Greening Vehicle Fleets: A Structural Analysis of Scrappage Programs during the Financial Crisis*

Taiju Kitano†
Graduate School of International Management, Aoyama Gakuin University

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Abstract

Vehicle scrappage programs (SPs) have been a common policy tool to replace aged and/or fuel-inefficient vehicles with fuel-efficient ones, recently adopted to make national vehicle fleets greener. This study evaluates the impacts of the SPs by examining the Japanese private passenger vehicle market in which the government allocated the second-largest program expenditure during the financial crisis. The evaluation is conducted based on the structural model of oligopolistic competition in the presence of the SP, which is estimated using market-level sales, price, and attribute data for each car model from FY2006 to FY2009. To conduct the structural analysis, this study develops a simple method to estimate the demand side in the presence of the SP, which incorporates data on aggregate program outcomes such as the program expenditure in the estimation of the discrete choice models. Given the estimates of the structural model, I simulate counterfactual outcomes under alternative SP designs and discuss program designs that could cost-effectively improve the environmental quality of vehicle fleets, considering the welfare and fiscal stimulus impacts.

Keywords: scrappage program; passenger vehicle market; attribute-based subsidy; structural estimation; discrete choice model; Japan

JEL Classification: H23; L13; L62

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†4-4-25 Shibuya, Shibuya-ku, Tokyo 150-8366, JAPAN. E-mail: kitano@gsim.aoyama.ac.jp

1 Introduction

Transport sector has 37% of global CO_2 emissions in 2021 because of its high reliance on fossil fuels (International Energy Agency (2022)). Many governments have adopted measures to promote fuel-efficient and low-emission vehicles to green the transport sector, such as the Corporate Average Fuel Economy standard in the US and tax incentives and/or subsidies for green car purchases in EU countries and Japan. While these focus on the new vehicle market, measures that affect vehicle fleets are required to green the entire transport sector. One such measure is vehicle scrappage programs (SPs) that are designed to provide incentives (i.e., subsidies) to consumers who purchase new vehicles that meet a certain eligibility criteria, contingent on the scrappage of target clunkers such as aged and/or fuel-inefficient vehicles.[1]

The purpose of this study is to provide evidence to design cost-effective SPs for greening vehicle fleets by examining the Japanese private passenger vehicle market, where an SP was introduced in 2009 as part of a fiscal stimulus package during the global financial crisis. Because it is not straightforward to assess fleet-level environmental impacts such as CO_2 emissions, I focus on two measurable impacts that could affect fleet-level environmental quality. One is the number of clunkers eliminated from vehicle fleets (i.e., the number of clunkers scrapped) and the other is the average fuel economy of new vehicle fleets. Although one objective of SPs is greening the vehicle fleets, welfare impacts (i.e., consumer and producer surpluses) and stimulus impacts do also matter because SPs during the financial crisis were adopted as part of fiscal stimulus packages. Therefore, in my cost-effectiveness analyses, I assess welfare and stimulus impacts in addition to the environmental impacts.[2]

Although SPs were widely adopted around the world during the financial crisis, Japan's SP was notable in the following two aspects. The first is its scale. Between April 2009 and September 2010, the government subsidized over 1.5 million new car purchases and aged car scrappages, which was more than double that under the well-known US cash-for-clunkers program. The second is its duration; specifically, it lasted for one-and-a-half years, which was much longer than the US program, in effect for just two months. Given those duration and scale, firms would have changed their behavior such pricing during the program period, implying that both demand and supply should be analyzed when examining the Japan's SP.[3]

[1]Recently, under the commitment of carbon neutral goals until 2050, some governments (e.g., France, Spain, and the state of California) have adopted SPs to promote the retirement of fossil-fuel vehicles and diffusion of zero-emission vehicles (e.g., battery electric vehicles).

[2]Ideally, the impacts of the negative externality of car use (e.g., GHG emissions) should be assessed in the framework of welfare analyses, although it is not straightforward to do so. Section 6.1.1 details outcome variables chosen in the analyses.

[3]According to Busse, Knittel, Silva-Risso, and Zettlemeyer (2012), the rebate under the US cash-for-clunker program was fully received by consumers, implying that firms did not pass-through the subsidy to car prices. One possible explanation of this result is the short-lived policy intervention, which might make

To analyze both the demand-side and the supply-side responses to the SP, I employ the structural model of oligopolistic competition developed by Berry, Levinsohn, and Pakes (1995) (hereafter, BLP). The demand side is specified by the random coefficient logit model, which is estimated from the market-level data on the sales, prices, and attributes of each car model. To estimate the demand function when the data are limited to the market level, it is necessary to derive the market-level demand for each car model by aggregating individual-level demand. The individual-level demand differs by the ownership of eligible vehicles for scrappage (i.e., eligible clunkers) that were vehicles aged 13 years or older. Therefore, aggregation into market-level demand requires information on the proportion of eligible clunker owners in the market, although such information is not always available.

In this study, I propose a simple way to deal with this problem by using additional data on aggregate program outcomes (e.g., subsidy expenditure) which can often be obtained from publicly available sources (e.g., IHS (2010a)). The underlying idea of this approach is the work of Petrin (2002) that incorporate micro-moment conditions to estimate demand for differentiated products. Specifically, I infer the proportion of clunker owners from a moment condition (or an equality constraint) between observed and predicted total subsidy payments, along with the demand estimation procedure in BLP.

Despite sizable policy intervention, few economists have paid attention to the impacts of Japan's SP when examining the Japanese car market. Although some previous studies (Konishi and Zhao (2017); Ito and Sallee (2018); Yoo, Wakamori, and Yoshida (2021)) have analyzed auto-related policy interventions, they focus only on policies other than the SP such as subsidies without scrappage and tax incentive measures, thereby assuming the SP to be absent. The sole exception is Kitano (2022), which examines the SP as well as other auto-related policy interventions. However, his analyses focus only on regular vehicles, excluding the mini-vehicles that account for 30% of all passenger car sales and are also targeted by the SP. The estimation with the aggregate program outcomes allows me to examine the impact of the SP on the entire new car market, including mini-vehicles.

Based on the estimate of the structural model, I simulate the counterfactuals of alternative program designs to assess their cost-effectiveness from environmental, welfare, and stimulus perspective. The alternative designs are constructed based on the SPs varying across countries. First, the eligiblity criteria on new cars for purchase is examined. Specifically, I compare Japan's attribute-based criteria, under which cut-off levels of fuel economy vary over a secondary attribute, namely a car weight, with non-attribute-based (i.e., uniform) criteria employed in other countries. Next, funding for the programs is examined. In particular, SPs are funded solely by the governments in the majority of countries, includ-

it difficult for automakers to adjust their prices in response to the SP.

ing Japan, while some European countries request that original equipment manufacturers (OEMs) to contribute to the funding. I examine how such a funding rule would have affected market outcomes by solving the equilibrium in the presence of OEM contribution.

The findings of this study are summarized as follows. First, the estimation with the equality constraint on the aggregate subsidy outcome reveals that 22.2% of households are eligible clunker owners. The simulated policy impacts obtained under the assumption of no SP differ substantially from those obtained from the model developed in this study (i.e., the model with the SP) if entire subsidy measure introduced in 2009, cosisted of the SP and the subsidy without scrappage, is assessed. However, the parameter estimates obtained from the models with and without the SP do not differ significantly.

Next, the cost-effectiveness analyses of alternative subsidy designs show the following. I find that the program impacts between the attribute-based (i.e., actual) criteria and corresponding uniform criteria are small, although industry revenue (as a measure of stimulus impacts) is slightly larger under the attribute-based criteria. The difference in the outcomes appears when the higher cut-offs under the attribute-based criteria and their corresponding uniform cut-offs are compared. In particular, the number of clunkers scrapped under the attribute-based criteria decreases for higher cut-offs, whereas that under the uniform criteria increases, albeit slightly. By contrast, the average fuel economies of new vehicle fleets under the attribute-based and uniform criteria increase at a similar level until the cut-offs 15% higher than the original ones.

While the above counterfactuals do not show an effective way to raise the number of clunkers scrapped, my analysis shows that the adoption of SPs with OEM contributions raises the number of clunkers scrapped substantially. Compared with no OEM contribution, the number of clunkers scrapped would have increased by approximately 50% if the government had requested OEMs to cover half of the program expenditure. However, the welfare, industry revenue, and average fuel economy of new vehicle fleets decline as the rate of OEM's contribution rises, indicating trade-offs between the number of clunkers scrapped and the other impacts.

The remainder of this paper is organized as follows. Section 2 introduces the related literature. Section 3 explains the SPs adopted worldwide after the financial crisis. Section 4 introduces the structural model of multi-product oligopolistic competition to analyze the SP adopted in Japan. Section 5 explains the estimation procedure and estimation results. Section 6 reports the counterfactual outcomes of alternative program designs based on the estimates of the structural model of oligopolistic competition. Finally, Section 7 concludes.

2 Related literature

A substantial body of research exists on the US SP, which is known as the cash-for-clunkers program. The majority of studies employ program evaluation methods to assess the impacts of SPs. Mian and Sufi (2012) exploit the county-level variation in policy exposure proxied by the number of eligible clunkers in a county. Li, Linn, and Spiller (2013) employ a difference-in-difference method by setting the Canadian car market as the control group. Hoekstra, Puller, and West (2017) and West, Hoekstra, Meer, and Puller (2017) apply a regression discontinuity design exploiting the eligibility cut-off of the program: the ownership of cars rated 18 miles per gallon (mpg) or lower. Similarly, by classifying the sample into treatment and control groups in the proximity of the cut-off fuel economy level, Green, Melzer, Parker, and Rojas (2020) analyze vehicle purchase and disposal behavior based on the difference-in-difference approach.

A few studies have adopted structural models to assess the US program. Specifically, Li, Liu, and Wei (2021) and Guan (2021) examine consumers' replacement decisions based on the dynamic discrete choice models developed by Gowrisankaran and Rysman (2012) and Schiraldi (2011). These studies assume that firms do not respond to the SP, thereby focusing only on consumer behavior. This assumption might be reasonable in the US studies because, as Busse, Knittel, Silva-Risso, and Zettlemeyer (2012) show, firms pass through little of the subsidy to car prices. However, as stated in the Introduction, it might be problematic to assume as such when examining Japan's SP, considering the institutional backgraound (i.e., the duration and scale of the SP). It is not straightforward to examine the dynamics of firms' behavior as well as consumers; therefore, this study employs the static model of oligopolistic competition by BLP, which has been widely adopted in car market studies.

These previous studies have examined the short- and medium-run effects of SPs, focusing on the durability of automobiles. Specifically, these assess not only increases in car sales during the SP period, but also how such short-run effects are offset in the medium-run because of the intertemporal substitution of car purchases. In the current study, the medium-run effects could not be assessed because a static model is adopted to analyze a supply side. Nonetheless, the short-run effect alone deserves closer scrutiny, as the main objective of a fiscal stimulus is to boost the economy during a recession.

Previous studies of SPs other than the US market are scarce. As for European countries, Kaul, Pfeifer, and Witte (2016) examine the German car market, where the largest expenditure was made on the SP, assessing the incidence of scrapping subsidies. Grigolon, Leheyda, and Verboven (2016) examine the SP designs varying over EU countries and assess how design differences impacted sales and revenues using a difference-in-difference approach based on panel data on EU countries. Although Grigolon, Leheyda, and Verboven (2016) focus on how the variation in subsidy designs would have affected market outcomes, they pay no attention to the difference in program funding across countries. Therefore, this study is the first to assess the effects of funding (i.e., SPs with OEM contributions), although they are derived from the Japanese car market.

For Japan, Kitano (2022) examines the regular vehicle market to assess auto-related policies, including the SP, and is closely relevant to the current study. As stated earlier, his analysis excludes mini-vehicles and thus does not cover the entire new passenger car market that was influenced by the SP. Moreover, it assumes that regular vehicle and mini-vehicle markets are segregated in the sense that the potential mass of households who would apply for the SP to purchase new eligible regular vehicles are the owners of aged regular vehicles only. In other words, it is assumed that the owners of aged mini-vehicles never switch to new eligible regular vehicles, by scrapping their mini-vehicles to apply for the SP.

As detailed in Section 4.1.1, Kitano (2022) imposes this assumption because of the limitation of data on eligible clunkers (i.e., the cars aged 13 years or older). In this study, I avoid such an assumption and assess the entire new passenger car market by using data on aggregate subsidy outcomes in the demand estimation procedure.

3 Institutional background

This section briefly overviews the SPs adopted in 2009 worldwide, including in Japan. Although these programs normally covered subsidies for private passenger vehicles and light commercial vehicles (LCVs) such as light trucks and vans, I limit the explanation to subsidies for private passenger vechiles, the market on which this study focuses. For more details of the SPs (including light commercial vehicles) worldwide, see IHS (2010a) and IHS (2010b).

3.1 Scrap incentive measures under the financial crisis

SPs have been popular in Europe and were already adopted in some EU countries (e.g., Italy, France and Spain) in the 1990s. The global recession triggered during the financial crisis led other EU countries (e.g., Germany and UK) and non-EU countries (e.g., Japan and the US) to adopt the measures as part of their fiscal stimulus packages.

Many countries adopted SPs in 2009, although their durations differed substantially across countries. The programs were normally terminated on the scheduled date or ended if the subsidy expenditure reached the budgeted amount set in advance.[4] In many cases, the

[4]Most governments set the budget constraints for the program, while a few (e.g., Italy) offered the

Table 1: SP expenditures by country

Country	Total expenditure (billion)	New cars (billion)
Germany	€5.000	€3.900
Japan	€2.275 (≈¥295.7)	€2.275 (≈¥295.7)
USA	€2.050 (≈$2.853)	€2.050 (≈$2.853)
Italy	€1.284	€1.284
France	€0.600	€0.600
UK	€0.460 (≈£0.400)	€0.460 (≈£0.400)
Spain	€0.280	€0.264

Notes: €1 ≈ ¥130, $1.40, £0.87 in 2009. "New cars" indicates the subsidy expenditure on new cars (i.e., excluding that on used cars). These values do not include the incentive provided by OEMs.
Source: IHS (2010a)

budget was exhausted before the scheduled end; as a result, the SPs in Germany, Japan and USA had lasted for nine months, one-and-a-half year and two months, respectively.

In most countries, the funds for the SP were solely provided by the government, whereas five EU countries (i.e., Austria, the Netherlands, Slovakia, Spain and UK) requested original equipment manufacturers (OEMs) to contribute to the funding. The details of the cost-split between the government and OEMs for selected countries are given in the following section.

The government expenditure under the SP is listed in Table 1. The second column of the table indicates the total subsidy expenditure. As some countries offered incentives to not only new cars but also barely used cars, the subsidy expenditure on new cars only is shown in the third column. The €5 billion spent in Germany is notable. Even limiting to the expenditure to new cars, the German expenditure of €3.9 billion is the largest in the world. The expenditure in Japan is the second largest at €2.27 billion (≈¥295.7 billion), followed by the US at €2.05 billion (≈$2.85 billion).

In the following, I introduce the details of the program designs by country.

3.1.1 European countries

Table 2 summarizes the details of the SPs in selected countries out of the 13 EU countries that adopted the program in 2009. Most governments determined eligible cars for scrappage by car age. One exception was that the SP in Spain, which was based on cumulative kilometers traveled as well. With regard to cars for purchase, most EU countries specified some environmental conditions such as maximum CO_2 emissions and/or compliance with

incentive without limit.

Table 2: Vehicle scrappage programs in selected EU countries

Country	Car for scrap	Car for purchase	Incentive (OEM contribution)
France	>10 years old	New car of CO_2 emission <160g/km	€1,000 (€0)
Germany	>9 years old	Euro-4 compliant new car or used car (<1 year old)	€2,500 (€0)
Italy	>9 years old	New gasoline (diesel) car of CO_2 emission <140g/km (130g/km)	€1,500 (€0)
Spain	>10 years old or >250,000km	New car of CO_2 emission <120g/km or <140g/km with additional equipments	€2,000 (€1,000)
UK	>10 years old	New car	€2,300 (€1,150)

Notes: In Italy, the scrap incentive was provided for the purchase of new cars powered by LPG, CNG, electricity (exclusively or dually with gasoline), or hydrogen. In Spain, the program came into effect in May 2009 is reported. The additional equipment to be eligible for the program included safety system (ESC and seat belt indicators for the front seats) and emission control system (a 3 way catalyst (EGR) for gasoline (diesel) vehicles). See IHS (2010b) for more details.
Source: IHS (2010a, 2010b)

Euro-4 norm, a standard for pollutant emissions (e.g. NOx and CO) in EU. However, as the EU has mandated the compliance of Euro-4 norm for all new car registrations since 2006, few car models should have been excluded from the SP under the condition of Euro-4 compliance. Therefore, in Germany and the UK, which did not specify any environmental regulations, any car models marketed during the SP periods were eligible for the SP. By contrast, as France, Italy, and Spain set maximum CO2 emissions, car models eligible for the SP could be biased toward smaller vehicles, which tend to be more fuel efficient.

The fourth column of Table 2 shows the incentive amount (i.e., per-unit subsidy) for each country: Germany has the largest, followed by UK and Spain. In Spain and the UK, OEMs were requested to contribute to the subsidy (specifically, half of the incentives), while the subsidy was funded solely by the governments in the rest of the countries. In general, firms have an incentive to adjust their prices in response to the changes in demand induced by the adoption of subsidy measures, and such an incentive might be enhanced by the request for OEM contributions that make the sale of eligible car models costly.

3.1.2 US

The SP in the US, known as the cash-for-clunkers program, was introduced in July 2009. As summarized in Table 3, the program set a car less than 25 years old and less than 18 mpg as

Table 3: Vehicle scrappage program in US

Car for scrap	Car for purchase	Incentive
<25 years old & <18 mpg	New car (category 1 truck) whose fuel economy is greater than a scrapped car by more than 4/10 (2/5)mpg.	\$3500/\$4500

Table 4: Vehicle scrappage program in Japan

Car for scrap	Car for purchase	Incentive (¥1000)
>13 years old	New regular vehicle (mini-vehicle) complying with 2010 FES	Regular vehicles: ¥250 Mini-vehicles: ¥125

Notes: €1 ≈ ¥130 in 2009. No OEM contribution was requested.

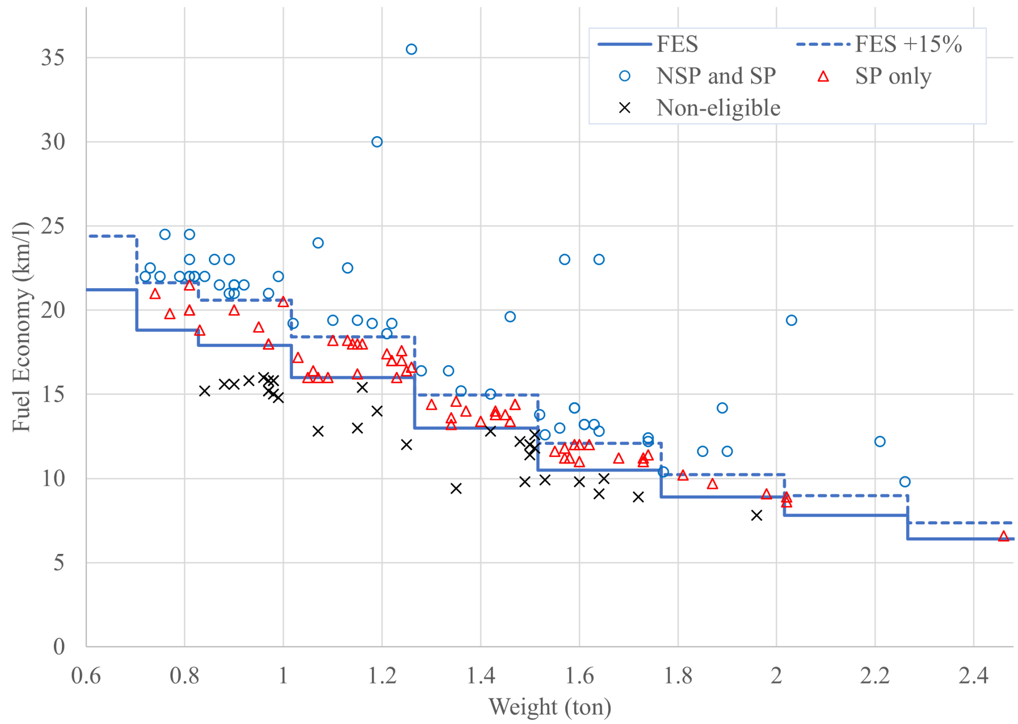
an eligible clunker. Those cars eligible for purchase were determined based on the difference in the fuel economies of a purchased car and a scrapped car. Specifically, a consumer who scrapped an eligible clunker was subsidized by \$3,500 (\$4,500) if they purchased a new car with fuel economy better (better by over 10 mpg) than the scrapped car. Although the program was scheduled to end in November 2009, it was terminated earlier because the budget for the program (\$2.85 billion) was spent in the first two months (July and August in 2009).

3.1.3 Japan

Japanese government adopted its SP in 2009 as part of the fiscal stimulus package to mitigate the negative economic impacts of the financial crisis. Under Japan's SP, cars aged 13 years or older were set as eligible clunkers and consumers were subsidized if they replaced their eligible clunkers with fuel-efficient new cars. The eligibility of cars for purchase was linked to fuel economy level; specifically, a car model was eligible for the subsidy if it complied with the 2010 fuel economy standard (FES). The FES specifies the target fuel economy level by weight class, as indicated by the solid line in Figure 1.

A key feature of Japan's program was the attribute-based subsidy design where the eligibility cut-off values for the fuel economy varied according to a secondary attribute (i.e., a car weight). In particular, lower cut-off values were set for heavier weight classes. Under the US fuel economy criteria and some EU countries' CO_2 emission criteria, eligible car models could be biased toward fuel-efficient ones, which tended to be lighter and cheaper cars, because the cut-off values of emissions were uniform or varied only with respect to engine type and other equipments. By contrast, under Japan's attribute-based design, eligible car models could be not only fuel-efficient, lighter, and cheaper car models but also heavy and expensive car models that might be fuel-inefficient among overall models but relatively fuel-

Figure 1: The 2010 FES and eligibility of the scrappage program (SP) and non-scrappage program (NSP)



efficient within their weight classes.

The incentives differ by vehicle type: ¥250,000 for regular vehicles and ¥125,000 for mini-vehicles.[5] The incentives were provided solely by the government and OEMs were not requested to contribute to the funding.

3.2 Auto-related policies in Japan

The SP was not the only auto-related policy intervention in effect during the study period, FY2006 – FY2009. I now introduce these auto-related policies.

3.2.1 Subsidy measure introduced in 2009

The 2009 subsidy measure consisted of not only the SP but also a subsidy without scrappages, namely a non-scrappage program (NSP). Under the NSP, a car model was eligible

[5]A mini-vehicle is a specific class in Japan. In particular, a car is classified as such if (1) the engine displacement is $\leq$ 660cc and (2) the car measures $\leq$ 3.4 m in length, $\leq$ 1.48m in width, and $\leq$ 2m in height. Otherwise, the car is classified as a regular vehicle.

for the subsidy if its fuel economy was greater than the fuel economy levels specified in the 2010 FES by over 15% and it complied with the 2005 emission standard that specifies the levels of pollutants emissions (e.g., NOx and CO). The incentives under the NSP were lower than those under the SP, namely ¥100,000 (¥50,000) for regular vehicles (mini-vehicles).

As shown in the subsidy design, car models eligible for the NSP were eligible for the SP. However, if consumers scrapped their eligible clunkers and purchased car models eligible for both the NSP and the SP, they could not receive incentives for both the SP and the NSP but had to choose either of them. It is reasonable to assume that such consumers would have chosen the SP because of its larger incentive than the NSP.

Figure 1 plots the fuel economy against car weight for car models marketed in 2009. The solid line shows the 2010 FES that specifies the cut-off levels of fuel economy to be eligible for the SP. The dashed line shows the cut-off levels of fuel economy to be eligible for the NSP, which is above the 2010 FES by 15%. The car models denoted by the circles are eligible for both the SP and NSP, while those denoted by the triangles are eligible for the SP only. The crosses denote the car models eligible neither the SP nor the NSP. Of the 149 models in 2009, 57 were eligible for both the SP and the NSP, and 60 were eligible for only the SP. Hence, the SP targeted much broader range of car models than the NSP.

As shown in Figure 2, the proportion of car models that complied with the FES (i.e., the eligibility criteria of the SP) slightly increased for regular vehicles from FY2006 to FY2009 and was nearly constant for mini-vehicles. From FY2008 to FY2009, there were slight changes in these proportions, while some changes were observed for the car models that complied with the FES above 15% (i.e., the eligibility criteria of the NSP).

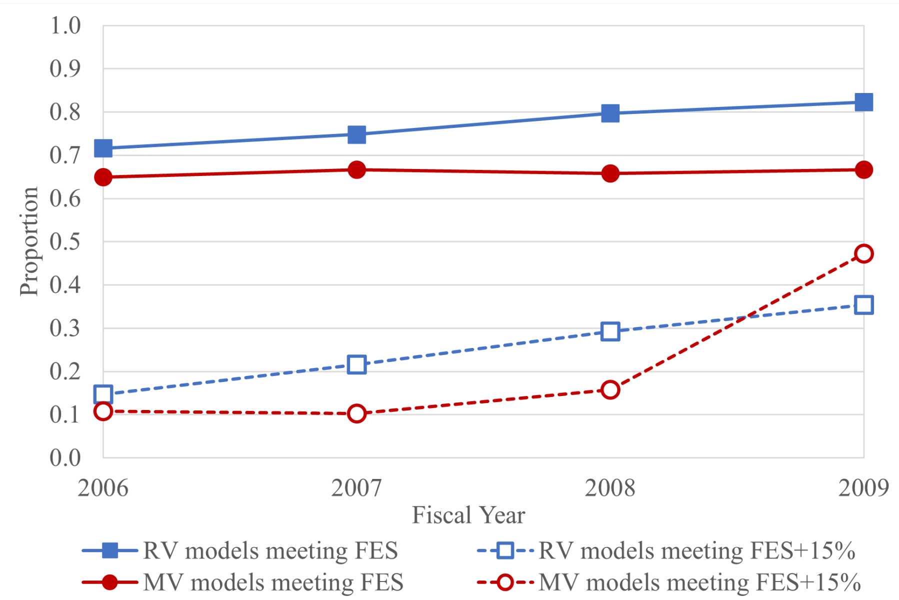
The subsidy measure commenced on June 19, 2009, but came into effect retroactively on April 10, 2009. It was initially scheduled to end on March 31, 2010 or earlier if the total subsidy expenditure reached the budgeted amount of ¥370 billion for this policy. However,

Table 5: Subsidy application on regular vehicles and mini-vehicles from April 2009 to September 2010

	Regular vehicles		Mini-vehicles	
Program	#Applications (1000 Units)	Subsidy Amount (¥Billion)	#Applications (1000 Units)	Subsidy Amount (¥Billion)
SP	941.4	235.34	482.9	60.36
NSP	2311.4	231.14	728.5	36.43
Total	3252.7	466.48	1211.4	96.79

Notes: The per-unit subsidies for regular vehicles (mini-vehicles) were ¥250,000 (¥125,000) under the SP and ¥100,000 (¥50,000) under the NSP. The subsidy expenditure in FY2009 (i.e., from April 2009 to March 2010) was ¥203.4 billion under the SP and ¥174.9 billion under the NSP.

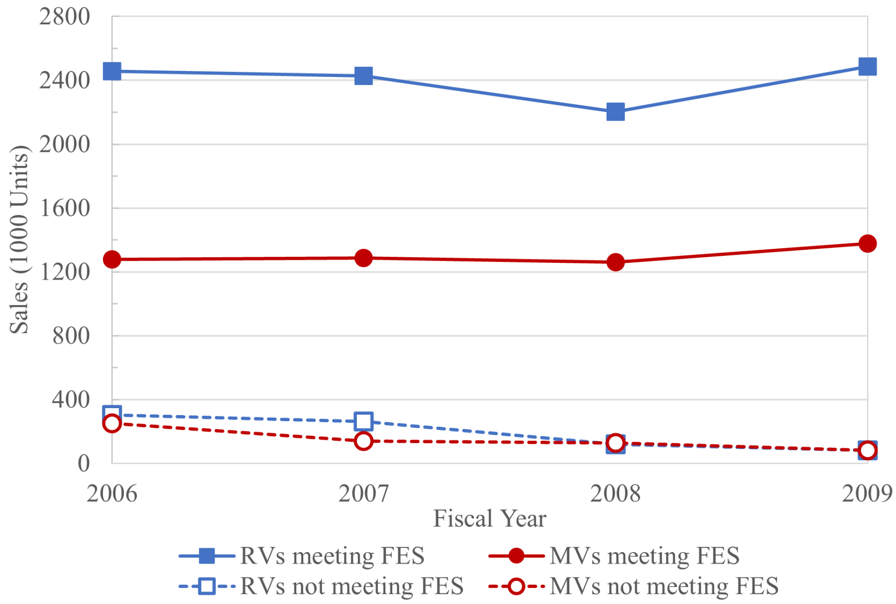
Figure 2: Proportion of regular vehicle and mini-vehicle models that complied with fuel economy standard (FES) and FES+15%



in December 2009, the government announced an extension of the program until September 30, 2010, with an additional budget of ¥260.9 billion. The policy ended slightly earlier than scheduled, namely, on September 7, 2010, because the subsidy budget had run out. Table 5 lists the policy outcomes by programs and vehicle types. The impacts of the SP were non-negligible as more than 1.5 million cars were replaced in one-and-a-half year program period, while the subsidy expenditure under the SP exceeded that under the NSP.

Figure 3 displays sales by vehicle types and compliance with the FES from FY2006 to FY2009. Sales of regular vehicles meeting the FES (i.e., eligible for the SP) decreased by approximately -9.2% during the financial crisis in FY2008, although it sharply recovered in FY2009, achieving a 19.5% increase from FY2008. By contrast, sales of mini-vehicles meeting the FES remained nearly unchanged throughout the period or it slightly decreased (by -5.4%) from FY2008 to FY2009 even with the subsidy provision. This decrease in mini-vehicle sales could potentially be explained by the lower per-unit subsidy amount of mini-vehicles, which induced substitution with regular vehicle sales. Regular vehicles and mini-vehicles not meeting the FES decreased their sales throughout the study period. However, the sales decrease from FY2008 to FY2009 was sufficiently large to explain the sales increase in regular vehicles eligible for the SP.

Figure 3: Sales by vehicle types and by compliances with FES



3.2.2 Tax system and tax incentive measures

In addition to the subsidy measure, the Japanese government adopted tax incentive measures to promote fuel-efficient and low-emission vehilces. These tax incentive measures are linked with the existing auto-related tax system that must be considered when designing the econometric model.

The tax system and relevant institutional background in the Japanese car market around 2009 are fairly complex, while the analyses of tax relevant policies are not the target of this study. I provide their details during the study period in Appendix A.

4 Model

This section introduces the empirical model for analyzing the SP. I first specify the demand side of the model, considering the presence of SP. The basic structure of the model is equivalent to that of Kitano (2022), who examined the Japanese new regular vehicle market, although this study examines the entire vehicle market, including not only regular vehicles but also mini-vehicles.

The auto-related tax system and tax incentive measures are usually revised at the beginning of fiscal year, starting on April 1 and ending on March 31 in Japan. Hence, I consider the markets on an FY basis. The study period is from FY2006 to FY2009. As the program ended in September 2010, my analyses do not cover the entire program period. Although the whole program's impacts cannot be assessed, this does not matter in terms of achieving the goals set in this study, namely, comparing the program outcomes among the various SP designs. The starting year is determined based on the availability of mini-vehicle sales data.

4.1 Demand side

A purchasing unit is a household and each household buys at most one car model or can choose an outside good (i.e., not buying any car models). The choice set each household faces is $J_t \cup \{0\}$, where J_t is the set of car models marketed at time t and $\{0\}$ is the outside good. As this study aims to introduce the model in the presence of the SP, I limit the explanation to $t = 2009$ when the SP was in effect. However, it is straightforward to model markets in the absence of the SP (i.e., $t < 2009$) from the model introduced below. For brevity, the time subscript t is omitted.

Each household chooses the alternative that provides the highest utility. Household i's indirect utility from purhasing car models $j \in J$ is

$$u_{ij} = -\alpha_i p_{ij}^e + \mathbf{x}_j \boldsymbol{\beta}_i + \xi_j + \epsilon_{ij}. \tag{1}$$

p_{ij}^e is the effective (tax- and subsidy-inclusive) price household i faces in purchasing the car model j. A key distinction from previous studies ((Konishi and Zhao (2017); Yoo, Wakamori, and Yoshida (2021)) is that the effective price has the index i and thus varies across households because the subsidy amount depends on a household's clunker ownership.

Let c_i be an indicator of clunker ownership. Then, the effective price can be expressed as

$$p_{ij}^e = p_j^\tau - S_j(c_i),$$

where p_j^τ is the tax-inclusive price of car model j and is calculated according to Japan's auto-related tax system and tax incentive measures, the details of which are presented in Appendix A. $S_j(c_i)$ is the subsidy that household i receives when buying the car model j:

$$S_j(c_i) = \begin{cases} 0.25c_i + 0.1(1 - c_i) & \text{if } j \in J_{NSP} \cap J_{rv} \\ 0.125c_i + 0.05(1 - c_i) & \text{if } j \in J_{NSP} \cap J_{mv} \\ 0.25c_i & \text{if } j \in \{J_{SP} \setminus J_{NSP}\} \cap J_{rv} \\ 0.125c_i & \text{if } j \in \{J_{SP} \setminus J_{NSP}\} \cap J_{mv} \\ 0 & \text{otherwise} \end{cases}, \tag{2}$$

J_{NSP} (J_{SP}) is the set of car models eligible for the NSP (SP) and J_{rv} (J_{mv}) is the set of regular vehicle models (mini-vehicle models). The digits in the equation correspond to the incentive amounts reported in Table 2. As shown, 0.25 (0.125) is the incentive in ¥million unit for regular vehicle (mini-vehicle) purchase under the SP, while 0.1 (0.05) is that for regular vehicle (mini-vehicle) purchase under the NSP.

α_i denotes the price sensitivity of household i. Following Barwick, Cao, and Li (2021), this is specified as

$$\alpha_i = e^{\bar{\alpha}+\alpha_y \ln(y_i)+\sigma_p \nu_{ip}}. \tag{3}$$

The first term, $e^{\bar{\alpha}}$, represents the base-level price sensitivity, which is common across households. $\bar{\alpha}$ is the parameter to be estimated. y_i is household i's income. Thus, the second term, $e^{\alpha_y \ln(y_i)}$, is the heterogeneity in the price sensitivity explained by income differences. α_y is expected to be negative because higher income households would have lower price sensitivities. A key factor to identify α_y is household-level income differences, which are generated from the empirical income distributions varying over markets in analyses based on market-level data. In this study, the markets are defined by year and thus my dataset has empirical income distributions for just four years. Although the estimation is technically feasible, the limited variation of the empirical income distributions makes it difficult to obtain precise estimate of α_y. Therefore, following Barwick, Cao, and Li (2021) and Berry, Levinsohn, and Pakes (1999), I set α_y to -1 rather than estimating it. The third term, $e^{\sigma_p \nu_{ip}}$, captures the idiosyncratic factors that affect price sensitivity, such as inheritance and accumulated savings, which vary across households. ν_{ip} is assumed to follow a standard normal distribution and σ_p is the parameter to be estimated.

$\mathbf{x}_j$ is the K-dimensional vector of the attributes of car model j. This includes a constant term that captures the preference for an inside good (i.e., $\forall j \in J$) relative to an outside good (i.e., not purchase any car models). $\boldsymbol{\beta}_i$ is the K-dimensional vector, and its k-th element β_{ik} is household i's marginal utility from the k-th attributes (i.e., x_{jk}), which is specified as

$$\beta_{ik} = \beta_k + \sigma_k \nu_{ik}, k = 1, 2, \ldots, K.$$

ν_{ik} is household i's preference for attribute k and is assumed to follow a standard normal distribution. β_k and σ_k denote the mean and variance of β_{ik}, respectively. These are the parameters to be estimated.

ξ_j is an unobserved attribute and/or demand shock specific to car model j. This captures the beauty of car design, demand enhancement induced by promotion, and all other factors affecting demand for car model j. The estimation strategy of this model is based on the moment conditions for ξ_j, as detailed in Section 5.

The utility obtained from choosing an outside good is

$$u_{i0} = \sigma_0 \nu_{i0} + \epsilon_{i0}, \tag{4}$$

where ν_{i0} is household i's specific preference for the outside good and σ_0 represents the variance in the preference for the outside good across households. σ_0 cannot be identified separately from the random coefficient of the constant term in Eq.(1), implying that the random coefficient of the constant term captures the preference for the outside good.

ϵ_{ij} is the idiosyncratic part of utility specific to household i and car model j, assumed to follow i.i.d. type I extreme value distribution. Then, household i's probability of choosing car model j can be derived as

$$s_{ij} = \frac{\exp(\delta_j + \mu_{ij})}{1 + \sum_{l \in J} \exp(\delta_l + \mu_{il})}. \tag{5}$$

δ_j is the part of utility common to all households, which is written as follows:

$$\delta_j = \mathbf{x}_j \boldsymbol{\beta} + \xi_j.$$

μ_{ij} represents household specific utility, which is specified as

$$\mu_{ij} = -\alpha_i p^e_{ij} + \sum_k \sigma_k \nu_{ik} x_{jk}. \tag{6}$$

The parameters in μ_{ij} are defined as $\boldsymbol{\theta} = (\alpha, \sigma_p, \sigma_1, \cdots, \sigma_K)'$. Following previous studies (e.g., Nevo(2001)), I hereafter refer to $\boldsymbol{\theta}$ as non-linear parameters as they enter non-linearly with respect to the error term in the estimation, ξ_j.

The market share function of car model j can be obtained by integrating the individual choice probability over the indiviudal-specific components. These includes c_i, which is an indicator of clunker ownership, y_i and $\boldsymbol{\nu}_i = (\nu_p, \nu_{i1}, \ldots, \nu_{iK})'$. Because c_i is a binary variable, the probability of clunker ownership in its population distribution can be defined as $\Pr(c_i = 1) = \phi$. Then, the market share function can be written as

$$\begin{aligned} s_j(\mathbf{p}^\tau, \mathbf{S}) =& \phi \underbrace{\int_{y_i} \int_{\boldsymbol{\nu}_i} s_{ij}(\mathbf{p}^\tau - \mathbf{S}(c_i = 1)) dF_\nu(\boldsymbol{\nu}_i) dF_y(y_i)}_{= s_j^{SP}} \\ &+ (1 - \phi) \underbrace{\int_{y_i} \int_{\boldsymbol{\nu}_i} s_{ij}(\mathbf{p}^\tau - \mathbf{S}(c_i = 0)) dF_\nu(\boldsymbol{\nu}_i) dF_y(y_i)}_{= s_j^{NSP}}. \end{aligned} \tag{7}$$

s_j^{SP} and s_j^{NSP} indicate the share functions of the car model j for clunker and non-clunker owners, respectively. $F_y(\cdot)$ is the empirical distribution of the household income obtained from publicly available sources. $F_\nu(\cdot)$ indicates the population distribution function for household-specific preferences for car attributes $\boldsymbol{\nu}_i$, which is assumed to be a standard normal distribution. $\mathbf{S}(c_i)$ is the $\#J$-dimensional vector of the per-unit subsidy (i.e., incentive), the j-th element of which is $S_j(c_i)$ defined in Eq.(2). In the estimation, the integrals in Eq.(7) are computed by simulation.

4.1.1 Proportion of clunker owners

As previously stated, the term ϕ denotes the proportion of clunker owners to the population. If ϕ is known, it is straightforward to apply BLP and Nevo (2001), who use the population income distribution and various other population demographic distributions to compute the market share function. Kitano (2022) adopts such estimation procedure in the study of the Japanese regular vehicle market (excluding mini-vehicles). Specifically, using an age distribution for regular vehicles, he defines ϕ as follows:

$$\phi = \frac{\#\text{ of registered regular vehicles aged 13 years or older}}{\#\text{ of households (market size)}}. \tag{8}$$

One of the problems here is that although any type of vehicle (i.e., not only regular vehicles but also mini-vehicles) was eligible for the SP if it was 13 years old or older, only the fleet of such aged regular vehicles was used in this calculation. As Kitano (2022) examine regular vehicles only, the exclusion of eligible mini-vehicles might have had little impacts on his analyses if the regular and mini-vehicle markets were segregated to some extent. In the current study, however, both regular and mini-vehicle markets are examined. Hence, it is necessary to consider the owners of mini-vehicles aged 13 years or older when constructing ϕ. One possible way to modify the calculation of ϕ is to add the number of eligible mini-vehicles into the numerator, but such mini-vehicle data are unavailable.

Therefore, in this study, I infer the proportion of clunker owners (i.e., ϕ) from the subsidy application data. Specifically, I estimate the value of ϕ so that the subsidy expenditure predicted by the model as is consistent with the observed subsidy expenditure. Let E_{SP} be the subsidy expenditure under the SP in FY2009 predicted from the model, which can be calculated as

$$E_{SP} = \phi M \left(0.25 \times \sum_{j \in J_{SP} \cap J_{rv}} s_j^{SP} + 0.125 \times \sum_{j \in J_{SP} \cap J_{mv}} s_j^{SP} \right), \tag{9}$$

where s_j^{SP} is the share function of car model j for clunker owners specified in Eq.(7) and 0.25(0.125) is the per-unit subsidy amount (in ¥million unit) under the SP for regular vehicles (mini-vehicles). Then, to infer the value of ϕ, I impose a constraint such that the predicted subsidy expenditure under the SP, that is (i.e., E_{SP}) equals the observed subsidy expenditure, E^*_{SP}, that is $E_{SP} = E^*_{SP}$. In FY2009, E^*_{SP} was ¥203.4 billion.[6]

This equality constraint is used to compute the predicted market shares to run contraction mapping procedure introduced by Berry, Levinsohn, and Pakes (1995). Section 5 provides more details on the estimation procedure and inference of ϕ.

4.1.2 Comarison with previous studies

Previous studies (i.e., Konishi and Zhao (2017); Yoo, Wakamori, and Yoshida (2021)) have assumed no clunker owners, which is equivalent to setting $\phi = 0$ in Eq.(7). Hence, in the following analyses, I estimate demand and simulate counterfactual market outcomes under $\phi = 0$ to understand the bias caused by such an assumption. In particular, I assess the degree of bias in the demand estimates and simulated policy impacts by comparing them with the results obtained from the model developed in this study, where the value of ϕ is inferred to be consistent with the subsidy application data.

4.1.3 Heterogeneity between clunker and non-cluner owners

In my model, the ownership of a car aged 13 years or older is assumed to affect consumers' choice only through the incentive provided under the SP. A possible concern with this assumption is that aged car owners might have a stronger preferene to replace their cars, implying that aged car (i.e., clunker) ownership might directly affect a consumer's car choice regardless of the SP. One possible way to address this concern is to include a dummy variable for aged car ownership (i.e., $\mathbb{1}[c_i = 1]$) in the utility function (specifically, in Eq.(6)) and estimate its coefficient that indicates aged car owners' specific preference to the inside option (i.e., new car purchases).

Naturally, as such direct effect can exist for periods in the absence of the SP, the dummy variable should be included in the equation for the years both with and without the SP. Hence, as shown in Eq. (7), the values of ϕ must be inferred for every year to compute the market share function. A problem is that the proportion of clunker owners is inferred using the aggregate subsidy application data, which are available only when the SP was in

[6]Another problem with the construction of ϕ by Eq.(8) is that not all vehicles aged 13 years or older were scrapped to apply for the SP because some old vehicle models had trade-in values higher than the incentives provided under the SP. The inference of ϕ proposed in this study can recover the proportion of households that had aged cars and applied for the SP if they purchased new car models eligible for the SP.

effect. Therefore, the proportion of aged car owners before 2009 cannot be inferred, and it is infeasible to include the variable $\mathbb{1}[c_i = 1]$ in the estimation.

Although the dummy variable for aged car ownership is omitted from Eq.(6), thi direct effect may have limited significance. First, as the trade-in values of used cars, a key determinant of the replacement decision, are normally higher for younger cars, the owners of older cars do not necessarily have a stronger preference for replacement than those of younger cars.[7] Second, the owners of aged cars might not care much about the latest equipment and are more likely to choose used cars. As the used cars are included in the outside option, the owners of aged cars might have less preference to the new car purchases, that is, the inside option.

In addition, as shown in the derivation of the market share function, it has been assumed that household income and clunker ownership are independently distributed, although they might have been correlated each other. Kitano (2022)shows the validity of this assumption by displaying little correlation between income per household and the number of regular vehicle clunkers per household at the prefecture level. Although it might be problematic to adopt this argument in the current study including mini-vehicles, this provides some credence to the analyses conducted in this study.

4.2 Supply side

The supply side of the model is multi-product oligopolistic competition. Following the literature, I assume that firms compete in a Bertrand fashion and that a pure-strategy Nash equilibrium in prices exists.

The profit function for firm f is specified as follows:

$$\pi_f = \sum_{j \in J_f} (p_j - mc_j) M \cdot s_j(\mathbf{p}^\tau, \mathbf{S}) - FC$$

p_j is the tax-exclusive price of car model j. c_j is the marginal cost of car model j, which is assumed to be constant over quantity (i.e., constant returns to scale). FC denotes the fixed cost of production. $M \cdot s_j$ represent demand for car model j, where M denotes the market size and s_j is the market share function specified in Eq.(7). The market share function

[7] It might be reasonable to consider that aged cars are more likely to be replaced if the trade-in values are controlled for when estimating the demand side. In fact, the estimates of a dynamic discrete choice model by Li, Liu, and Wei (2021) show that aged car owners have a stronger preference for replacement after controlling for the trade-in values of cars they own. In the current study, information on the cars households owned and their trade-in values is unknown.

depends on $\mathbf{p}^{\tau}$, the vector of tax-inclusive prices whose j-th element can be written as

$$p_j^{\tau} = (1 + t_j)p_j + T_j,$$

where t_j and T_j are respectively an ad valorem tax rate and a specific tax amount for car model j. Appendix B introduces the specific values of t_j and T_j.

Under the Nash equilibrium, the price of each car model satisfies the following first-order condition of the profit maximization problem:

$$s_j(\mathbf{p}^{\tau}, \mathbf{S}) + (1 + t_j) \sum_{l \in J_f} (p_l - mc_l) \frac{\partial s_l}{\partial p_j^{\tau}} = 0, \forall j \in J_f, \forall f \tag{10}$$

The marginal cost of each car model can be derived from the first-order conditions. Let $\mathbf{mc}$, $\mathbf{p}$ and $\mathbf{s}$ be J-dimensional vectors of marginal costs, prices, and market shares, respectively. In vector notation, the marginal cost vector can be written as

$$\mathbf{mc} = \mathbf{p} - \mathbf{\Delta}^{-1} \left[\left(\frac{\mathbf{1}}{\mathbf{1} + \mathbf{t}} \right) \circ \mathbf{s} \right]. \tag{11}$$

$\mathbf{\Delta}$ is the $J \times J$ matrix whose (j, r)-element is defined as $\Delta_{jr} = H_{j,r} \cdot (-\partial s_r / \partial p_j^{\tau})$. $H_{j,r}$ is an indicator of firms' car ownership structure, taking 1 if car models j and r are owned by the same firm and 0 otherwise. $\left(\frac{\mathbf{1}}{\mathbf{1}+\mathbf{t}}\right)$ is a J-dimensional vector whose j-th element is $(1 + t_j)^{-1}$. $\circ$ indicates an operator of the Hadamard product (i.e., element-by-element multiplication).

5 Estimation

The paramters in the model, namely, $(\boldsymbol{\beta}, \boldsymbol{\theta})$, are estimated from the moment condition on the unobserved attributes, namely $\boldsymbol{\xi} = (\xi_1, \xi_2, \cdots, \xi_{\#J})'$. The estimation procedure incorporates a contraction mapping to solve the vector of mean utility, $\boldsymbol{\delta}$ by following BLP. As unobserved product attribute or demand shock might be correlated with the price, a set of instrumental variables, $\mathbf{Z}$ must be introduced to deal with the endogeneity in price. The set of instruments used in the estimation is explained in Section 5.1.

A problem in applying a standard BLP-style estimation is that a population demographic distribution on the clunker ownership, a key individual attribute in my model, is unavailable. Hence, in this study, the value of ϕ is inferred from an equality constraint in the observed subsidy application data. The underlying idea of this approach is from Petrin (2002), although I use the equality constraint (i.e., moment condition) to derive the value of a particular parameter (ϕ) directly, rather than to construct a generalized method of moments (GMM) objective function.

Following BLP, the estimation procedure incorporates contraction mapping to solve the vector of mean utility $\boldsymbol{\delta}$. Let $\mathbf{s}(\boldsymbol{\delta};\boldsymbol{\theta})$ be the vector of the market shares predicted by the model, which is now expressed as a function of $\boldsymbol{\delta}$ and $\boldsymbol{\theta}$. From Eq.(7), the j-th element can be expressed as follows:

$$s_j(\boldsymbol{\delta};\boldsymbol{\theta}) = \phi(\boldsymbol{\delta};\boldsymbol{\theta})s_j^{SP}(\boldsymbol{\delta};\boldsymbol{\theta}) + (1-\phi(\boldsymbol{\delta};\boldsymbol{\theta}))s_j^{NSP}(\boldsymbol{\delta};\boldsymbol{\theta}).$$

A key distinction of the standard BLP approach is that the proportion of clunker owners, ϕ, is derived from an equality constraint on program expenditure. Specifically, based on the equality constraint (i.e., $E_{SP} = E_{SP}^*$) and Eq.(9),

$$\phi(\boldsymbol{\delta};\boldsymbol{\theta}) = \frac{E_{SP}^*}{M\left(0.25\times\sum_{j\in J_{SP}\cap J_{rv}} s_j^{SP}(\boldsymbol{\delta};\boldsymbol{\theta}) + 0.125\times\sum_{j\in J_{SP}\cap J_{mv}} s_j^{SP}(\boldsymbol{\delta};\boldsymbol{\theta})\right)}. \tag{12}$$

Here, ϕ is written as a function of $\boldsymbol{\delta}$ and $\boldsymbol{\theta}$, as it is obtained from market share functions for clunker owners.

Then, for a given value of $\boldsymbol{\theta}$, the mean utility $\boldsymbol{\delta}$ solving $\mathbf{s}(\boldsymbol{\delta};\boldsymbol{\theta}) = \mathbf{s}^*$, where $\mathbf{s}^*$ denotes the vector of observed market shares, is obtained by computing the following series:

$$\boldsymbol{\delta}^{h+1} = \boldsymbol{\delta}^h + \ln(\mathbf{s}^*) - \ln(\mathbf{s}(\boldsymbol{\delta}^h;\boldsymbol{\theta})), \tag{13}$$

where h denotes the number of iterations, $\mathbf{s}^*$ denotes the vector of observed market shares, and $\mathbf{s}(\boldsymbol{\delta};\boldsymbol{\theta})$ denotes the vector of predicted market shares computed using Eq.(7), which is expressed as a function of $\boldsymbol{\delta}$ and $\boldsymbol{\theta}$.

In the presence of the equality constraint, there is no guarantee that Eq.(13) constitutes contraction mapping and converges to a unique fixed point. However, I find that the series of iteration achieves convergence for the range of parameter values examined in the estimation. The starting values are commonly used in the literature (e.g. Nevo (2001)), namely $\delta_j^0 = \ln(s_j^*) - \ln(s_0^*)$ and it is confirmed that the iteration converges to the same values of $\boldsymbol{\delta}$ if the starting values are changed by a factor of 0.9 and 1.1.

The GMM objective function is as follows:

$$\min_{\boldsymbol{\theta}} \boldsymbol{\xi}(\boldsymbol{\theta})\mathbf{ZWZ}\boldsymbol{\xi}(\boldsymbol{\theta})$$

where $\mathbf{W}$ is a weighting matrix. The estimation is conducted using a two-step efficient GMM developed by Hansen (1982). The weighting matrix in the first is $(\mathbf{ZZ}')^{-1}$ and that in the second is $(\tilde{\boldsymbol{\xi}}\tilde{\boldsymbol{\xi}}')^{-1}$, where $\tilde{\boldsymbol{\xi}}$ is the vector of residuals calculated from the first estimates.

Although the set of parameters to be estimated is $(\boldsymbol{\beta}, \boldsymbol{\theta})$, the optimization here is only with respect to the non-linear parameters (i.e., $\boldsymbol{\theta}$). This is because for arbitrary values of $\boldsymbol{\theta}$, the estimate of the linear parameters (i.e., $\boldsymbol{\beta}$) can be derived as a function of $\boldsymbol{\theta}$:

$$\hat{\boldsymbol{\beta}}(\boldsymbol{\theta}) = (\mathbf{XZWZX})^{-1}\mathbf{XZWZ}\boldsymbol{\delta}(\boldsymbol{\theta}),$$

where $\mathbf{X} = (\mathbf{x}_1, \cdots, \mathbf{x}_{\#J})$. I use the Nelder-Mead simplex search method to obtain the estimates of $\boldsymbol{\theta}$.

5.1 Instrumental variables

The estimation is based on the moment condition on ξ_j. ξ_j is interpreted as the car model j's attribute and demand shock unobservable (or unmeasurable) to the researchers but observable to market participants. Because such unobserved attribute and demand shock will be correlated with price p_j, the identification of the demand side parameters requires instrumental variables correlated with p_j but uncorrelated with ξ_j.

The set of instruments is constructed based on the assumption proposed by BLP, namely, mean independence between the observed and unobserved attributes (i.e., $E[\boldsymbol{\xi}|\mathbf{X}] = 0$). Under this assumption, the attributes of competing products $\mathbf{x}_{-j}$ can be candidates of the instruments because the price p_j is set by accounting for the attributes of competing car models that determine its demand, namely Ms_j. (1) A car model's own attirbutes $\mathbf{x}_j$, (2) the sum of the attributes of other car models belonging to the same cluster, $\sum_{h \in \mathcal{C}_j} \mathbf{x}_h$ and (3) the sum of the attributes made by the same firm and belonging to the same cluster, $\sum_{h \in \mathcal{C}_j \cap \mathcal{J}_f} \mathbf{x}_h$. The cluster is defined by body type, which consists of mini-vehicle, compact, sedan/wagon, minivan, sports utility vehicle (SUV), and coupe. $\mathcal{C}_j$ denotes the set of car models in the cluster that car model j belongs to.

In addition, the set of instruments includes the taxes assessed on the attributes (the size of engine displacement and weight) for each car models, namely automobile tax and tonnage tax. Following Konishi and Zhao (2017), I constructed three sets of instruments on the taxes as above (1) - (3). As detailed in Appendix A, the taxes varied across car models and over time because of the revision of the tax incentive measures during the study period.

5.2 Data

This study uses market data on private passenger vehicles (regular vehicles and mini-vehicles) in Japan from FY2006 to FY2009. The observation unit is car model and FY. Because of the data availability, the dataset includes the car models produced by Japanese firms only, thereby excluding the import cars. This has a limited impact on my econometric analysis of the SP, as import car sales were tiny during the study period (about 2% of private passenger vehicle sales).

The sales (new registrations) data for regular vehicles and mini-vehicles are obtained from *Jidousha Touroku Toukei Jouhou: Shinsha-hen* (*New Car Registration Statistics*) published by the Japan Automobile Dealers Association and *Kei-Yonrinsha Tsuushoumei-Betsu Shinsha Hanbai Daisu* (*New Mini-Four-Wheel Vehicle Sales by Model Name*) released by the National Light Motor Vehicle Association Federation (*Zenkeijikyo*). These sales data are available at the monthly level, aggregating them on an FY basis. The price and attribute data are obtained from a car magazine, *Saishin Kokusan & Yunyuu-sha Kounyuu Guide* (*Current Domestic and Foreign Cars Purchase Guide*), published biannually by JAF Publishing Company Limited. All the prices are deflated to 2009 price levels using the consumer price index produced by the Statistics Bureau.

The price and attributes data are available at the grade-level (trim-level), whereas the sales data are available at the car model level (nameplate-level).[8] Because each car model has multiple grades, it is necessary to associate the model-level sales data with the grade-level price and attributes data. As the weight and fuel economy can differ across grades within a car model, the eligibility of the SP (i.e., compliance with the FES) and that of the other measures may vary across grade within a model. This means that the method of the association determines the ranges of car models eligible for the SP in the dataset, thereby influencing the policy assessment by the counterfactual simulations. In this study, I use the price and attributes of the "recommended grade" reported by JAF because the magazine's experts are likely to have made their recommendations based on information about the tax incentive and subsidy measures. In addition, I avoid using grades of a manual transmission when associating with the (nameplate-level) sales data because the proportion of the sales of manual transmission cars is tiny during the study period (less than 1%).[9]

The number of households for each year is obtained from the data released by AIRIA, which are constructed based on the demographic data of the Ministry of Internal Affairs and Communications.[10] The household income distribution is obtained from *Kokumin Seikatsu*

[8]For instance, Honda CIVIC had multiple grades, such as 1.8G, 1.8GL, and 2.0GL, in 2008. In general, for a given car model, the grade level indicates which equipment and features are included as standard. It includes mechanical changes such as different engines, transmissions (e.g., CVT, AT, or MT), and drive systems (e.g., FF or 4WD) as well as different interior and exterior features such as different seat quality (e.g., fabric or leather seats) and number of doors. Since these differences affect the weight and fuel economy, the eligibility of the tax incentive and subsidy measures can differ across grades.

[9]For the sales by transmission type, see *Shinsha Touroku-daisuu Nenpouu* (*Annual Report of New Car Registrations*) published by the Japan Automobile Dealers Association.

[10]Available at `https://www.airia.or.jp/publish/statistics/mycar.html` (in Japanese).

Table 6: Summary statistics

(a) Regular vehicle	FY2006		FY2007		FY2008		FY2009	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sales(1000 units)	23.81	27.27	24.23	28.66	20.58	26.31	24.04	38.54
Price(¥million)	2.53	1.37	2.55	1.51	2.58	1.52	2.57	1.37
Car Space(m^3)	3.85	1.15	3.84	1.16	3.96	1.21	3.99	1.20
Engine Displacement(1000cc)	2.15	0.84	2.13	0.83	2.14	0.88	2.08	0.80
Fuel Cost(¥/km)	10.55	2.88	11.14	3.03	11.00	3.26	9.12	2.60
Fuel Economy(km/l)	13.90	4.07	14.13	4.11	14.40	4.58	14.88	4.54
Horsepower(ps)/Weight(ton)	82.12	23.28	81.80	25.74	81.63	26.91	79.32	22.12
Wheelbase(m)	2.67	0.18	2.67	0.18	2.67	0.18	2.67	0.18
Tank Capacity(l)	58.93	13.10	58.66	13.01	58.35	13.26	57.85	12.95
#Obs.	116		111		113		113	

(b) Mini-vehicle	FY2006		FY2007		FY2008		FY2009	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sales(1000 units)	41.33	50.10	36.56	49.81	36.53	50.84	35.40	49.20
Price(¥million)	1.05	0.21	1.07	0.23	1.09	0.23	1.12	0.21
Car Space(m^3)	2.88	0.47	2.92	0.49	2.94	0.51	3.01	0.54
Engine Displacement(1000cc)	0.66	0.00	0.66	0.00	0.66	0.00	0.66	0.00
Fuel Cost(¥/km)	7.28	1.11	7.81	1.17	7.80	1.23	6.56	1.13
Fuel Economy(km/l)	19.07	2.70	19.07	2.70	19.03	2.87	19.58	3.15
Horsepower(ps)/Weight(ton)	64.32	8.20	64.09	8.42	64.31	8.54	63.80	7.77
Wheelbase(m)	2.36	0.11	2.36	0.11	2.36	0.11	2.38	0.07
Tank Capacity(l)	34.22	4.41	34.31	4.46	34.55	4.73	34.36	4.77
#Obs.	37		39		38		36	

Notes: Total number of observations is 603. Fuel cost is calculated by dividing the price of fuels (gasoline or diesel) per liter by the fuel economy (i.e., kilometer per liter of fuels).

Kiso Chosa (*Comprehensive Survey of Living Conditions of the People on Health and Welfare*), which is released annually by the Ministry of Health, Labour, and Welfare.

The subsidy application data are provided by the Ministry of Economy, Trade and Industry for research purposes. The original data include information of subsidy applications at the individual level, such as the program applied for as well as the dates of subsidy application, new car registration, and scrappage. The values shown in Table 5 are obtained by aggregating these individual data by program and type of vehicle (regular vehicles and mini-vehicles).

Table 6 presents the summary statistics for the variables in the dataset by vehicle type. The size of engine displacement for mini-vehicles has low standard errors because most mini-vehicle models are bunched just below the threshold level (i.e., 660 cc).

Table 7: Estimation results

	(i) $\phi = 0$				(ii) ϕ estimated			
	Mean (β)		Std. Dev. (σ)		Mean (β)		Std. Dev. (σ)	
Variable	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Const	-14.784	4.151	3.052	2.985	-14.844	4.025	3.064	2.063
Car Space	0.589	0.341	0.428	0.360	0.598	0.305	0.419	0.293
HP/Weight	0.025	0.236	0.463	0.228	0.024	0.180	0.463	0.136
Fuel Cost	-0.338	0.072	0.114	0.063	-0.338	0.078	0.115	0.062
SUV	-13.804	7.254	11.432	3.535	-13.962	7.174	11.520	3.607
Tank Capacity	0.050	0.018	-	-	0.050	0.018	-	-
Engine Displacement	0.584	0.455	-	-	0.593	0.404	-	-
Wheelbase	1.354	0.800	-	-	1.353	0.764	-	-
	Est.(α)	S.E.	Est.(σ_p)	S.E.	Est.(α)	S.E.	Est.(σ_p)	S.E.
Term on Price	2.814	0.318	0.518	0.325	2.812	0.325	0.516	0.144
J-stat.	23.408				23.164			
Est. of ϕ	0 [-]				0.222 [0.009]			

Note: Body type, firm and FY dummy variables are included in the estimation. The standard error of ϕ is computed by the delta method. For (i), ϕ is not estimated but is preset to 0; hence, it has no standard error.

5.3 Estimation results

Table 7 reports the estimation results of the demand specifications in the absence (i.e., $\phi = 0$) and presence of clunker owners (i.e., $\phi > 0$). In the second specification, ϕ is inferred from the equality constraint in Eq.(12) and thus determined endogenously. As shown in the bottom row of Table 7 (ii), the estimate of ϕ is 0.222, which indicates that 22.2% of households were clunker owners—the owners of cars aged 13 years or older—and were thus eligible for the SP. The standard error of the estimate computed by the delta method is 0.011, indicating that the 95% confidence interval of the clunker owners' share is $[20.4\%, 24.0\%]$. Under the specification in the absence of clunker owners, ϕ is set to zero a priori and has no standard error.

As shown in the table, the two specifications produce similar parameter estimates. This is not surprising because these two models differ only in the last year of the study period, namely FY2009, while they are exactly the same before FY2008. In other words, the observations in specification (i) of the table are subject to measurement errors by assuming the absence of the SP, but such a measurement error problem is relevant only for a small proportion of the sample and thus has little effect on the parameter estimates.

Although overlooking the SP might have limited impacts on the demand estimates, this does not mean that the counterfactual simulations of the no subsidy measure (i.e., no SP and no NSP) produce similar outcomes between these two models. This is because the model specification affects not only the estimation results, but also the marginal costs and counterfactuals recovered from a given model specification. In addition, it is trivial that the effects of the SP on market outcomes (e.g., consumer and producer surpluses) never be measured or determined to be zero a priori under the assumption of no clunker owners. The impacts of the NSP can be simulated, but their estimates must be biased because under $\phi = 0$, all households that purchased cars eligible for both the SP and the NSP were assumed to receive the incentive under the NSP. However, in reality, some of them must have received the incentive under the SP by scrapping their clunkers, implying that the subsidy expenditure under the NSP is overestimated under $\phi = 0$. By contrast, the model with ϕ estimated from the equality constraint allows me to capture the impacts of the SP whose subsidy expenditure was ¥203.4 billion. In addition, the model predicts the proportion of buyers applying to the SP for sales of car models eligible for both the SP and the NSP, implying that the assessment of the NSP is expected to be precise. In Section 6.1, I confirm such differences in the simulated policy impacts based on these model specifications.

If the misspecification has limited impacts on the parameter estimates, the counterfactual outcomes of no policy will be similar for the periods in the absence of the SP, regardless of whether the demand estimates are used to simulate the counterfactuals. In the current study, the auto-related policies from FY2006 to FY2008, when only the tax incentive measures were in effect, are the same for each model specification. This implies that the counterfactuals of no tax incentive for these periods can be simulated similarly using either of the demand estimates. Hence, although Konishi and Zhao (2017) assume the absence of the SP (i.e., $\phi = 0$), their assessment of the tax incentive and subsidy measures other than the SP period (i.e., April 2009 to September 2010) and counterfactual experiments might be valuable.

Before conducting counterfactual simulations, I discuss the parameter estimates based on the main specification of Table 7(ii). The parameters of price α and σ_p in Eq.(3) are both statistically significant. The estimate of σ_p indicates that the degree of sensitivity differs across households with the same income level (note that the coefficient of income is set to -1). The mean valuation of SUV is negative and statistically significant, but substantial heterogeneity is found around the mean, implying that a certain proportion of consumers value SUVs positively. As for the variables of car attributes, the estimates of the mean coefficients have mostly reasonable signs, although some (e.g., HP/Weight) are statistically indistinguishable from zero. The standard deviations of HP/Weight and Fuel costs are estimated to be significant, implying that the valuation of larger horsepower and more fuel efficiency differs across consumers. The other estimates of the standard deviations are not statistically significant at conventional levels but close to P-value < 0.1.

6 Counterfactual simulations

This section presents the results of the counterfactual simulations. First, I show the quantitative assessment of the subsidy measure based on the estimates in Table 7, along with the assessment of the bias of the policy assessment due to the exclusion of the SP. Next, I present the simulation results of alternative subsidy designs: (i) non-attribute-based (i.e., uniform) eligibility criteria on new vehicles for purchase and (ii) subsidy with an OEM contribution. In particular, I assess the alternative designs based on cost-effectiveness analyses in which program impacts are compared under subsidy budget constraint. Before reporting the simulation results, I introduce outcome variables focused in this study.

6.1 Outcome variables

The impacts of the subsidy program are obtained by comparing market outcomes between two alternative scenarios such as the actual scenario (i.e., under the subsidy measure) and the counterfactual scenario of no subsidy measure. The outcome variables focused on in this study are relevant to the welfare, environmental and economic stimulus impacts.

6.1.1 Welfare impacts

As a measure of welfare, I focus on the consumer surplus and the producer surplus and government revenue. The effect on consumer surplus (ΔCS) is computed using a formula derived by Small and Rosen (1981):

$$\Delta CS = \int_{c_i}\int_{y_i}\int_{\boldsymbol{\nu}_i} \frac{\log\left[\sum_{l\in\mathcal{J}}\exp(\delta_j+\mu_{ij})\right]-\log\left[\sum_{l\in\mathcal{J}}\exp(\delta_j+\tilde{\mu}_{ij})\right]}{\alpha_i} dF(\boldsymbol{\nu}_i)dF(y_i)dF(c_i).$$

Here, the effect is represented as the difference in the consumer surplus between the actual scenario and the counterfactual of the no subsidy measure. Specifically, $\tilde{\mu}_{ij}$ is the household-specific deviation from the mean under the counterfactual, which is calculated by placing the counterfactual effective price in Eq.(6). The effect on the producer surplus (ΔPS) is computed by taking the difference between the actual and counterfactual profits. Government revenue should be the sum of the tax revenue and the subsidy expenditure, but here I focus only on the subsidy expenditure ($\Delta Subsidy$). This is because when constructing the stimulus packages, the government usually sets the budget for the package without paying attention to the impacts on tax revenues, as was the case for the subsidy measure.

To fully conduct the welfare analyses, it is desirable to examine the impacts of car use on the negative externalities caused by CO_2 emissions. Previous empirical studies that have employed a structural model similar to this study (e.g., Beresteanu and Li (2011); Huse and Lucinda (2013); Konishi and Zhao (2017); Grigolon, Reynaert, and Verboven (2018)) have quantified the impacts of CO_2 emissions based on the expected mileage driven by new cars sold. A problem when applying their approach to the assessment of the SP is that it focuses only on the CO_2 emissions from newly sold cars, although the SP would have induced the replacement that lead to the emissions reduction from the replaced cars (scrapped cars). It may be capable of measuring the overall impacts of the program on CO_2 emissions if detailed information on scrapped cars such as their model names and fuel economies could be used. Unfortunately, such information is unavailable, thereby avoiding the measurement of the negative externality from the CO_2 emission in the current study.

6.1.2 Environmental impacts

Although the direct measurement of CO_2 emissions is difficult, the assessment of the environmental impacts is necessary given the policy objective of the SP. As stated in the Introduction, SPs could influence an environmental quality at fleet level, not only by promoting fuel-efficient new vehicles but also by eliminating aged vehicles (i.e., clunkers), which generally have higher pollutant emissions and lower fuel efficiency in vehicle fleets. Accordingly, I assess following two measurable outcomes as environmental impacts.

The first is the number of clunkers scrapped induced by SPs, which is denoted as $\Delta Scrap$. $\Delta Scrap$ is defined as the difference in the number of clunkers scrapped between two alternative scenarios such as those in the presence and absence of the SP. Specifically, the number of clunkers scrapped is calculated as the number of purchases by clunker owners, which is the sum of clunker owners' demand for every vehicle model:

$$Scrap = \phi M \sum_{j \in J} s_j^{SP}.$$

The underlying assumption here is that the owners of clunkers (i.e., vehicles aged 13 years or older) would have scrapped their vehicles regardless of the application of the SP. Hence, this calculation may overestimate the number of aged vehicles scrapped because the owners of aged vehicles not applying for the SP could keep or trade in their vehicles. However, it is reasonable to consider that the majority of car owners would choose to scrap because the ownership cost of vehicles aged 13 years or older is high in Japan[11] and the trade-in values of such aged vehicles are generally low.

In addition, this number ($Scrap$) does not include clunkers scrapped by clunker owners

[11] Taxes during ownership increase from car age 13 in Japan. See Appendix A for details on the taxes.

who choose the outside option such as a used vehicle purchase.[12] As is the case with new vehicles, clunker owners might scrap their clunkers upon the purchases of used vehicles, implying the underestimation of the number of clunkers scrapped. However, the number of new vehicle purchases by clunker owners can be an effective indicator to assess the number of clunkers scrapped unless increase in new vehicle sales induced by SPs are perfectly substituted with decrease in used vehicle sales.

The second is on the environmental quality of replaced vehicles, which I set as the average fuel economy of new vehicle fleets. The average fuel economy is measured as a harmonic weighted average:[13]

$$AFE = \frac{\sum_{j \in J} q_j}{\sum_{j \in J} (1/fe_j) \times q_j},$$

where fe_j is the fuel economy (km/l) of car model j. In the following simulation analyses, I focus on the changed in the average fuel economy, namely, ΔAFE.

6.1.3 Economic stimulus impacts

A key objective of the measure was to mitigate the economic depression due to the financial crisis at that time. Here, I focus on sales volume and firms' revenue, which are often investigated when assessing the program in terms of the effectiveness of economic stimulus policies (e.g., Mian and Sufi (2012); Grigolon, Leheyda, and Verboven (2016); Hoekstra, Puller, and West (2017)).

6.2 Impacts of the subsidy measure

The simulation analyses start by obtaining the counterfactuals of the no subsidy measure. More specifically, I compute the counterfactual price vector $\mathbf{p}'$ (and corresponding share vector $\mathbf{s}'$) that meet the first-order conditions under no subsidy (i.e., $\mathbf{S} = \mathbf{0}$) in Eq.(10). Following the literature (e.g., Berry, Levinsohn, and Pakes (1999)), I assume the observed and unobserved attributes, $(\mathbf{X}, \boldsymbol{\xi})$, remain unchanged under the counterfactuals.

I first assess the degree of bias in the quantitative impacts of the subsidy measure due to the assumption of no SP. Specifically, I simulate the counterfactuals of no subsidy measure based on the model specifications of (i)$\phi = 0$ and (ii)ϕ estimated in Table 7. Table 8 presents

[12] In addition, some clunker owners might choose scrappage by retiring from driving. This does not matter when analyzing by $\Delta Scrap$, as the number of the retirement is likely to be similar between alternative designs.

[13] Many countries have implemented environmental policies in new car markets. As for Japan, the average fuel economy of newly sold cars have been treated as one of key policy indicators. In particular, the FES was originally set as the target level of the average fuel economy of newly sold cars with which each manufacturer comply until the target years.

Table 8: Bias of the subsidy impacts due to the exclusion of the SP

	$\phi = 0$	ϕ estimated	
Counterfactual of:	(i)No subsidy measure	(ii)No subsidy measure	(iii)No NSP
(A) Welfare impacts			
ΔCS (¥billion)	254.7	413.0	189.7
ΔPS (¥billion)	90.4	141.1	70.1
$\Delta Subsidy$ (¥billion)	218.9	376.9	175.3
(B) Stimulus impacts			
$\Delta Revenue$ (¥billion)	323.2	533.7	247.8
$\Delta Sales$ (1000 units)	250.1	403.0	187.8
(C) Environmental impacts			
$\Delta Scrap$ (1000 units)	0	187.9	7.7
ΔAFE (km/l)	0.235	0.234	0.169

Notes: The table shows the changes in the outcome variables between the actual and counterfactual outcomes. The average fuel economy (AFE) in actual is 18.192km/l.

the results of the counterfactual simulation, showing the difference in the outcome variables between the actual and corresponding counterfactual outcomes.

The second column of the table shows the simulated policy impacts of the subsidy program under the model specification of $\phi = 0$ (i.e., no clunker owners). Here, the demand estimate shown in Table 7(i) is used. This shows that the consumer and producer surpluses were increased by ¥254.7 billion and ¥90.4 billion, respectively. As stated in Section 5.3, under the assumption of $\phi = 0$, all subsidy payments are made under the NSP. Then, the subsidy expenditure can simply be computed by multiplying the incentive under the NSP by eligible vehicle sales:

$$0.1 \times \sum_{j \in J_{NSP} \cap J_{rv}} q_j + 0.05 \times \sum_{j \in J_{NSP} \cap J_{mv}} q_j.$$

The former part of this equation is the expenditure (¥million) for regular vehicles and the latter part is that for mini-vehicles. The total expenditure is ¥218.9 billion, as reported in the first column of Table 8 (i). As shown in the above equation, this is simply calculated from the sales for each car model observed in the dataset and thus obtained without using the estimation results.

It is worth comparing this subsidy expenditure with the actual expenditure to understand the potential bias due to misspecification. The actual expenditure for the subsidy measure (i.e., sum of the expenditures of the SP and NSP) is ¥378.2 billion, which is much higher than the expenditure presumed by the model of $\phi = 0$ (i.e., ¥218.9 billion). This clearly indicates that the subsidy impacts predicted from the model of $\phi = 0$ must be substantially underestimated compared with the actual impacts.

To understand the degree of bias in more detail, I now discuss the subsidy impacts predicted by the full model where ϕ is estimated by the equality constraint on the SP expenditure. Table 8 (ii) shows the results for the no subsidy measure. The prediction of the subsidy expenditure (i.e., ¥376.9 billion) is close to the actual expenditure, implying that the estimated model can predict the external data well.[14]

Given the validity of the full model, the bias can be assessed by comparing the subsidy impacts of the full model with those predicted under the assumption of $\phi = 0$. As shown by the two columns of the no subsidy measure in Table 8, the differences in the impacts are substantial, except for the average fuel economy. The welfare and stimulus impacts predicted by the full model are larger by over 60% than those predicted by the model of $\phi = 0$. The impacts on the average fuel economy of newly sold cars are accidentally similar, but their environmental impacts should not be regarded as equivalent given the large difference in sales (see $\Delta Sales$) between them.

Under the assumption of $\phi = 0$, only the NSP is relevant to the policy assessment, and thus some might consider that the results in Table 8 (i) capture the impacts of the NSP. This is incorrect because the actual expenditure under the NSP is ¥174.9 billion, which is much lower than the expenditure predicted from the model of $\phi = 0$ (i.e., ¥218.9 billion). As stated in Section 5.3, households who purchased car models eligible for both the SP and the NSP could have received ncentives under either SP or NSP, depending on their clunker ownership status. However, regarding the model of $\phi = 0$, all such car models were assumed to be sold under the NSP. This leads higher NSP expenditure under the assumption of $\phi = 0$.

In the full model specification, it is possible to simulate what would happen if either program was eliminated. Here, I eliminate the NSP only from the actual situation and simulate the outcome in such a situation. The second column of Table 8 (ii) shows the difference in the outcome variables between the actual situation and the counterfactual of no NSP. The consumer surplus would have decreased by ¥189.7 billion if the NSP had been eliminated from the actual. Given the impacts of the entire subsidy program of ¥413.0 billion, it can be argued that both the SP and the NSP contributed to the consumer surplus. Similar results are shown in the estimates of the other outcome variables on the welfare and stimulus impacts.

The number of clunkers scrapped must be zero under the assumption of $\phi = 0$, but it

[14]The expenditure under the SP predicted from the model equals the actual expenditure because of the equality constraint, but this is not the case for the expenditure under the NSP. This result indicates that the expenditure of the NSP is accurately predicted; specifically, the difference in the NSP expenditure between the actual and predicted cases is less than 1%.

can be measured in the full model specification. As shown in Table 8 (ii), the actual subsidy measure induced an additional 187.9 thousand vehicles aged 13 years or older to be scrapped, which corresponds to a 23.6% increase from the counterfactual of no subsidy. It is somewhat surprising that the number of cars scrappted increases (albeit slightly) by adding the NSP that would never be applied by clunker owners (see Table 8 (iii)). Intuitively, the adoption of the NSP might have increased the prices of car models eligible for the NSP, leading to a decrease in purchases by clunker owners compared with the situation in which the only the SP was in effect. However, I find that the adoption of the NSP could have decreased the prices of eligible car models, which explains the increase in the number of cars scrapped by adopting the NSP.

In the current demand specification, the price sensitivity differs across households. In general, subsidies have a greater influence on demand by households with higher price sensitivities. This means that the subsidy leads to not only a upward shift in demand for eligible car models but also a change in the curvature of demand. In addition, given such subsidy impacts on demand, the strategic interactions among firms could be either strategic complements or substitutes.[15] These specific features of the current model could somewhat explain the unusual results on the effect of subsidies on prices and the number of cars scrapped (i.e., demand by clunker owners).

6.3 Alternative SP designs

I now analyze what would have happened if the alternative SP designs had been introduced. Hereafter, the impacts of these alternative designs are measured by taking the difference from the outcomes under the market with no subsidy measure.

In this study, I mainly focus on two features of SP designs, namely (i)the eligibility criteria for car models for purchase (i.e., the attribute-based criteria and uniform criteria) and (ii)the SP with the OEM contribution. In order to reveal the difference in outcomes between the SP designs, it is desirable to consider a simpler SP design as baseline. For Japan's SP, the incentives (per-unit subsidy amounts) for regular vehicles and mini-vehicles are different, and such difference may present unnecessary complication when interpreting program impacts across alternative designs. Therefore, I first analyze what would have happened if the incentives had been the same for regular vehicles and mini-vehicles. Then, setting a baseline SP as common incentive over vehicle types, I investigate the two features of SP designs.

[15]See pp.419 – 420 of Berry, Levinsohn, and Pakes (1999) related to the discussion here.

Table 9: Program impacts under the common incentive

Incentive design	(i) SP&NSP		(ii) SP only	
	Actual	Common	Actual	Common
(A) Welfare impacts				
ΔCS (¥billion)	413.0	398.0	223.3	214.6
ΔPS (¥billion)	141.1	136.2	70.9	68.3
$\Delta Subsidy$ (¥billion)	376.9	377.1	201.6	201.7
(B) Stimulus impacts				
$\Delta Revenue$ (¥billion)	533.7	487.6	285.8	259.2
$\Delta Sales$ (1000 units)	403.0	438.0	215.2	233.8
(C) Environmental impacts				
$\Delta Scrap$ (1000 units)	187.9	204.6	180.3	200.6
ΔAFE (km/l)	0.234	0.344	0.065	0.135

6.3.1 Common incentive across vehicle types

Under Japan's subsidy measure, the incentives for regular vehicles were twice as large as those of mini-vehicles. I first simulate the outcomes for the case in which the incentives are the same for regular vehicles and mini-vehicles. Specifically, I focus on common incentives that achieve the subsidy expenditure that most closely matches the actual one, keeping the ratio between the subsidies under the SP and NSP unchanged.

The common incentive should be between the incentives for regular vehicles and mini-vehicles. Hence, the common incentive (¥million) for car model j can be written as

$$\bar{S}_j(c_i) = \begin{cases} \kappa \cdot [0.125c_i + 0.05(1-c_i)] + (1-\kappa) \cdot [0.25c_i + 0.1(1-c_i)] & \text{if } j \in J_{NSP} \\ \kappa \cdot 0.125c_i + (1-\kappa) \cdot 0.25c_i & \text{if } j \in J_{SP} \setminus J_{NSP} \\ 0 & \text{otherwise} \end{cases},$$

where $\kappa \in [0, 1]$ is the weight on the incentive of mini-vehicles. I search for the value of κ under which the subsidy expenditure matches with the actual expenditure (¥376.9 billion) by simulating the counterfactuals for alternative values of $\kappa \in [0, 1]$ with a step size of 0.02. The simulation shows that the subsidy expenditure at $\kappa = 0.344$ (¥377.1 billion) is the closest to the actual expenditure. The common incentives across vehicle types for the NSP and SP are ¥82,800 and 207,000, respectively.

The impacts of the subsidy measure under the common incentive are presented in Table 9(i), which also shows the results under the actual incentives for comparison. The consumer and producer surplus are smaller for the common incentive. The revenue is smaller for the common incentive, while the sales is larger. On the environmental impacts, the common incentive is better: larger number of scraps and higher average fuel economy. The larger sales and number of scraps would be due to the increase in the incentive for the mini-vehicles which make some households with high price sensitivity choose to purchase a new car (of mini-vehicles) from non-purchase.

Such a difference would have affected the program outcomes and might explain the difference in the sales trend between regular vehicles and mini-vehicles eligible for the SP from 2008 to 2009, as shown in Figure 3.

The program impacts in Table 9(i) come from not only the SP but also the NSP. To focus exclusively on the SP, I consider a counterfactual in which the subsidy measure consists only of the SP. Then, the common incentive for car model j can be written as

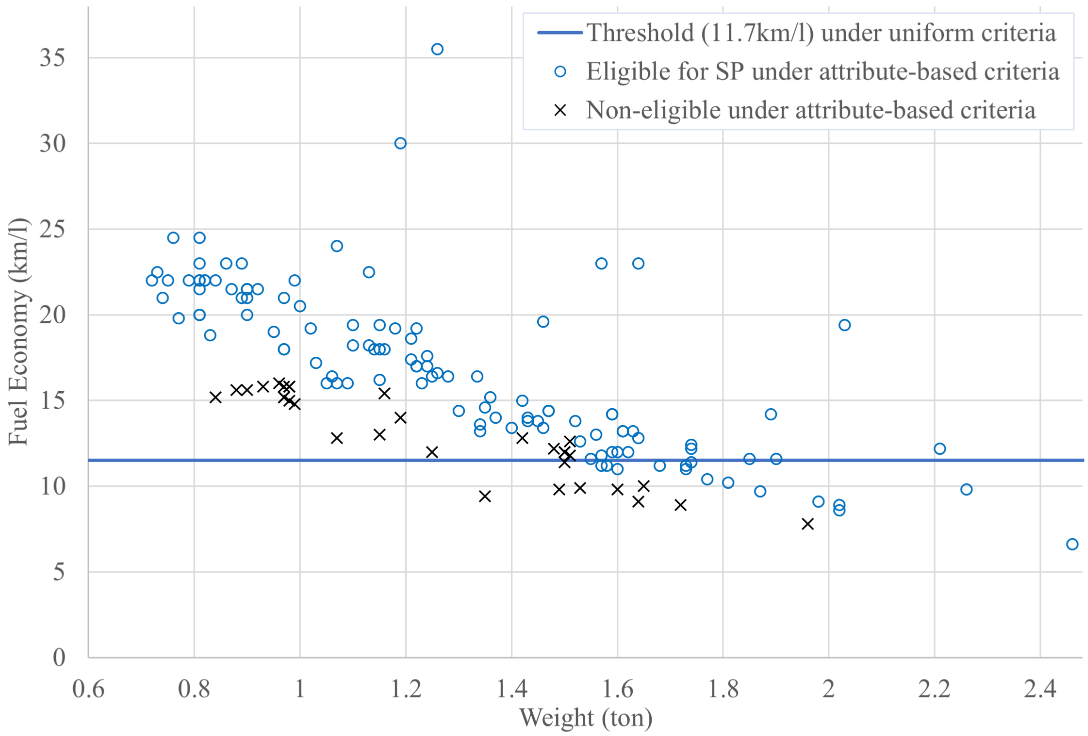
$$\bar{S}_j(c_i) = \begin{cases} \kappa \cdot 0.125c_i + (1-\kappa) \cdot 0.25c_i & \text{if } j \in J_{SP} \\ 0 & \text{otherwise} \end{cases}.$$

The value of κ is chosen based on the subsidy expenditure under the counterfactual of the SP only for the case of the actual design where the incentive of regular vehicles is twice as large as that of mini-vehicles. Such subsidy expenditure is derived as ¥201.6 billion. Then, I simulate the counterfactuals as previously and find that the subsidy expenditure under the common incentive is ¥201.7 billion at $\kappa = 0.324$, which most closely matches the actual design. The common incentive at the value of κ is ¥209,500.

As shown in Table 9(ii), the differences between the actual and common incentives are qualitatively similar to the results shown in (i) of the table. The quantitative impacts mostly fall by eliminating the NSP under which ¥174.9 billion in expenditure was spent. A sole exception is the number of clunkers scrapped, although this is not surprising because clunker owners never applied for the NSP.

Hereafter, I further examine how particular features (i.e., attribute-based/uniform criteria for the eligibility of car models and cost split between the government and OEMs) of the SPs affect market outcomes. It is desirable to make a baseline SP design as simple as possible to reveal the impacts of such features. Hence, I consider the case of the common incentive across vehicle types as the baseline SP design. In addition, as this study focuses only on the SP, I eliminate the NSP from the following analysis. Accordingly, the results in the second column of Table 9(ii) are set as the baseline outcomes for comparison with the outcomes obtained from the alternative designs studied below.

Figure 4: Uniform criteria



6.3.2 Attribute-based criteria vs. uniform criteria

As stated in Section 2, a key difference of Japan's SP design from those of other countries is that the new car models eligible for the program were determined based on the fuel economy thresholds that varied (declined) over the secondary attribute (i.e., a car weight). Here, I evaluate how such an attribute-based design affected market outcomes by comparing it with a uniform eligibility rule under which the subsidy target is determined by a single fuel economy threshold.

I here consider the case of no NSP and a common incentive across vehicle types (¥209,500). Then, the fuel economy threshold is constructed by matching the subsidy expenditure under the uniform criteria with that under the attribute-based criteria (¥201.7 billion) as closely as possible. By simulating market outcomes under various threshold values, I find the fuel economy level to be 11.7 km/l. The total subsidy expenditure under this threshold is ¥201.0 billion.

The difference in eligible car models between the actual (i.e., attribute-based) criteria and uniform criteria can be confirmed from Figure 4 that plots fuel economy against car weight for car models marketed in FY2009. The circles (crosses) indicate eligible (ineligible)

Table 10: Attribute-based vs. uniform criteria

	(i) Attribute-based	(ii) Uniform
(A) Welfare impacts		
ΔCS (¥Billion)	214.6	212.5
ΔPS (¥Billion)	68.3	65.7
Subsidy expenditure (¥Billion)	201.7	201.0
(B) Stimulus impacts		
$\Delta Revenue$(¥Billion)	259.2	244.7
$\Delta Sales$ (1000 Units)	233.8	235.1
(C) Environmental impacts		
$\Delta Scrap$ (1000 Units)	200.6	202.3
ΔAFE (km/l)	0.135	0.151

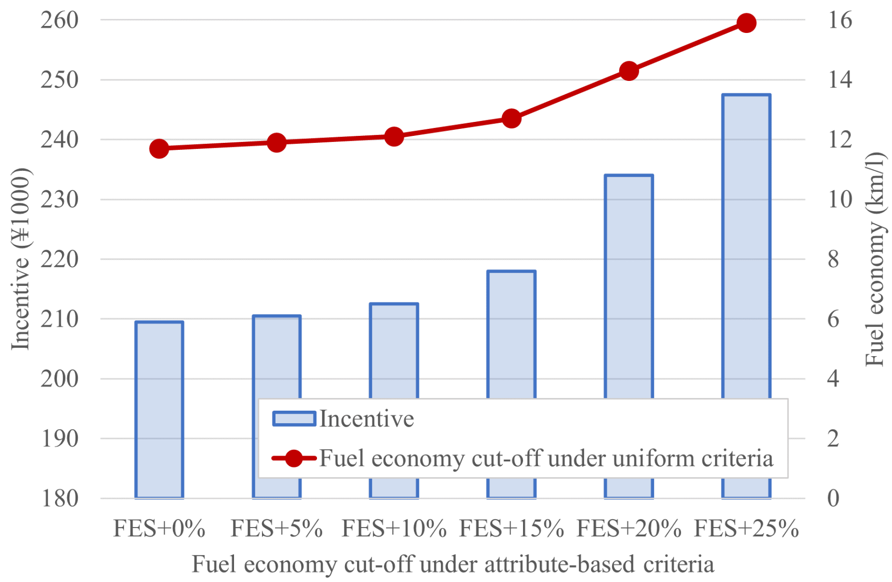
Notes: The average fuel economy under the counterfactual of no subsidy is 18.116km/l.

car models under the attribute-based criteria and the solid line indicates the fuel economy threshold under the uniform criteria. Under the uniform criteria, a few heavy car models are eligible for the program as well as lighter car models; in particular, all mini-vehicle models are eligible. By contrast, under the attribute-based criteria, a variety of the car models, from the lighter to heavier weight class, are eligible for the SP.

Table 10 reports the counterfactual outcomes for the uniform criteria and attribute-based criteria (i.e., the baseline SP). The latter outocmes are identical to the results in the second column of Table 9(ii). The differences in the consumer surplus, sales, and the number of aged car scrappage between these criteria are less than 1%. A somewhat large difference is found for industry revenue, which is higher under the attribute-based criteria by 14.5 billion or 5.5%. This might be because the subsidy target includes heavy expensive car models under the attribute-based criteria, while they tend to be light and cheaper car models. According to the study of the US cash-for-clunkers program by Hoekstra, Puller, and West (2017), fuel economy restrictions might have shifted purchase trends toward cheaper and fuel-efficient car models, leading to limited subsidy impacts on car expenditure. In contrast to this US case, Japan's attribute-based criteria might have secured industry revenue by including heavier car models in the program.

Nonetheless, the differences in market outcomes across the attribute-based and uniform criteria seem to be small overall. This might be due to many overlaps of eligible car models between these criteria. (Note that about 80% of car models qualified under the actual criteria.) The differences in program impacts might be clarified by setting a tighter standard, which may produce a variation in the range of eligible car models between the criteria.

Figure 5: Incentives for alternative attribute-based criteria and the fuel economy cut-offs under uniform criteria



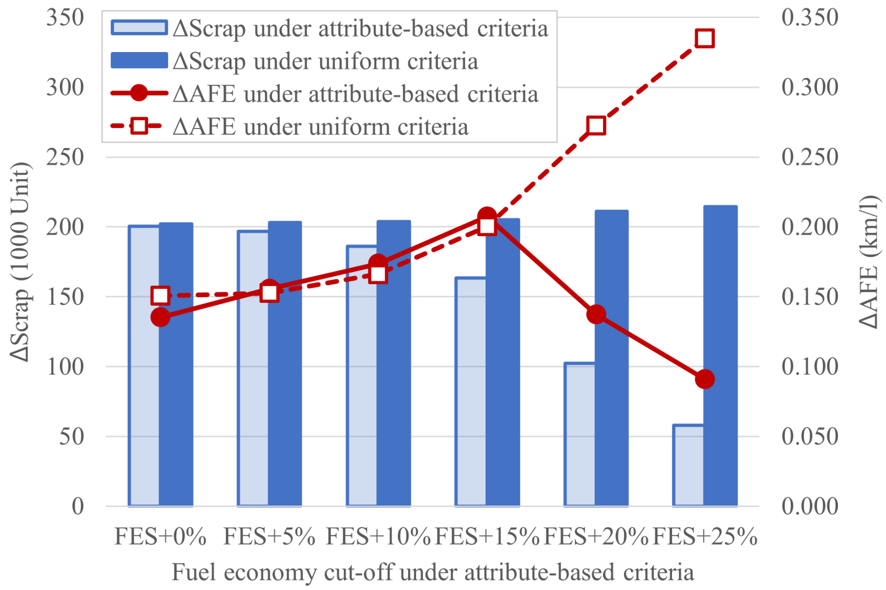
Notes: FES+x% indicates the fuel economy cut-off for each weight class in the FES (see Figure 1) increased by x%. The incentives for the alternative fuel economy cut-offs under the attribute-based criteria are obtained under the budget constraint on the subsidy expenditure of the baseline SP design (¥201.7 billion). For each alternative incentive, the fuel economy cut-off for the uniform criteria is derived under the same budget constraint.

Alternative attribute-based criteria: Given the above mentioned, I set the alternative attribute-based criteria under which the fuel economy threshold for each weight class in the FES is changed by 5% to 25%. This choice of alternative criteria is practically acceptable, as Japan's auto-related policies have adopted such a way, as was the case of the NSP under which the fuel economy cut-offs were set to FES+15%.

Then, for the simulated outcome under the various cut-offs to be comparable, I choose the levels of the incentive for each alternative criteria to match the subsidy expenditures under the alternative as closely as possible with that under the baseline SP design (i.e., ¥201.7 billion). The incentives for each attribute-based criteria derived as such are shown by the bars in Figure 5. The label on the horizontal axis shows the fuel economy cut-offs under the alternative attribute-based criteria. Specifically, FES+x% indicates that the eligibility cut-off values are higher by x% from the fuel economy for each weight class in the FES. Hence, the leftmost bar corresponds to the incentive under the baseline SP, namely, ¥209,500. Not surprisingly, the incentive increases as the cut-off levels rise.

Using the incentives for the alternative attribute-based criteria, I further derive the cor-

Figure 6: Environmental impacts for the alternative attribute-based and uniform criteria

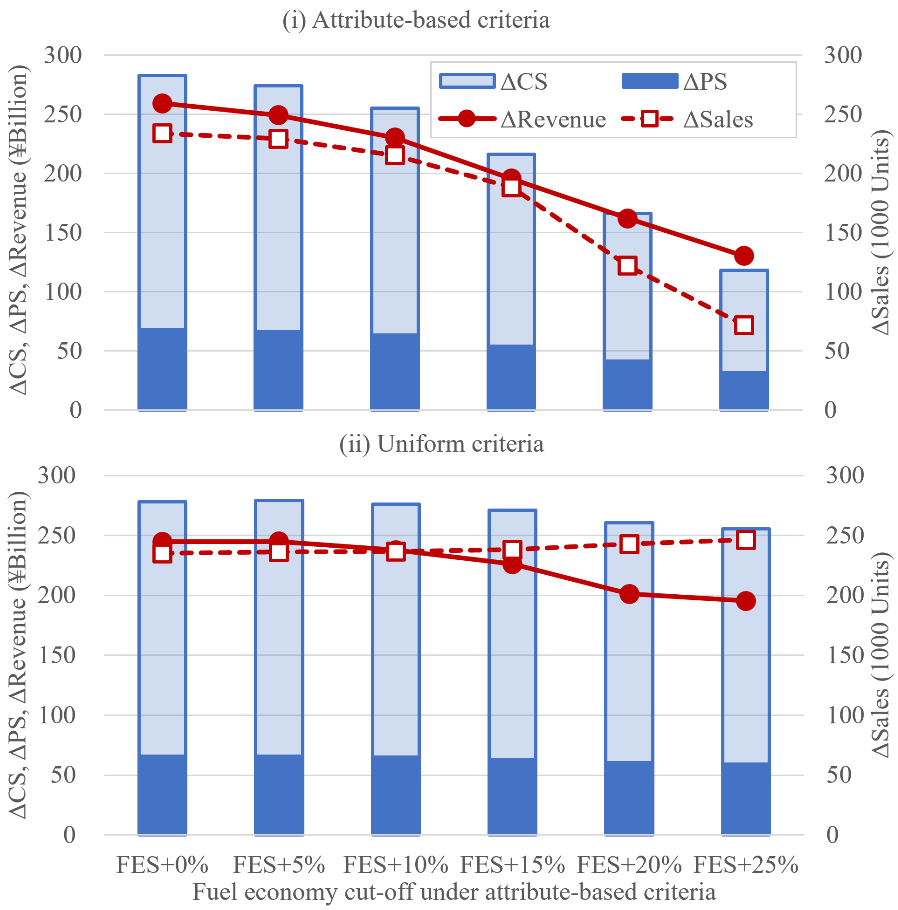


responding uniform fuel economy thresholds under which the subsidy expenditures most closely matches with the baseline of ¥201.7 billion. The solid line with the circle in Figure 5 indicates the fuel economy cut-offs under the uniform criteria.

Figure 6 shows the environmental impacts for the alternative attribute-based criteria and uniform criteria. The bars in the figure illustrate the number of aged car scrappage induced by the SP, showing that $\Delta Scrap$ decreases for the higher cut-offs under the attribute-based criteria. By contrast, $\Delta Scrap$ increases as the cut-off under the uniform criteria rise, albeit only moderately. The solid and dashed lines with marks show the changes in the average fuel economy for the attribute-based and uniform criteria, respectively from that for the no subsidy counterfactual. Under the attribute-based criteria, ΔAFE increases until FES+15% but decreases thereafter. This reversal of the trend is due to the nature of the proportional increase in cut-off levels under the attribute-based criteria. Specifically, this makes the eligibility cut-off levels for the lighter weight class rise larger amount, leading to excluding the substantial part of mini-vehicle models from the subsidy target. By contrast, ΔAFE constantly increases as the cut-off rises under the uniform criteria.

The comparison of the outcomes between the criteria reveals that the number of aged car scrappge is always larger for the uniform criteria, while the average fuel economy is not always higher. The number of vehicles sold under the SP is almost the same between the attribute-based and uniform criteria, as the subsidy expenditure is set as close as possible each other given the same incentives. Hence, under the uniform criteria, the larger $\Delta Scrap$

Figure 7: Environmental impacts for the alternative attribute-based and uniform criteria



indicates the higher number of clunker owners who shifts their choices from non-purchase to purchase. This would be due to the greater variety of light and thus cheap models qualified under the uniform criteria, which has a greater influence on price-sensitive households that tend to choose the outside option without the program.

The average fuel economy is slightly higher under the attribute-based criteria for the range from FES+5% to FES+15%, while $\Delta Scrap$ is lower. This implies that the SP with the attribute-based criteria for this range does induce clunker owners who purchase new vehicles regardless of the SP to shift their choice to more-fuel efficient vehicles.

The welfare and stimulus impacts are summarized in Figure 7. Sales under the uniform criteria slightly increase as the cut-off rises, consistent with the finding on the number of cars scrapped. By contrast, the higher the cut-off, the lower revenue. This might be due to the shift of purchases to the lighter and cheaper vehicles eligible for the program, in line with the finding by Hoekstra, Puller, and West (2017).

Implications for the subsidy design: Based on these findings, I discuss implications for the program design, not only for the SP but also for the NSP, accounting for the potential impacts on CO_2 emissions at the fleet level. To understand the discussion, note that the higher sales under the SP are associated with the higher number of replacements, thereby contributing to the CO_2 emissions reduction. By contrast, the sales increase under the NSP might contribute a little to the replacement but lead to the larger fleet size. This implies that CO_2 emissions might be increased across the transport sector, even though the higher average fuel economy of new vehicle fleets is achieved.

Given these features of the SP and NSP, the counterfactual analyses conducted here have the following policy implications. First, the uniform criteria might be suitable for the SP (rather than the attribute-based one), as they induce the larger number of replacements. In particular, the higher cut-off for the uniform criteria leads to a higher average fuel economy, thereby desirable from an environmental perspective. However, industry revenue and welfare decline for the higher criteria. Therefore, policymakers should choose the cut-off, considering the trade-off between the environmental impacts and the welfare/stimulus impacts.

Second, the attribute-based criteria might be suitable for the NSP (rather than the uniform one), as they do not induce higher new car sales (thereby less impact on fleet size), but do raise the average fuel economy. The average fuel economy is maximized at FES+15%, but industry revenue and welfare are lower than those under the lower FES. Again, the preferred subsidy design should be chosen, considering the trade-off between the environmental impacts and the welfare/stimulus impacts.

6.3.3 SP with OEM contribution

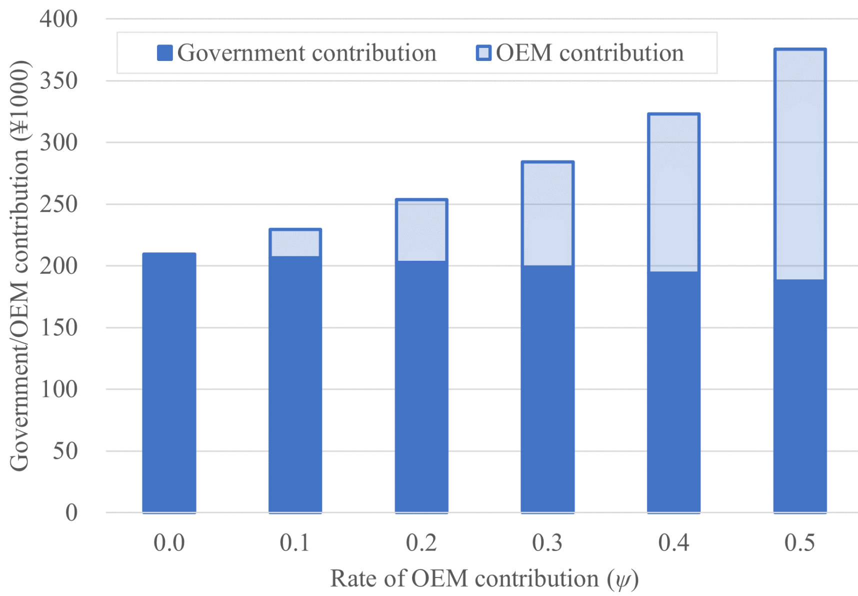
Here, I examine what would have happened if the government had requested OEMs to cover a proportion of the subsidy expenditure. The eligibility criteria for the new cars for purchase are identical to the baseline SP (i.e., the attribute-based criteria).

Let S_j^{OEM} be the subsidy (incentive) that buyers of car j receive under the SP and $\psi \in [0,1]$ be the proportion of the subsidy expenditure that the car manufacturers cover. Then, the profit function of firm f in the presence of the OEM contribution can be specified as follows:

$$\pi_f^{OEM} = \sum_{j \in J_f} \left[(p_j - mc_j) M s_j(\mathbf{p}^\tau, \mathbf{S}^{OEM}) - (\psi S_j^{OEM}) \times \phi M s_j^{SP}(\mathbf{p}^\tau, \mathbf{S}^{OEM}) \right] - FC, \quad (14)$$

where $\mathbf{S}^{OEM} = \{S_j^{OEM}\}_{j \in J}$, namely, the vector of the incentives. The second term in the

Figure 8: Incentives in the presence of the OEM contribution



Note: The height of bars is the total incentive granted to the program applicants.

bracket represents the subsidy expenditure covered by the firm (i.e., OEM expenditure). From the first-order condition for profit maximization with respect to prices, the pricing equation (in vector form) can be derived as follows:

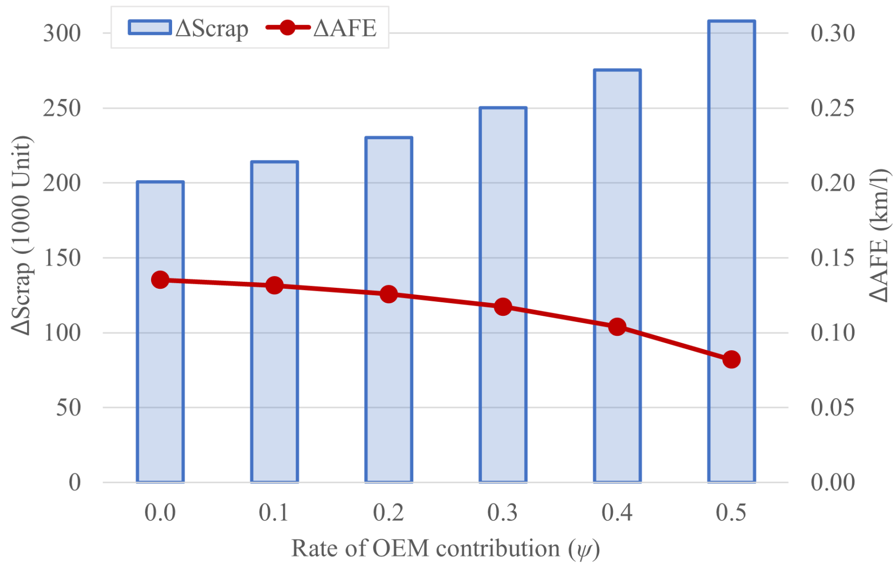
$$\mathbf{p}^{OEM} = \mathbf{mc} + \mathbf{\Delta}^{-1}\left[\left(\frac{\mathbf{1}}{\mathbf{1}+\mathbf{t}}\right)\circ \mathbf{s}\right] + \psi\phi\mathbf{\Delta}^{-1}\mathbf{\Delta}^{SP}\mathbf{S}^{OEM},$$

where $\mathbf{\Delta}^{SP}$ is the $J \times J$ matrix with the (j,r)-element $\Delta_{jr}^{SP} = H_{j,r} \cdot (-\partial s_r^{SP}/\partial p_j^{\tau})$. The counterfactual price vector under the OEM contribution $\mathbf{p}^{OEM}$ is obtained by solving the above equation.

According to the SPs adopted in reality, the rate of OEM contribution was chosen in the range of $[0, 0.5]$. Hence, I examine the outcomes for values of $\psi = 0, 0.1, \cdots, 0.5$. ($\psi = 0$ corresponds to no OEM contribution, and thus the baseline SP.) For each value of $\psi > 0$, I derive $S_j^{OEM}(\psi)$, the incentive for a car model j in the presence of the OEM contribution as a function of ψ, such that the government subsidy expenditure (i.e., the subsidy expenditure net of the OEM expenditure) under the value of ψ matches the government expenditure of the baseline SP, namely, ¥201.7 billion.

Figure 8 displays the incentives across different values of ψ. The stacked bars indicate the government and OEM contributions to the incentives, while the height of the bars (i.e., the sum of the contributions) indicates the total incentive granted to program applicants. The

Figure 9: Environmental impacts in the presence of the OEM contribution

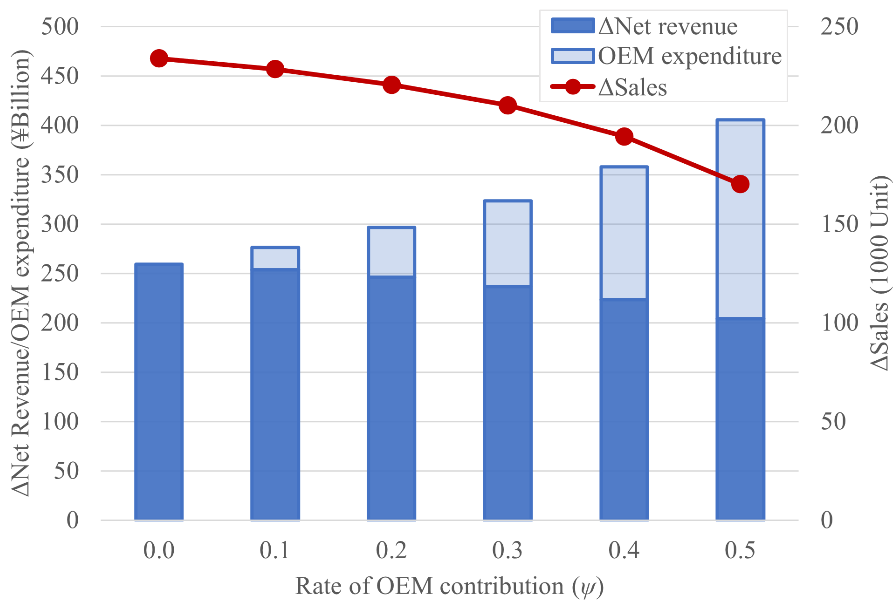


total incentive is larger for larger ψ, while the government contribution decreases slightly as ψ rises. Compared with $\psi = 0$ (i.e., the baseline SP), the government contribution for $\psi = 0.5$ decreases by approximately 10% from ¥209,500 of the baseline. As the subsidy expenditures is set as closely as possible across the values of ψ, the number of subsidy applications, which can be computed as the subsidy expenditure over the government contribution, is also larger by 10% for $\psi = 0.5$.

The environmental impacts in the presence of the OEM contribution are shown in Figure 9. As shown in the figure, the number of cars scrapped increases substantially as ψ rises. For $\psi = 0.5$, $\Delta Scrap$ increases by more than 50% from the baseline of approximately 200 thousand. The increase in the cars scrapped might be partially due to the difference in the number of subsidy applications (resulting from the difference in the government contribution). However, most of them would come from clunker owners' shift from non-purchase to the purchase of new vehicles. The average fuel economy decreases as ψ rises, implying that an increase in the number of replacements can be achieved at the cost of a lower average fuel economy.

Figure 10 shows the effects of stimulus. Here, I focus on OEMs' net revenue, which is calculated as their gross revenue minus the OEM expenditure (i.e., the second in the brackets in Eq.(14)). The figure shows that the higher ψ, the lower are sales and net revenue. Compared with the baseline, $\Delta Sales$ and $\Delta Net\ revenue$ under $\psi = 0.5$ are lower by approximately 27% and 21%, respectively. This implies that the adoption of OEM contributions

Figure 10: Stimulus impacts in the presence of the OEM contribution



Note: Net revenue is calculated as OEMs' gross revenue minus the OEM expenditure on the subsidy. The height of the stacked bars indicates the gross revenue for each ψ.

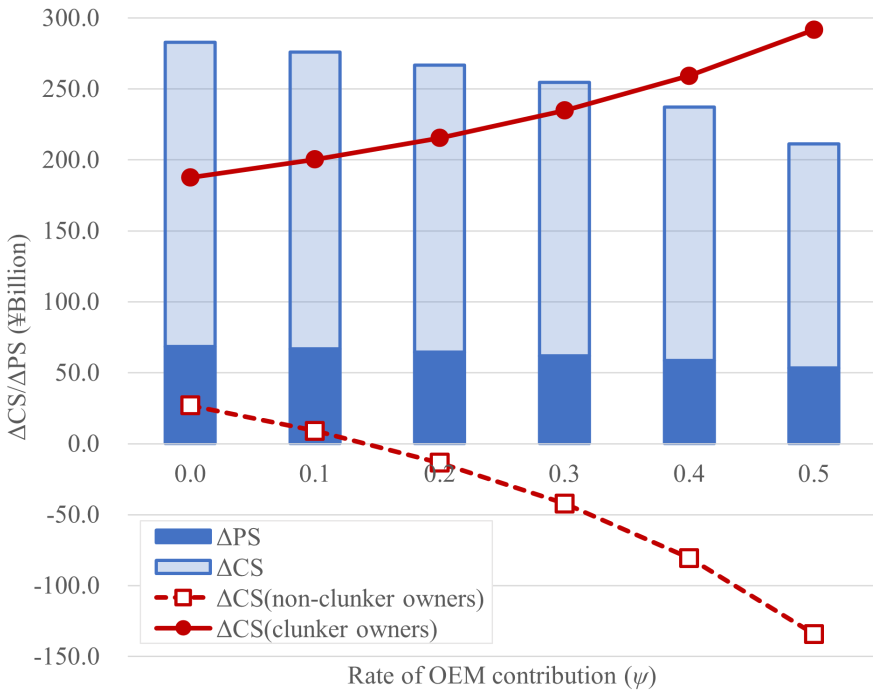
might mitigate the stimulus impacts.

Finally, the welfare impacts are shown in Figure 11. As shown by stacked bars in the figure, the producer and consumer surpluses decrease as ψ increases. It might thus be worth paying attention to the distributional impacts on clunker and non-clunker owners, as firms would have an incentive to raise the prices of the eligible car models in the presence of the OEM contribution to cover their subsidy expenditure. The solid and dashed lines with the marks show the consumer surplus of clunker owners and non-clunker owners, respectively.

In general, clunker owners, which are estimated to be 22.2% of the population, gain much larger than non-clunker owners and the difference in the consumer surplus widens as ψ increases. Somewhat counterintuitive outcomes are found for the consumer surplus of non-clunker owners, which is positive for $\psi \leq 0.1$. Simplistically, upon the adoption of the SP, firms may be inclined to raise their prices of car models eligible for the program. As a result, non-clunker owners, who are not subsidized, incur a loss from the adoption of the SP. However, a positive consumer surplus is inconsistent with this intuition.

A possible explanation of this result is as follows. First, there might be the case that the SP affects the strategic interactions among firms, leading to competitive outcomes (i.e., lower prices of eligible car models). Next, the current demand specification in which the price sensitivity varies across households may lead to seemingly unusual outcomes related to

Figure 11: Welfare impacts in the presence of the OEM contribution



the discussion in the last paragraph of Section 6.1.2. Nonetheless, the consumer surplus of non-clunker owners becomes negative at higher value of ψ under which firms have a stronger incentive to increase the prices of eligible cars.

Implications for the subsidy design: A key implication from the findings here is that SPs with an OEM contribution could promote the replacement of targeted clunkers substantially. As discussed, if the rate of the OEM contribution is set to 0.5 (as in Spain and UK) the number of aged car scrappage increased by 50%. However, this is achieved at the cost of the average fuel economy of new vehicle fleets, which decreases by approximately 40% for $\psi = 0.5$. Moreover, the additional number of replacements is achieved at the cost of the welfare and stimulus impacts. Therefore, policymakers should choose the rate of the OEM contribution considering the trade-off between the volume of replacements and other impacts.

7 Concluding remarks

This study examined the Japanese passenger car market to assess the impact of SPs during the financial crisis in 2009. It first introduced a simple method to analyze the SP, which incorporates data on the aggregate program outcome, namely subsidy expenditure, in a demand estimation based on discrete choice models. Next, I showed the degree of bias in the policy assessment under the assumption of no SP, which previous empirical studies of the Japanese car market have commonly adopted. It was found that although the parameter estimates in the discrete choice model were affected little by this assumption, the policy assessment based on the counterfactual simulations was substantially affected.

Finally, I simulated counterfactual outcomes under alternative program designs — non-attribute-based (or uniform) program eligibility criteria and the OEM contribution — to search for cost-effective program designs from environmental, welfare and stimulus perspective. The results showed that the outcomes between the attribute-based (i.e., actual) criteria and corresponding uniform criteria are small, although industry revenue is slightly higher under the attribute-based criteria. The difference in the outcomes appears when the higher cut-offs under the attribute-based design and their corresponding uniform cut-offs are compared. In particular, the number of clunkers scrapped under the attribute-based criteria decreases for higher cut-offs, while that under the uniform criteria increases only slightly. By contrast, the adoption of OEM contribution in the SP increases the number of replacements, although the welfare, industry revenue and the average fuel economy of new vehicle fleets decline for a higher rate of OEM contribution. This indicates that a higher number of clunkers scrapped can be achieved at the cost of other impacts.

The following future issues are noted. First, as automobiles are durables, it is desirable to apply a dynamic structural model to examine the impacts of the SP. Some recent studies (Li, Liu, and Wei (2021); Guan (2021)) have applied dynamic discrete choice models to investigate the US cash-for-clunkers program. These have modeled consumers' dynamic-decision making only, while the supply-side responses to the SPs are assumed to be absent. Although it is not trivial to model both the demand and the supply sides in the current context, future research can address the impacts of SPs on firm behavior as well. Second, as this study examined the Japanese automobile market, it did not analyze countries where SPs with OEM contributions have actually been introduced. It would be desirable to measure the SP impacts in such countries (e.g., Spain and the UK).

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Appendix

A Tax system and tax incentive measures

This appendix introduces the detail of the tax system and the tax incentive measures that were in effect during the study period, FY2006 to FY2009. Here, I refer to *The Motor Industry of Japan*, the annual publication of the Japanese Automobile Manufacturers Association (JAMA), which details the tax system and tax incentive measures implemented.[16] I explain the taxes levied on acquisition and during ownership, which were the target of the tax incentive measures implemented during the study period.

A.1 Tax system

In addition to a 5% a consumption (sales) tax, an automobile acquisition tax were levied on purchase of an automobile.[17] As summarized in Table 11, the acquisition tax rate was 5% for regular vehicles and 3% for mini-vehicles. These tax rates were not imposed directly on car prices but on tax bases set for each car model. As the tax base was approximately 90% of a car's price, the real tax rate could be approximated as 4.5% for regular vehicles and 2.7% for mini-vehicles.

The taxes levied during ownership include an automobile tax, a mini-vehicle tax, and a tonnage (car weight) tax. During the study period, the automobile tax was assessed to regular vehicles, with annual amounts ranging from ¥29,500 to 111,000, depending on the

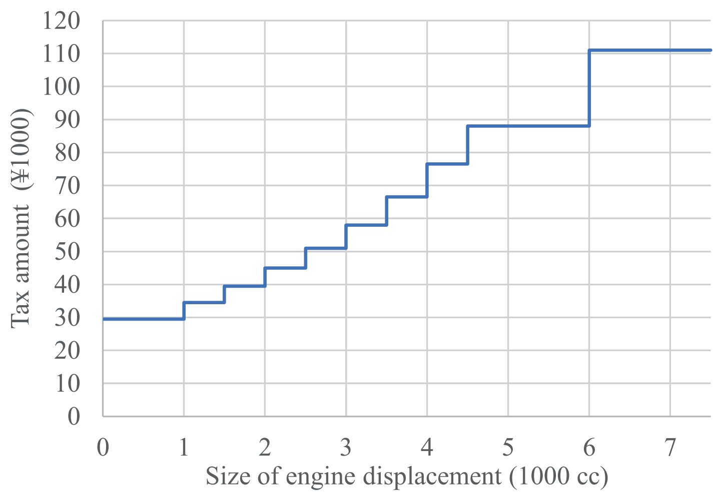
[16]The recent publications can be downloaded from JAMA's website. See the following link: `http://www.jama-english.jp/publications/industry.html`

[17]Specifically, the acquisition tax was assessed if a car price was greater than or equal to ¥500,000. During the study period, all new car models had prices greater than this value. It was abolished after the consumption tax has increased to 10% in October 2019.

Table 11: Auto-related taxes, FY2006–FY2009

	Regular vehicles	Mini-vehicles
Acquisition tax	5%	3%
Automobile tax	¥29,500–111,000 (see Figure 12 for more details)	¥0
Mini-vehicle tax	¥0	¥7,200
Tonnage (car weight) tax	¥6,300/0.5 ton	¥4,400

Figure 12: Automobile tax



engine displacement size (see Figure 12). By contrast, mini-vehicle owners paid the mini-vehicle tax instead of the automobile tax. The mini-vehicle tax rate did not depend on the engine displacement size but was fixed at ¥7,200. Both taxes were normally levied every April, but at the time of purchase, the tax amount from the month of purchase to March was levied.

As summarized in Table 11, the annual tonnage tax amount for regular vehicles was ¥6,300 per 0.5 ton, while that for mini-vehicles did not increase according to the car weight but was fixed at ¥4,400. The tonnage tax was levied at the time of the new car purchase and mandatory car inspections. On each occasion, car owners paid the taxes until next mandatory car inspection. The first car inspection was conducted three years after the new car purchase, and thus the amount of tonnage tax paid on purchase was three-year tax amount.[18]

[18] After the first car inspection, the car inspection was conducted every other year; hence, car owners paid a two-year tax amount upon each car inspection.

Table 12: Tax incentive measures, FY2006–FY2012

FY	Criteria[a]	Acquisition tax[b]	Automobile tax[c]	Tonnage tax
2006	FES+10%	Deductible up to ¥150,000	25% cut (1 year)	-
	FES+20%	Deductible up to ¥300,000	50% cut (1 year)	-
	Hybrid cars	44% cut	-	-
2007	FES+10%	Deductible up to ¥150,000	25% cut (1 year)	-
	FES+20%	Deductible up to ¥300,000	50% cut (1 year)	-
	Hybrid cars+FES+20%	40% cut	50% cut (1 year)	-
2008	FES+10%	Deductible up to ¥150,000	25% cut (1 year)	-
	FES+20%	Deductible up to ¥300,000	50% cut (1 year)	-
	Hybrid cars+FES+20%	36% cut	50% cut (1 year)	-
2009	FES+15%	50% cut	25% cut (1 year)	50% cut (3 years)
	FES+25%	75% cut	50% cut (1 year)	75% cut (3 years)
	Hybrid cars+FES+25%	100% cut	50% cut (1 year)	100% cut (3 years)

Notes:

[a] In addition to the requirement on the fuel economy levels, a 75% emission certification was necessary to be eligible for the tax incentive measures.

[b] A tax deduction of ¥x is equivalent to a tax cut of $x \times 5\%(3\%)$ for regular vehicles (mini-vehicles), where 5% (3%) is the acquisition tax rate (the tax cut is lower if the car price is less than ¥x, but it is less common).

[c] In FY2006, hybrid car models were eligible for the automobile tax cut if they met the gasoline car's fuel economy criteria. The rates of tax cuts were the same as for gasoline cars.

A.2 Tax incentive measures

Tax incentive measures for fuel-efficient and low-emission cars have been implemented since April 2004. The acquisition, automobile and tonnage (car-weight) taxes were the target of the measures, while the mini-vehicle tax was excluded. The criteria and benefits of these measures were revised over time, generally at the beginning of the fiscal year on April 1. Here, I introduce these measures for the study period from FY2006 to FY2009.

Table 12 reports the details of the tax incentive measures implemented from FY2006 to FY2009. The second column of the table shows the criteria for the tax incentive measures. As shown, these criteria depend on the extent to which the car exceeded the target fuel economy level set in the 2010 FES (see the solid line in Figure 1). The third to fifth columns present the details of the tax incentive measures pertaining to the acquisition, automobile, and tonnage taxes for car models that meet the criteria mentioned in the second column. As shown, the criteria and amount of tax cuts varied over time. In addition, hybrid cars received advantageous treatment.

For the automobile and tonnage taxes assessed during ownership, the period of tax cut is shown in the table. The automobile tax cut was applied for at most a year, while the

Table 13: 2005 emissions standard: Target pollutants and values

NOx	Non-methane Hydrocarbon	CO
0.05g/kwh	0.05g/kwh	1.15g/kwh

Notes: The emissions for each car model are measured based on a test cycle specified by the Ministry of Land, Infrastructure, Transport and Tourism .

tonnage tax cut was applied for three years, the period from the new car purchase to the first car inspection. The years of the tonnage tax cut corresponds to the years of the tax levied at the time of purchase and at the first mandatory car inspection, which are three and two years, respectively.

A.3 Emissions standards

In addition to GHG emissions, the Japanese government has regulated the emission of certain pollutants. For private gasoline cars, CO, NOx, and non-methane hydrocarbon were target pollutants in the 2005 emissions standard. This standard specifies an acceptable level of emissions of these pollutants, and car models that did not meet the standards were not authorized (marketed).

Low emission certification is provided based on the degree of improvement over pollutant emissions specified by the 2005 standard. There are two levels of low emission certifications: 50% and 75% reduction. These certifications are provided if the emissions of NOx and non-methane hydrocarbon are 50% (or 75%) lower than that specified in the 2005 emissions standard, if the CO emission level is lower than that specified in the standard, and if the PM emission level is below the detection limit (i.e., is a trace amount). The Ministry of Land, Infrastructure, Transport and Tourism releases a list of car models complying with the 50% and 75% certifications.[19]

[19] The list of car models complying with the certifications is available from `https://www.mlit.go.jp/jidosha/lowgas/lowgaskouhyou/index.html` (in Japanese).