive perspectives such as conserving the natural environment are not correlated to bike-sharing choices when people are commuting.

On the other hand, thee results show that when people are going and returning from shopping, positive perspectives are highly correlated to the bike-sharing demands. This result, in the same line with Chapter 3, also suggests that consumers in the geographically close areas can have different perceptions and that different perceptions affect the mode choice. The results provide insights to policymakers that promoting bike-sharing would require considering diverse perspectives of environmental awareness, as well as situational factors and socio-demographic factors.

As this study only focuses on Shanghai and Tokyo, investigating whether the different types of environmental awareness also have various responses towards bike-sharing in cities and countries other than the two, such as developing countries, would add value in future research. Another possible next research topic is thoroughly investigating the detailed reason and factors on why such differences between the two cities would happen. For example, the results show that in the case of shopping (Scenario 2 and 3), "Indifference" is mostly statistically insignificant for Tokyo. However, results indicate that "Indifference" is a statistically significant variable with positive coefficients, possibly indicating that having a high level of "Indifference" in Tokyo would be positively correlated to more choices of bike-sharing. Understanding these results would require data on more micro-level data, which might include bike ownership, frequency of going shopping, and more detailed questions on environmental awareness to categorize environmental awareness in a precise manner. Answering these topics would be left for future research.

6.2 Future Perspectives

This study provides advantages through investigating the impact of consumer behavior towards emissions from the transportation sector. One of the possible future research topics is incorporating the supply sector to the model. In all chapters, the results indicate that the change in consumer behaviors may increase emissions by increasing the number of vehicles sold, therefore causing rebounds (Chapter 2 and 3), increased travel distances (Chapter 4), and let consumers choose less environmentally friendly transport modes (Chapter 5). Hence, one cannot completely interpret this result as a 'production response.' In other words, the results and implications of this study would be more fruitful if explained with supply sides. For example, firms may also change automobile prices to correspond to consumers' changing preferences towards fuel economy. Furthermore, governments can also shift their policies according to consumer behavior, for example, by setting bike-sharing stations to the shopping area more than the commuting area, as our results indicate the people who are going/returning from the shopping show higher usages of bike-sharing compared to those who commute. Future research that estimates a dynamic response from suppliers or governments to consumer behavior would be an essential complement of this study.

Another possible future research is testing whether the model and implications can be extended to other countries, particularly developing countries. As tackling the oil dependency and on-road emissions are crucial not only for developed countries but also to developing countries, investigating consumer behavior and seeking for measures that can reduce emissions using this study as a reference will provide meaningful policy implications to achieve emissions and oil usage reductions successfully.

REFERENCES

Aamaas, Borgar, Jens Borken-Kleefeld, and Glen P. Peters (2013). "The climate impact of travel behavior: A German case study with illustrative mitigation options". In: *Environmental Science & Policy* 33, pp. 273–282. DOI: 10.1016/j.envsci.2013.06.009.

Ahn, Jiwoon, Gicheol Jeong, and Yeonbae Kim (2008). "A Forecast Of Household Ownership And Use Of Alternative Fuel Vehicles: A Multiple Discrete-continuous Choice Approach". In: *Energy Economics* 30, pp. 2091–2104.

Al-Alawi, Baha M. and Thomas H. Bradley (2013). "Total Cost of Ownership, Payback, and Consumer Preference Modeling of Plug-in Hybrid Electric Vehicles". In: *Applied Energy* 103, pp. 488–506.

Anderson, Soren T. et al. (2011). "Automobile Fuel Economy Standards: Impacts, Efficiency, and Alternative". In: *Review of Environmental Economics and Policy* 5.1, pp. 89–108.

Bamberg, Sebastian, Icek Ajzen, and Peter Schmidt (2013). "The Roles of Past Behavior, Habit, and Reasoned Action". In: *Basic and Applied Social Psychology* 25.3.

Barla, Philippe et al. (2009). "Traveled Distance, Stock And Fuel Efficiency Of Private Vehicles In Canada: Price Elasticities And Rebound Effect". In: *Transportation* 36, pp. 389–402.

Berry, Steven T. (1994). "Estimating Discrete-Choice Models of Product Differentiation". In: *RAND Journal of Economics* 25.2, pp. 242–262.

Berry, Steven, James Levinsohn, and Ariel Pakes (1995). "Automobile Prices in Market Equilibrium". In: *Econometrica* 63.4, pp. 841–890.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan (2004). "How Much Should We Trust Differences-In-Differences Estimates?" In: *The Quarterly Journal of Economics* 119, pp. 249–275.

Bike Share Program Investigation-Best Practices Investigation (2009). METROLINX.

Bitsche, O. and G. Gutmann (2004). "Systems for Hybrid Cars". In: *Journal of Power Sources* 127, pp. 8–15.

Bjertnæs, Geir H. (2019). “Efficient Combinations of Taxes on Fuel and Vehicles”. English. In: *The Energy Journal* 40.

Borger, Bruno De, Ismir Mulalic, and Jan Rouwendal. (2016). “Measuring The Rebound Effect With Micro Data: A First Difference Approach”. In: *Journal of Environmental Economics and Management* 79, pp. 1–17.

Breetz, Hanna L. and Deborah Salon (2018). “Do electric vehicles need subsidies? Ownership costs for conventional, hybrid, and electric vehicles in 14 U.S. cities”. In: *Energy Policy* 120, pp. 238–249. DOI: 10.1016/j.enpol.2018.05.038.

Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer (2009). “Pain at the Pump: The Differential Effect of Gasoline Prices on New and Used Automobile Markets”. In: *NBER Working Paper No. 15590*.

Campbell, Andrew A. et al. (2016). “Factors influencing the choice of shared bicycles and shared electric bikes in Beijing”. In: *Transportation Research Part C: Emerging Technologies* 67, pp. 399–414. DOI: 10.1016/j.trc.2016.03.004.

Carley, Sanya et al. (2017). “Global Expansion of Renewable Energy Generation: An Analysis of Policy Instruments”. In: *Environmental and Resource Economics* 68, pp. 397–440.

Caulfield, Brian, Séona Farrell, and Brian McMahon (2010). “Examining Individuals Preferences for Hybrid Electric and Alternatively Fuelled Vehicles”. In: *Transport Policy* 17.6, pp. 381–387.

Cervero, Robert (2002). “Induced Travel Demand: Research Design, Empirical Evidence, and Normative Policies”. In: *Journal of Planning Literature* 17.1, pp. 3–20.

Chen, Wendy Y. and Frankie Hin Ting Cho (2019). “Environmental information disclosure and societal preferences for urban river restoration: Latent class modelling of a discrete-choice experiment”. In: *Journal of Cleaner Production* 231, pp. 1294–1306. DOI: 10.1016/j.jclepro.2019.05.307.

Chen, Xiao et al. (2018). “How vehicle market is segmented and influenced by subsidy policy: A theoretical study”. In: *Transportation Research Part A: Policy and Practice* 118, pp. 776–782. DOI: 10.1016/j.tra.2018.10.026.

Cheng, Yung-Hsiang and Ssu-Yun Chen (2015). “Perceived accessibility, mobility, and connectivity of public transportation systems”. In: *Transportation Research Part A: Policy and Practice* 77, pp. 386–403. DOI: 10.1016/j.tra.2015.05.003.

Choisdealbha, Áine Nı, Shane Timmons, and Peter D. Lunn (2020). “Experimental evidence for the effects of emissions charges and efficiency information on consumer car choices”. In: *Journal of Cleaner Production* 254, p. 120140. DOI: 10.1016/j.jclepro.2020.120140.

Choo, Sangho and Patricia L Mokhtarian (2004). “What Type of Vehicle Do People Drive? The Role of Attitude and Lifestyle in Influencing Vehicle Type Choice”. In: *Transportation Research Part A: Policy and Practice* 38.3, pp. 201–222.

Clark, Christopher F., Matthew J. Kotchen, and Michael R. Moore (2003). “Internal and external influences on pro-environmental behavior: Participation in a green electricity program”. In: *Journal of Environmental Psychology* 23, pp. 237–246.

Clerides, Sofronis and Theodoros Zachariadis (2008). “The Effect of Standards and Fuel Prices on Automobile Fuel Economy: An International Analysis”. In: *Energy Economics* 30.5, pp. 2657–2672.

Creutzig, Felix et al. (2011). “Climate Policies For Road Transport Revisited (I): Evaluation Of The Current Framework”. In: *Energy Policy* 39, pp. 2396–2406.

Dahl, C. and T. Sterner (1991). “Analyzing Gasoline Demand Elasticities: A Survey”. In: *Energy Economics* 13, pp. 203–210.

Daziano, Ricardo A. and Denis Bolduc (2013). “Incorporating Pro-environmental Preferences towards Green Automobile Technologies through a Bayesian Hybrid Choice Model”. In: *Transportmetrica A: Transport Science* 9.1, pp. 74–106.

D’Haultfoeuille, Xavier, Isis Durrmeyer, and Philippe Fevrier (2016). “Disentangling Sources of Vehicle Emissions Reduction in France: 2003-2008”. In: *International Journal of Industrial Organization* 47, pp. 186–229.

Diamond, David (2009). “The Impact of Government Incentives for Hybrid-electric Vehicles: Evidence from US States”. In: *Energy Policy* 37, pp. 972–983.

Dimitropoulous, Alexandros, Walid Oueslati, and Christina Sintek (2018). “The Rebound Effect in Road Transport: A Meta-analysis Ofempirical Studies”. In: *Energy Economics* 75, pp. 163–179.

Ding, Chuan et al. (2017). “Investigating The Impacts of Built Environment on Vehicle Miles Traveled And Energy Consumption: Differences Between Commuting and Noncommuting Trips”. In: *Cities* 68, pp. 25–36.

“Energy Efficiency And Consumption - The Rebound Effect - A Survey” (2000). In: *Energy Policy* 28, pp. 389–401.

Faghih-Imani, Ahmadreza et al. (2017). “An Empirical Analysis of Bike Sharing Usage and Rebalancing: Evidence from Barcelona and Seville”. In: *Transportation Research Part A* 97, pp. 177–191.

Fishman, Elliot (2016). “Bikeshare: A Review of Recent Literature”. In: *Transport Reviews* 36.1, pp. 92–113.

Frade, Ines and Anabela Riberio (2014). "Bicycle Sharing System Demand". In: *EWGT2013 – 16th Meeting of the EURO Working Group on Transportation* 111, pp. 518–527.

Galarraga, Ibon, Steffen Kallbekken, and Alessandro Silvestri (2020). "Consumer purchases of energy-efficient cars: How different labelling schemes could affect consumer response to price changes". In: *Energy Policy* 137, p. 111181. DOI: 10.1016/j.enpol.2019.111181.

Gallagher, Kelly S. and Erich Muehlegger (2011). "Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology". In: *Journal of Environmental Economics and Management* 61.1, pp. 1–15.

Goodwin, Phil, Joyce Dargay, and Mark Hanly (2003). "Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review". In: *Transport Reviews* 24, pp. 275–292.

Greene, David L. (2012). "Rebound 2007: Analysis Of U.S. Light-duty Vehicle Travel Statistics". In: *Energy Policy* 41, pp. 14–28.

Greene, D.L. (1990). "CAFE Or Price? An Analysis Of The Effects Of Federal Fuel Economy Regulations And Gasoline Price On New Car MPG, 1978–1989". In: *Energy Journal* 11, pp. 37–57.

Haan, Peter De, Michel G.Mueller, and Roland W. Scholz (2009). "How Much Do Incentives Affect Car Purchase? Agent-based Microsimulation of Consumer Choice of New Cars, Part II: Forecasting Effects of Feebates Based on Energy-efficiency". In: *Energy Policy* 37.3, pp. 1083–1094.

Haan, Peter De, Michel G. Mueller, and Anja Peters (2006). "Does the Hybrid Toyota Prius Lead to Rebound Effects? Analysis of Size and Number of Cars Previously Owned by Swiss Prius Buyer". In: *Ecological Economics* 58, pp. 592–605.

Haan, Peter de, Michel G.Mueller, and Anja Peters. (2006). "Does The Hybrid Toyota Prius Lead to Rebound Effects? Analysis of Size and Number of Cars Previously Owned by Swiss Prius Buyers". In: *Ecological Economics* 58, pp. 592–605.

Haan, Peter de, Anja Peters, and Roland W. Scholz (2007). "Reducing Energy Consumption In Road Transport Through Hybrid Vehicles: Investigation Of Rebound Effects, And Possible Effects Of Tax Rebates". In: *Journal of Cleaner Production* 15, pp. 1076–1084.

Hackbarth, André and Reinhard Madlener (2013). "Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis". In: *Transportation Research Part D: Transport and Environment* 25, pp. 5–17.

Hamamoto, Mitsutsugu (2019). "An Empirical Study on the Behavior of Hybrid-electric Vehicle Purchasers". In: *Energy Policy* 125, pp. 286–292.

Hardman, Scott et al. (2017). "The effectiveness of financial purchase incentives for battery electric vehicles – A review of the evidence". In: *Renewable Sustainable Energy Rev.* 80, pp. 1100–1111.

Heath, Yuko and Robert Gifford (2002). "Extending the Theory of Planned Behavior: Predicting the Use of Public Transportation". In: *Journal of Applied Social Psychology* 32.10, pp. 2154–2189.

Hess, Stephane et al. (2012). "A Joint Model for Vehicle Type and Fuel Type Choice: Evidence from a Cross-Nested Logit Study". In: *Transportation* 39, pp. 593–625.

Hiratsuka, J., G. Perlaviciute, and L. Steg (2018). "Testing VBN theory in Japan: Relationships between values, beliefs, norms, and acceptability and expected effects of a car pricing policy". In: *Transportation Research Part F: Traffic Psychology and Behaviour* 53, pp. 74–83. DOI: 10.1016/j.trf.2017.12.015.

Hird, Mackenzie D. and Seastian M. Pfotenhauer (2017). "How Complex International Partnerships Shape Domestic Research Clusters: Difference-in-Difference Network Formation and Research Re-orientation in the MIT Portugal Program". In: *Research Policy* 46.3, pp. 557–572.

Hopkins, Debbie (2016). "Can environmental awareness explain declining preference for car-based mobility amongst generation Y? A qualitative examination of learn to drive behaviours". In: *Transportation Research Part A: Policy and Practice* 94, pp. 149–163. DOI: 10.1016/j.tra.2016.08.028.

Iwaki, Bunta, Yutaka Ishiyama, and Ken Yamashita (2015). "Study on Carbon Dioxide Emission Reduction Potential in the Residential Sector of Niigata Prefecture Based on a Questionnaire Survey". In: *People and Environment* 41.3, pp. 15–26.

Jacobson, M.Z., W.G. Colella, and D.M. Golden (2005). "Cleaning the Air and Improving Health with Hydrogen Fuel-Cell Vehicles". In: *Science* 308.5730, pp. 1901–1905.

Jenn, Alan, Inas L. Azevedo, and Pedro Ferreira (2013). "The Impact of Federal Incentives on the Adoption of Hybrid Electric Vehicles in the United States". In: *Energy Economics* 40, pp. 936–942.

Johansson, Maria Vredin, Tobias Heldt, and Per Johansson (2006). "The effects of attitudes and personality traits on mode choice". In: *Transportation Research Part A: Policy and Practice* 40.6, pp. 507–525. DOI: 10.1016/j.tra.2005.09.001.

Kagawa, Shigemi et al. (2013). "Better Cars Or Older Cars?: Assessing CO2 Emission Reduction Potential Of Passenger Vehicle Replacement Programs". In: *Global Environmental Change* 23, pp. 1807–1818.

Kasraiana, Dena, Kees Maat, and Bert van Wee (2018). “Urban Developments and Daily Travel Distances: Fixed, Random and Hybrid Effects Models Using A Dutch Pseudo-panel over Three Decades”. In: *Journal of Transport Geography* 72, pp. 228–236.

Kim, Jinhee, Soora Rasouli, and Harry Timmermans (2014). “Expanding Scope Of Hybrid Choice Models Allowing For Mixture Of Social Influences And Latent Attitudes: Application To Intended Purchase Of Electric Cars”. In: *Transportation Research Part A: Policy and Practice* 69, pp. 71–85.

Klier, Thomas and Joshua Linn (2012). “New-vehicle characteristics and the cost of the Corporate Average Fuel Economy standard”. In: *The RAND Journal of Economics* 43.1, pp. 186–213.

Knittel, Christopher R. (2012). “Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector”. In: *American Economic Review* 101, pp. 3368–3399.

Konishi, Yoshifumi and Meng Zhao (2015). “Can Green Car Taxes Restore Efficiency? Evidence from the Japanese New Car Market”. In: *Journal of the Association of Environmental and Resource Economists* 4.1, pp. 51–87.

Konstantakis, Konstantinos N., Christina Milioti, and Panayotis G. Michaelides (2017). “Modeling the Dynamic Response of Automobile Sales in Troubled Times: A Real-Time Vector Autoregressive Analysis with Causality Testing for Greece”. In: *Transport Policy* 2017, pp. 75–81.

Li, Weibo and Maria Kamargianni (2018). “Providing quantified evidence to policy makers for promoting bike-sharing in heavily air-polluted cities: A mode choice model and policy simulation for Taiyuan-China”. In: *Transportation Research Part A: Policy and Practice* 111, pp. 277–291. DOI: 10.1016/j.tra.2018.01.019.

Liu, Diyi et al. (2017). “The influence of social-psychological factors on the intention to choose low-carbon travel modes in Tianjin, China”. In: *Transportation Research Part A: Policy and Practice* 105, pp. 42–53. DOI: 10.1016/j.tra.2017.08.004.

Liu, Weisheng, Ying Liu, and Boqiang Lin (2018). “Empirical Analysis on Energy Rebound Effect from the Perspective of Technological Progress—a Case Study of China’s Transport Sector”. In: *Journal of Cleaner Production* 205, pp. 1082–1093.

Luo, Xlao et al. (2017). “Analysis on Spatial-Temporal Features of Taxis’ Emissions from Big Data Informed Travel Patterns: a Case of Shanghai, China”. In: *Journal of Cleaner Production* 142.2, pp. 926–935.

M., Ben-Akiva and Bierlaire M. (1999). “Discrete Choice Methods and their Applications to Short Term Travel Decisions.” In: *Handbook of Transportation Science* 23, pp. 5–33.

MacKenzie, Ian A. and Markus Ohndorf (2012). “Cap-and-trade, Taxes, And Distributional Conflict”. In: *Journal of Environmental Economics and Management* 63, pp. 51–65.

Mateo-Babiano, Iderlina, SameeraKumar, and AlvinMejiab (2017). “Bicycle sharing in Asia: a stakeholder perception and possible futures”. In: *Transportation Research Procedia* 25, pp. 4966–4978.

Matsuhashi, Keisuke and Toshinori Ariga (2016). “Estimation of Passenger Car CO2 Emissions With Urban Population Density Scenarios for Low Carbon Transportation in Japan”. In: *IATSS Research* 39.2, pp. 117–120.

McFadden, Daniel (1977). “Quantitative Methods for Analyzing Travel Behaviour of Individuals: Some Recent Developments,” in: *Cowles Foundation Discussion Papers*.

Meddin, Russell (2013). “Dock It - 2014, Bike Sharing World [Online]”. In: *D.C.: Bike Share Blogspot*.

Midgley, Peter (2011). “Bicycle-Sharing Schemes: Enhancing Sustainabile Mobility in Urban Areas”. In: *Commission on Sustainable Development Nineteenth Session*, p. 2011.

Moshiri, Saeed and Aliyev Kamil (2017). “Rebound Effect of Efficiency Improvement in Passenger Cars on Gasoline Consumption in Canada”. In: *Ecological Economics* 131, pp. 330–341.

M.Sallee, James, Sarah E.West, and Wei Fan (2016). “Do Consumers Recognize the Value of Fuel Economy? Evidence from Used Car Prices and Gasoline Price Fluctuations”. In: *Journal of Public Economics* 135, pp. 61–73.

Munyon, Vinola Vincent, William Bowen, and John Holcombe (2018). “Vehicle Fuel Economy and Vehicle Miles Traveled: An Empirical Investigation of Jevons’s Paradox”. In: *Energy Research & Social Science* 38, pp. 19–27.

Nässén, J. and J. Holmberg (2009). “Quantifying The Rebound Effects Of Energy Efficiency Improvements And Energy Conserving Behaviour In Sweden”. In: *Energy Efficiency* 2, pp. 221–231.

Noland, Robert B (2011). “Relationships Between Highway Capacity and Induced Vehicle Travel”. In: *Transportation Research A: Policy and Practice* 35.1, pp. 47–72.

Nordfjærn, Trond et al. (2019). “The role of social cognition in perceived thresholds for transport mode change”. In: *Transport Policy* 83, pp. 88–96. DOI: 10.1016/j.tranpol.2019.09.006.

Nordhaus, William (2015). “Climate Clubs: Overcoming Free-Riding in International Climate Policy”. In: *American Economic Review* 105.4, pp. 1339–1370.

Nordlund, A., J. Jansson, and K. Westin (2018). “Acceptability of electric vehicle aimed measures: Effects of norm activation, perceived justice and effectiveness”. In: *Transportation Research Part A: Policy and Practice* 117, pp. 205–213. DOI: 10.1016/j.tra.2018.08.033.

Parkes, Stephen D. et al. (2013). “Understanding the Diffusion of Public Bikesharing Systems: Evidence from Europe and North America”. In: *Journal of Transport Geography,* 31, pp. 94–103.

Paulssen, Marcel et al. (2014). “Values, Attitudes and Travel Behavior: a Hierarchical Latent Variable Mixed Logit Model of Travel Mode Choice”. In: *Transportation* 41, pp. 873–888.

Penz, Elfriede, Barbara Hartl, and Eva Hofmann (2019). “Explaining consumer choice of low carbon footprint goods using the behavioral spillover effect in German-speaking countries”. In: *Journal of Cleaner Production* 214, pp. 429–439. DOI: 10.1016/j.jclepro.2018.12.270.

Polzin, Steven E., Xuehao Chu, and Jodi Godfrey (2014). “The Impact of Millennials’ Travel Behavior on Future Personal Vehicle Travel”. In: *Energy Strategy Reviews* 5, pp. 59–65.

Potoglou, Dimitris and Pavlos S. Kanaroglou (2007). “Household Demand and Willingness to Pay for Clean Vehicles”. In: *Transportation Research Part D: Transport and Environment* 12.4, pp. 264–274.

Qui, Lu-Yi and Ling-Yun He (2017). “Can Green Traffic Policies Affect Air Quality? Evidence from A Difference-in-Difference Estimation in China”. In: *Sustainability* 9, p. 1067.

Ralph, Kelcie et al. (2016). “Millennials, built form, and travel insights from a nationwide typology of U.S. neighborhoods”. In: *Journal of Transport Geography* 57, pp. 228–226.

Regue, Robert and Will Recker (2014). “Proactive Vehicle Routing with Inferred Demand to Solve the Bikesharing Rebalancing Problem”. In: *Transportation Research Part E* 72, pp. 192–209.

Reichert, Alexander, Christian Holz-Rau, and Joachim Scheiner (2016). “GHG emissions in daily travel and long-distance travel in Germany – Social and spatial correlates”. In: *Transportation Research Part D: Transport and Environment* 49, pp. 25–43. DOI: 10.1016/j.trd.2016.08.029.

Ringquist, Evan J. and Tatiana Kostadinova (2004). “Assessing the Effectiveness of International Environmental Agreements: The Case of the 1985 Helsinki Protocol”. In: *American Journal of Political Science* 49, pp. 86–102.

Sallee, James (2011). “The Surprising Incidence of Tax Credits for the Toyota Prius”. In: *American Economics Journal: Economics Policy* 3, pp. 189–219.

Sallee, James M. (2008). “The Incidence of Tax Credits for Hybrid Vehicles”. In: *University of Michigan*.

Schipper, L. (2008). "Automobile Fuel Economy and CO2 Emissions in Industrialized Countries: Troubling Trends Through 2005-2006." In: *Transportation Research Board 87th Annual Meeting, Paper08-2784*.

Shaheen, Susan A., Stacey Guzman, and Hua Zhang (2010). "Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future". In: *Transportation Research Record: Journal of the Transportation Research Board*, p. 2143.

Si, Hongyun et al. (2019). "Mapping the Bike Sharing Research Published from 2010 to 2018: A Scientometric Review". In: *Journal of Cleaner Production* 213, pp. 415–247.

Small, Kenneth and Kurt Van Dender (2007). "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect". In: *Energy Journal* 28, pp. 25–52.

Spielmann, Michael, Peter de Haan, and Roland W.Scholz (2008). "Environmental Rebound Effects of High-Speed Transport Technologies: a Case Study of Climate Change Rebound Effects of a Future Underground Maglev Train System". In: *Journal of Cleaner Production* 16.13, pp. 1388–1398.

Sprei, F. and D. Bauner (2011). "Incentives Impact on EV Markets – Report to the Electromobility Project". In: *Report to the Electromobility Project, Viktoria Institute,Gothenburg.*

Sprei, Francis and Stern Karlsson (2013). "Energy Efficiency Versus Gains In Consumer Amenities: An Example From New Cars Sold In Sweden." In: *Energy Policy* 53, pp. 490–499.

Stapleton, Lee, Steve Sorrell, and Tim Schwanen (2017a). "Peak Car And Increasing Rebound: A Closer Look At Car Travel Trends In Great Britain". In: *Transportation Research Part D: Transport and Environment* 53, pp. 217–233.

— (2017b). "Peak Car and Increasing Rebound: A Closer Look at Car Travel Trends in Great Britain". In: *Transportation Reserach Part D: Transport and Environment* 53, pp. 217–233.

Stepp, Matthew D. et al. (2009). "Greenhouse gas mitigation policies and the transportation sector: The role of feedback effects on policy effectiveness". In: *Energy Policy* 37, pp. 2774–2787.

Tang, Yang, Haixiao Pan, and Yibo Fei (2017). "Research on Users' Frequency of Ride in Shanghai Minhang Bikesharing System". In: *Transportation Research Procedia*, pp. 4979–4987.

Tanishita, Masayoshi, Sigeru Kashima, and Willian J. Hayes (2003). "Impact Analysis of Car-Related Taxes on Fuel Consumption in Japan". In: *Journal of Transport Economics and Policy* 37.2, pp. 133–155.

Tran, Kenneth E. and Clifford Winston (2007). "Vehicle Choice Behavior and the Declining Market Share of U.S. Automokaers". In: *International Economic Review* 48.4, pp. 1469–1496.

Tran, Tien Dung, Nicolas Ovtracht, and Bruno Faivre d'Arcier (2015). "Modeling Bike Sharing System using Built Environment Factors". In: *Procedia CIRP* 30, pp. 293–298. DOI: 10.1016/j.procir.2015.02.156.

Tran, Yen, Toshiyuki Yamamoto, and Hitomi Sato (2020). "The influences of environmentalism and attitude towards physical activity on mode choice: The new evidences". In: *Transportation Research Part A: Policy and Practice* 134, pp. 211–226. DOI: 10.1016/j.tra.2020.02.012.

Vivanco, David Font, Jaume Freire-González, et al. (2014). "The Remarkable Environmental Rebound Effect of Electric Cars: A Microeconomic Approach". en. In: *Environmental Science & Technology* 48.20, pp. 12063–12072.

Vivanco, David Font, Rene Kemp, and Ester van der Voet (2016). "How To Deal With The Rebound Effect? A Policy-oriented Approach". In: *Energy Policy* 94, pp. 114–125.

Wadud, Zia, Daniel J. Graham, and Robert B. Noland (2010). "Gasoline Demand with Heterogeneity in Household Responses". In: *The Energy Journal* 31.1, pp. 47–74.

Wang, Kailai and Gulsah Akar (2019). "Gender gap generators for bike share ridership: Evidence from Citi Bike system in New York City". In: *Journal of Transport Geography* 76, pp. 1–9. DOI: 10.1016/j.jtrangeo.2019.02.003.

Weber, Sylvain and Mehdi Farsi (2018). *Travel Distance, Fuel Efficiency, And Vehicle Weight: An Estimation Of The Rebound Effect Using Individual Data In Switzerland*. IRENE Working Paper 14-03. Neuchâtel.

West, Jeremy et al. (2017). "Vehicle Miles (Not) Traveled: Fuel Economy Requirements, Vehicle Characteristics, and Household Driving". In: *Journal of Public Economics* 145, pp. 65–81.

Whitmarsh, Lorraine and Saffron O'Neill (2010). "Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours". In: *Journal of Environmental Psychology* 30.3, pp. 305–314. DOI: 10.1016/j.jenvp.2010.01.003.

Wu, Xiaoxu et al. (2016). "Impact of Climate Change on Human Infectious Diseases: Empirical Evidence and Human Adaptation". In: *Environment International,* 86, pp. 14–23.

Xing, Jianwei, Leard Benjamin, and Shajun Li (2018). "What Does an Electric Vehicle Replace?" In: *preliminary draft.*

Yang, Yuan, Can Wang, and Wenling Liu (2018). "Urban Daily Travel Carbon Emissions Accounting and Mitigation Potential Analysis Using Surveyed Individual Data". In: *Journal of Cleaner Production* 192, pp. 821–834.

Yoo, Sunbin, Naoki Wakamori, and Yoshikuni Yoshida (2019). "Which Comes First in CO2 Emissions: Preference or Technology? Evidence from the Automobile Industry". In: *Working paper*.

Yoo, Sunbin et al. (2019a). "Revisiting Jevons's Paradox of Energy Rebound: Policy Implications and Empirical Evidence in Consumer-Oriented Financial Incentives from the Japanese Automobile Market, 2006–2016". In: *Energy Policy* forthcoming.

— (2019b). "Revisiting Jevons's Paradox of Energy Rebound: Policy Implications and Empirical Evidence in Consumer-Oriented Financial Incentives from the Japanese Automobile Market, 2006–2016". In: *Energy Policy* forthcoming.

Zhang, Yongping and Zhifu Mi (2018). "Environmental Benefits of Bik Sharing: A Big Data-based Analysis". In: *Applied Energy* 220.

Zhang, Yue-Jun et al. (2015). "Direct Energy Rebound Effect For Road Passenger Transport In China: A Dynamic Panel Quantile Regression Approach". In: *Energy Policy* 87, pp. 303–313.

Zhao, Pengjun and Shengxiao Li (2017). "Bicycle-metro integration in a growing city: The determinants of cycling as a transfer mode in metro station areas in Beijing". In: *Transportation Research Part A: Policy and Practice* 99, pp. 46–60. DOI: 10.1016/j.tra.2017.03.003.

Zhao, Pengjun, Shengxiao Li, et al. (2018). "How does air pollution influence cycling behaviour? Evidence from Beijing". In: *Transportation Research Part D: Transport and Environment* 63, pp. 826–838. DOI: 10.1016/j.trd.2018.07.015.

Zhuge, Chengxiang et al. (2020). "The potential influence of cost-related factors on the adoption of electric vehicle: An integrated micro-simulation approach". In: *J. Clean. Prod.* 250, p. 119479.

Ziegler, Adreas (2012). "Individual Characteristics and Stated Preferences for Alternative Energy Sources and Propulsion Technologies in Vehicles: A Discrete Choice Analysis for Germany". In: *Transportation Research Part A: Policy and Practice* 46.9, pp. 1372–1385.

APPENDIX

Appendix A

Chapter 2

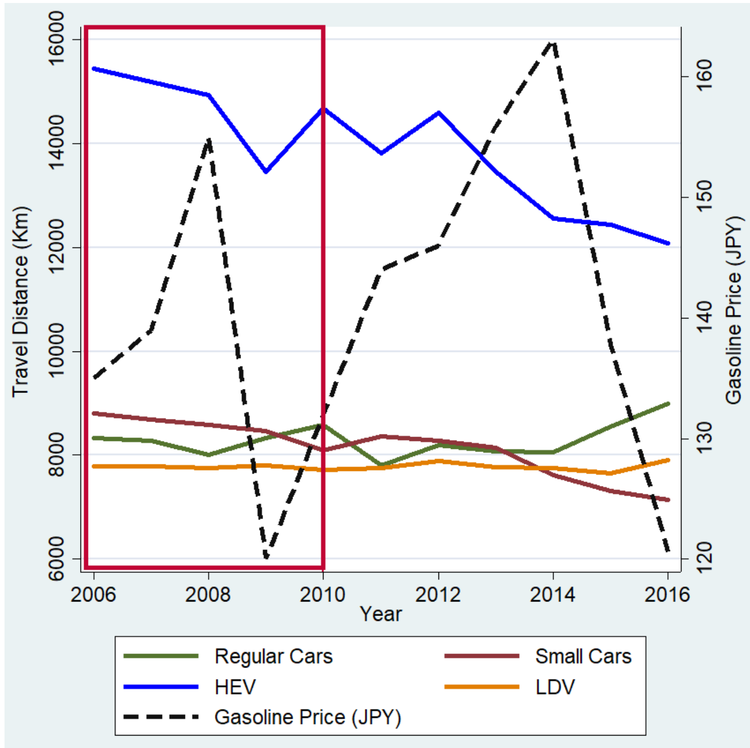
Appendix

Th driving distances of hybrid automobiles were regressed to gasoline price after 2010. Let D_{a,t_2010} is the travel or driving distance of automobile type a after 2010, then the driving distance was extrapolated as in Equation A.1.

$$D_{a,t_{2010}} = \alpha FC_t + \epsilon_{D_{a,t}} \tag{A.1}$$

FC_t is the fuel cost of year t, and $\epsilon_{D_{a,t}}$ is an error term. Driving distances were regressed to gasoline price, then extrapolated driving distances from 2006 to 2009 according to the estimated parameters.

Figure A1 Driving Distance According to Car Type. Vertical line refers to year 2010.



A1 Placebo Test

This subsection presents the results of the placebo tests of all dependent variables. The results are consistent with the estimates in Section 2.3.2.

Table A1 Placebo Test Results: Dependent variable: TFU.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.561***	-2.482***	-2.392***	-2.752***
	(0.078)	(0.235)	(0.235)	(0.230)
Policies				
Fuel Economy * Year 2006	0.053***	0.057***	0.042***	0.040***
	(0.010)	(0.009)	(0.010)	(0.010)
Fuel Economy * Year 2007	0.044***	0.047***	0.032**	0.029**
	(0.009)	(0.009)	(0.010)	(0.009)
Fuel Economy * Year 2009	0.038**	0.042*	0.024	0.021
	(0.012)	(0.011)	(0.012)	(0.012)
Time Trend			-0.086***	-0.092***
			(0.024)	(0.023)
Sales * Year 2015	0.025	0.028	0.059**	0.058**
(Income Tax Reform)	(0.021)	(0.020)	(0.022)	(0.021)
Gasoline Price	1.241*	1.386*	1.061	0.976
	(0.588)	(0.564)	(0.568)	(0.546)
Vehicle attributes				
Weight		3.860***	3.912***	3.989***
		(0.420)	(0.418)	(0.406)
Displacement		-0.963**	-1.164**	-1.724***
		(0.353)	(0.355)	(0.350)
Horsepower		1.372***	1.399***	2.040***
		(0.289)	(0.288)	(0.286)
Light-Duty Vehicles		0.533*	0.433*	0.758***
		(0.215)	(0.216)	(0.211)
Constant	4.805*	-13.20***	-10.41***	-8.557**
	(2.402)	(2.917)	(2.983)	(2.846)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1424	1424	1424	1424
R-sq	0.085	0.166	0.173	0.242

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table A2 Placebo Test Results: Dependent variable: TFU*Travel Distance.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.527***	-2.495***	-2.401***	-2.759***
	(0.078)	(0.235)	(0.235)	(0.230)
Policies				
Fuel Economy * Year 2006	0.055***	0.059***	0.043***	0.040***
	(0.010)	(0.009)	(0.010)	(0.010)
Fuel Economy * Year 2007	0.045***	0.048***	0.033**	0.029**
	(0.009)	(0.009)	(0.010)	(0.009)
Fuel Economy * Year 2009	0.038**	0.041***	0.022	0.020
	(0.012)	(0.011)	(0.012)	(0.012)
Time Trend			-0.090***	-0.096***
			(0.024)	(0.023)
Sales * Year 2015	0.022	0.026	0.058**	0.057**
(Income Tax Reform)	(0.021)	(0.020)	(0.022)	(0.021)
Gasoline Price	1.092	1.230*	0.890	0.807
	(0.588)	(0.564)	(0.569)	(0.546)
Vehicle attributes				
Weight		3.845***	3.900***	3.966***
		(0.420)	(0.418)	(0.406)
Displacement		-1.006**	-1.216**	-1.772***
		(0.353)	(0.356)	(0.350)
Horsepower		1.443***	1.417***	2.109***
		(0.290)	(0.288)	(0.286)
Light-Duty Vehicles		0.462*	0.357	0.681**
		(0.215)	(0.216)	(0.211)
Constant	12.35***	-4.967	-2.490	-0.553**
	(3.027)	(3.547)	(3.592)	(3.467)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1424	1424	1424	1424
R-sq	0.082	0.165	0.173	0.242

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table A3 Placebo Test Results: Dependent variable: TFC.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.561***	-2.482***	-2.392***	-2.752***
	(0.078)	(0.235)	(0.235)	(0.230)
Policies				
Fuel Economy * Year 2006	0.053***	0.057***	0.042***	0.040***
	(0.010)	(0.009)	(0.010)	(0.010)
Fuel Economy * Year 2007	0.044***	0.047***	0.032**	0.029**
	(0.009)	(0.009)	(0.010)	(0.009)
Fuel Economy * Year 2009	0.038**	0.042***	0.024	0.021
	(0.012)	(0.011)	(0.012)	(0.012)
Time Trend			-0.086***	-0.092***
			(0.024)	(0.023)
Sales * Year 2015	0.025	0.028	0.059**	0.058**
(Income Tax Reform)	(0.021)	(0.020)	(0.022)	(0.021)
Gasoline Price	2.241*	2.386*	2.061***	1.976***
	(0.588)	(0.564)	(0.568)	(0.546)
Vehicle attributes				
Weight		3.860***	3.912***	3.989***
		(0.420)	(0.418)	(0.406)
Displacement		-0.963**	-1.164**	-1.724***
		(0.353)	(0.355)	(0.350)
Horsepower		1.372***	1.399***	2.040***
		(0.289)	(0.288)	(0.286)
Light-Duty Vehicles		0.533*	0.433*	0.758***
		(0.215)	(0.216)	(0.211)
Constant	2.782	-14.92***	-12.55***	-10.65**
	(3.020)	(3.544)	(3.589)	(3.465)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1424	1424	1424	1424
R-sq	0.087	0.167	0.175	0.243

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table A4 Placebo Test Results: Dependent variable: TFC*Travel Distance.

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.527***	-2.495***	-2.401***	-2.759***
	(0.078)	(0.235)	(0.235)	(0.230)
Policies				
Fuel Economy * Year 2006	0.055***	0.059***	0.043***	0.040***
	(0.010)	(0.009)	(0.010)	(0.010)
Fuel Economy * Year 2007	0.045***	0.048***	0.033**	0.029**
	(0.009)	(0.009)	(0.010)	(0.009)
Fuel Economy * Year 2009	0.038**	0.041***	0.022	0.020
	(0.012)	(0.011)	(0.012)	(0.012)
Time Trend			-0.090***	-0.096***
			(0.024)	(0.023)
Sales * Year 2015	0.022	0.026	0.058**	0.057**
(Income Tax Reform)	(0.021)	(0.020)	(0.022)	(0.021)
Gasoline Price	1.092	1.230*	0.890	0.807
	(0.588)	(0.564)	(0.569)	(0.546)
Vehicle attributes				
Weight		3.845***	3.900***	3.966***
		(0.420)	(0.418)	(0.406)
Displacement		-1.006**	-1.216**	-1.772***
		(0.353)	(0.356)	(0.350)
Horsepower		1.443***	1.417***	2.109***
		(0.290)	(0.288)	(0.286)
Light-Duty Vehicles		0.462*	0.357	0.681**
		(0.215)	(0.216)	(0.211)
Constant	12.35***	-4.967	-2.490	-0.553**
	(3.027)	(3.547)	(3.592)	(3.467)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1424	1424	1424	1424
R-sq	0.083	0.166	0.174	0.243

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table A5 Placebo Test Results: Dependent variable: Sales (Q).

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.991***	-2.601***	-2.526***	-2.887***
	(0.0793)	(0.242)	(0.243)	(0.237)
Policies				
Fuel Economy * Year 2006	0.0516***	0.0556***	0.0428***	0.0404***
	(0.010)	(0.010)	(0.011)	(0.010)
Fuel Economy * Year 2007	0.043***	0.046***	0.034**	0.030**
	(0.009)	(0.009)	(0.010)	(0.010)
Fuel Economy * Year 2009	0.038***	0.042***	0.026*	0.024
	(0.012)	(0.012)	(0.013)	(0.012)
Time Trend			-0.071***	-0.079***
			(0.025)	(0.024)
Sales * Year 2015	0.034*	0.036*	0.061**	0.060**
(Income Tax Reform)	(0.021)	(0.020)	(0.022)	(0.021)
Gasoline Price	1.215*	1.362*	1.092	1.001
	(0.600)	(0.581)	(0.587)	(0.563)
Vehicle attributes				
Weight		3.289***	3.333***	3.401***
		(0.433)	(0.432)	(0.418)
Displacement		-1.288***	-1.455***	-2.044***
		(0.363)	(0.367)	(0.361)
Horsepower		1.469***	1.492***	2.152***
		(0.298)	(0.297)	(0.294)
Light-Duty Vehicles		0.247	0164	0.495*
		(0.221)	(0.223)	(0.217)
Constant	7.859*	-5.453	-3.484	-1.418
	(3.080)	(3.652)	(3.705)	(3.573)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1424	1424	1424	1424
R-sq	0.154	0.212	0.217	0.284

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Table A6 Placebo Test Results: Dependent variable: Fuel Economy (E).

	Model (i) Limited Controls	**Model (ii) Limited Controls**	**Model (iii) Limited Controls**	**Model (iv) Full Model**
Automobile Price	-0.43***	-0.119***	-0.134***	-0.135***
	(0.008)	(0.020)	(0.020)	(0.019)
Policies				
Fuel Economy * Year 2006	-0.0001	-0.0006	0.002*	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
Fuel Economy * Year 2007	-0.0003	-0.001	0.002*	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
Fuel Economy * Year 2009	0.0003	-0.0002	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Time Trend			0.014***	0.013***
			(0.002)	(0.002)
Sales * Year 2015	0.009*	0.008***	0.0025	0.0022
(Income Tax Reform)	(0.002)	(0.002)	(0.002)	(0.002)
Gasoline Price	-0.0265	-0.0237	0.0306	0.0251
	(0.060)	(0.048)	(0.047)	(0.046)
Vehicle attributes				
Weight		-0.571***	-0.580***	-0.588***
		(0.036)	(0.035)	(0.034)
Displacement		-0.325***	-0.292***	-0.320***
		(0.030)	(0.030)	(0.030)
Horsepower		0.097***	0.083***	0.112***
		(0.024)	(0.024)	(0.024)
Light-Duty Vehicles		-0.286***	-0.269***	-0.264***
		(0.018)	(0.018)	(0.018)
Constant	5.078***	9.465***	9.070***	9.229***
	(0.310)	(0.299)	(0.299)	(0.293)
Year Trends	No	No	Yes	Yes
Company Fixed Effects	No	No	No	Yes
Number Of Observations	1424	1424	1424	1424
R-sq	0.687	0.807	0.814	0.824

*Note: Standard errors in Parentheses. *,**, and *** represent significance at the 10, 5, and 1% level, respectively.*

Appendix B

Chapter 4

Appendix

As there is no clear definition of a rural area and a city, this study referred to (A) the proportion of the people working in agricultural industry, but also (B) proportion of people taking agriculture as a second job, (C) and a product of (A)*(1-B). As a result, prefectures that have more than 11% of (A) were defined as rural areas in this study. Table A1 shows the calculated value announced by the agricultural census, Japan.

Table A1 List of Rural Prefectures, Japan

Prefecture Name	(A)	(B)	(C)
Akita	23.0%	63.7%	8.3%
Iwate	21.2%	63.5%	7.7%
Yamagata	19.2%	59.4%	7.8%
Fukushima	18.1%	68.3%	5.7%
Tottori	18.0%	67.0%	5.9%
Shimane	16.6%	70.4%	4.9%
Saga	16.5%	51.4%	8.0%
Niigata	15.3%	68.6%	4.8%
Aomori	15.0%	45.8%	8.1% [1]
Fukui	14.8%	81.9%	2.7%
Nagano	14.1%	59.5%	5.7%
Ibaraki	12.9%	62.0%	4.9%
Toyama	12.9%	83.4%	2.1%
Kumamoto	12.8%	45.4%	7.0%
Tochigi	12.8%	64.1%	4.6%
Kanagawa	12.7%	65.8%	4.4%
Tokushima	12.5%	54.7%	5.6%
Miyagi	12.4%	70.4%	3.7%
Miyazaki	11.%	37.6%	7.0%

Table A2 displays the Japanese fuel economy standards of Target year 2015 and Target year 2020.

Table A2 Japanese Fuel Economy Standards

Weight (kg)	2015 Standards (km/l)	2020 Standards (km/l)
$0 \sim 600$	22.5	24.6
$601 \sim 740$	21.8	24.6
$741 \sim 855$	21.0	24.5
$856 \sim 970$	20.8	23.7
$971 \sim 1,080$	20.5	23.4
$1,081 \sim 1,195$	18.7	21.8
$1,196 \sim 1,310$	17.2	20.3
$1,311 \sim 1,420$	15.8	19.0
$1,421 \sim 1,530$	14.4	17.6
$1,531 \sim 1,650$	13.2	16.5
$1,651 \sim 1,760$	12.2	15.4
$1,761 \sim 1,870$	11.1	14.4
$1,871 \sim 1,990$	10.2	13.5
$1,991 \sim 2,100$	9.4	12.7
$2,101 \sim 2,270$	8.7	11.9
2,271 plus	7.4	10.6

Note: Source: Ministry of Land, Infrastructure, Transport and Tourism, Japan.

Figure A1 shows the example questions for calculating travel distances in Survey 1 and 2.

Q5 Driving on weekdays (work days and school days): How much do you drive per day?

	1	2	3	4	5	6
Overall	~10km	11km~30 km	31km~50 km	51km~10 0km	101km~	I don't drive on Weekdays.

Q8 Driving on weekends (Holidays): How much do you drive per day?

	1	2	3	4	5	6
Overall	~10km	11km~30 km	31km~50 km	51km~10 0km	101km~	I don't drive on Weekends.

Figure A1 Survey Example for Survey 1 and 2