Research Institute for Environmental Economics and Management

Discussion Paper Series No.2506

The Effects of Fuel Economy Misreporting on Consumer Welfare and Environmental Externalities Prior to Public Disclosure: Evidence from Japan's Automobile Market

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March 2026

WASEDA

The Effects of Fuel Economy Misreporting on Consumer Welfare and Environmental Externalities Prior to Public Disclosure: Evidence from Japan's Automobile Market

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Abstract

This study examines the distortion effect of persistent product performance misinformation on consumer choice, market allocation, and environmental outcomes in the case of fuel economy misreporting in the Japanese automobile market. The analysis focuses on consumer decisions made under incorrect performance assumptions before public disclosure. Using monthly data from 2005 to 2016, the study estimates a structural aggregate logit demand model using Berry–Levinsohn–Pakes and Lewbel instruments to address price endogeneity. Counterfactual simulations based on corrected fuel economy show that manipulated vehicles experienced substantial demand gains primarily through reallocation from competing models. Misinformation generated measurable welfare loss and social damages. The market-level results indicate that inaccurate information provided by firms can distort resource allocation and weaken the effectiveness of performance-based environmental policies. These findings highlight the importance of accurate performance reporting and regulatory monitoring in markets where policy incentives and consumer decisions rely heavily on firm-reported attributes.

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1. Introduction

In many markets, consumers rely on performance information provided by firms when making purchase decisions (Akerlof, 1970; Stiglitz, 2000). When such information is distorted or imperfectly understood, consumers may form incorrect beliefs, leading to inefficient choices and welfare losses (Chetty et al., 2009; Handel and Kolstad, 2015). Empirical studies further document that misperceptions about product attributes or operating costs can generate substantial welfare losses and distort market outcomes (Abaluck and Gruber, 2011; Allcott and Wozny, 2014). Therefore, understanding how persistent misperceptions affect market allocations and economic outcomes is a central issue in information economics and industrial organization.

These concerns are particularly relevant in the markets characterized by durable goods with energy-related attributes. In such markets, consumers make long-term decisions based on expected operating costs and performance. For instance, a difference of several kilometers per liter in fuel economy can translate into substantial lifetime fuel cost savings, capitalized as consumer willingness to pay. Consequently, misperceptions at the time of purchase may affect not only consumer welfare but also energy use and environmental externalities over the product's lifetime.

Although a growing body of literature (e.g., Allcott and Rogers, 2014; Allcott and Wozny, 2014; Newell and Siikamäki, 2014) examines information provision, labeling policies, and consumer misperceptions, most existing evidence focuses on behavioral responses once information becomes publicly available.

Moreover, the effects of incorrect or distorted information on consumer choices and market allocation are underexplored when misinformation remains in place.

This study examines how persistent misinformation distorts consumer choice, market allocation, and environmental outcomes. The study uses the case of fuel economy misreporting in the Japanese automobile market involving Mitsubishi Motors Corporation, which was publicly disclosed in Japan on April 20, 2016. To study consumer decisions made under incorrect performance beliefs rather than market reactions after an information shock is revealed, the analysis focuses on the period before the public disclosure of misconduct.

This case study provides a suitable setting to identify the effects of misinformation. Fuel economy manipulation involves the falsification of testing data, whereas the actual physical performance of vehicles and production technologies remains unchanged. Importantly, misconduct does not involve direct manipulation of listed vehicle prices or production costs. However, because prices are determined at equilibrium, misreporting may indirectly affect market prices through demand shifts. Therefore, although such manipulation does not mechanically alter prices, it may generate a price premium as an endogenous market response. Consequently, the episode can be interpreted as a pure information shock that affects consumers' perceived fuel efficiency without altering the underlying supply conditions. Moreover, misconduct remains undisclosed during the study period; thus, no reputational effects or post-disclosure demand adjustments occur. This setting allows an isolation of a clean demand-side misperception shock and examination of its impact on market outcomes.

The Japanese automobile market provides an economically important context in which these distortions may have substantial consequences. Fuel economy plays a central role in vehicle choice, and government policies such as fuel-efficiency labeling and eco-car tax incentives further strengthen the link between reported performance and consumer demand. Because automobiles are durable goods, incorrect beliefs about fuel efficiency affect not only purchase decisions, but also long-term fuel consumption and associated carbon dioxide (CO_2) emissions. Therefore, a misreported fuel economy may distort both market competition and environmental outcomes.

Despite the policy relevance of these issues, existing empirical studies on corporate misconduct have primarily examined post-disclosure outcomes, such as changes in sales, stock prices, and firm value following the discovery of fraud (e.g., Mansouri, 2016; Dura, 2019; Barth et al., 2022; Ater and Yoseph, 2022). Although these studies provide valuable evidence of market discipline and reputation effects, they offer limited insight into how misinformation affects resource allocation while it remains undetected. Specifically, empirical evidence on how incorrect performance information distorts demand across competing products, affects consumer welfare, and generates environmental externalities through changes in product usage is limited.

Previous studies have shown that information friction and misperception can lead to inefficient choices and welfare losses (e.g., Allcott and Wozny, 2014; Handel and Kolstad, 2015). However, the majority of these studies focus on consumer biases, post-disclosure responses, and policy interventions, offering little evidence of how intentional misinformation affects market outcomes while it remains undetected.

This study contributes to the literature by quantifying the economic consequences of misinformation across three dimensions. First, it estimates how overstated fuel efficiency affects consumer choice and measures the resulting change in consumer surplus. By comparing the observed demand under the reported performance with the counterfactual demand under the true performance, the analysis evaluates the welfare loss arising from distorted beliefs about operating costs. Second, it examines how misinformation alters market outcomes by adjusting the sales distribution across vehicle models. Third, the environmental impact is evaluated by applying the difference between the reported and actual fuel efficiency to the observed sales volumes of the affected vehicles. This approach measures the additional CO_2 emissions generated by excess fuel consumption relative to a counterfactual scenario in which vehicles achieve their reported fuel economy performance.

More broadly, this study provides market-level evidence on how firms' persistent misinformation affects resource allocation, consumer welfare, and environmental externalities. It aims to highlight the economic consequences of inaccurate firm-provided information and underscore the importance of reliable performance reporting for the effective design and enforcement of performance-based environmental policies.

The remainder of this paper is organized as follows. Section 2 describes the institutional background and the fuel economy misconduct in Japan. Section 3 reviews the related literature on consumer misperception, corporate misconduct, and environmental information. Section 4 presents a conceptual framework that describes how distorted performance information affects consumer beliefs, demand, and welfare. Section 5 introduces the data, and Section 6 outlines our empirical strategy and estimation methods. Section 7 reports the main results and quantifies consumer welfare and environmental impacts, with Section 8 presenting extensions and robustness checks. Finally, Section 9 concludes with policy implications and directions for future research.

2. Institutional Background: Fuel Economy Misreporting by Mitsubishi Motors

This study examines the fuel economy misreporting scandal involving Mitsubishi Motors Corporation, which was publicly disclosed in Japan on April 20, 2016. According to the official investigation report (Mitsubishi Motors Corporation, 2016), the company manipulated the road load resistance data used in emissions and fuel economy tests conducted as part of vehicle-type certification. These manipulations resulted in overstated fuel efficiency figures reported to regulators and consumers.

The misconduct affected four mini-vehicle models produced between June 2013 and April 2016: the *eK Wagon* and *eK Space* and two Original Equipment Manufacturer (OEM) models supplied to Nissan, the *Dayz* and *Dayz Roox*. These vehicles were designed and marketed as fuel-efficient mini-cars, a segment in which fuel economy is a key competitive attribute. During this period, competing manufacturers repeatedly updated their models to achieve higher fuel-efficiency targets. The investigation report suggests that, in response to this competitive pressure, Mitsubishi progressively intensified its manipulation of testing data to maintain competitive performance claims.

Figure 1 depicts a timeline of the major events related to the misconduct. The gradual escalation of manipulation under strong competitive pressure suggests that an overstated fuel economy may have generated economic benefits for the firm.

The mechanisms through which these benefits arise are as follows. First, an overstated fuel economy may have enabled the firm to set higher prices than what would have been feasible under the vehicle's true performance. For instance, the 2016 model of the *eK Wagon E* (2WD) was marketed with a reported fuel efficiency of 26 km/L at a price of 1.08 million yen. After the scandal, the same model was sold in January 2017 with a corrected fuel efficiency of 23.6 km/L at a reduced price of 1.0314 million yen. This simple comparison indicates a price difference of approximately 48,600 yen per vehicle.[4]

Second, the overstated fuel economy may have increased sales by improving perceived product quality. Fuel efficiency is a critical attribute in vehicle purchase decisions, particularly in the mini-vehicle segment. Therefore, consumers who would not have purchased a vehicle given the accurate performance information may have selected manipulated models.

Third, misreporting impacts the eligibility for government tax incentives. During the misconduct period, eligibility for the eco-car tax reduction program depended on whether the vehicle met the fuel-efficiency standards established by the Ministry of Land, Infrastructure, Transport, and Tourism. Vehicles that exceeded the threshold received reductions in acquisition and weight taxes, effectively lowering their purchase price. Because eligibility was determined based on the reported fuel economy, overstated performance allowed some vehicles to qualify for tax benefits that they would not have received with accurate information. For example, the 2016 *eK Wagon* met the FY2020 fuel-efficiency standard based on the reported figures, but failed to meet the standard based on its true performance. Consequently, vehicles obtained tax benefits for which they were not eligible, further stimulating demand.

Therefore, misconduct affects market outcomes through two mechanisms. First, overstated fuel economy increases the perceived product quality by lowering expected operating costs, thereby shifting demand outward. Second, the inflated fuel economy figures allowed the vehicles to qualify

[4] Fuel economy figures and price information are based on official manufacturer specifications released before and after the disclosure (Mitsubishi Motors Corporation, 2016).

for eco-car tax incentives, effectively reducing consumer purchase prices. These demand-shifters led to higher equilibrium sales and price premium relative to the counterfactual without manipulation.

Importantly, the manipulation affected reported performance without changing the physical characteristics or production costs of the vehicles. This is interpreted as a demand-side information distortion rather than a supply shock, providing a suitable setting for empirically examining how incorrect performance information affects consumer choice and market allocation.

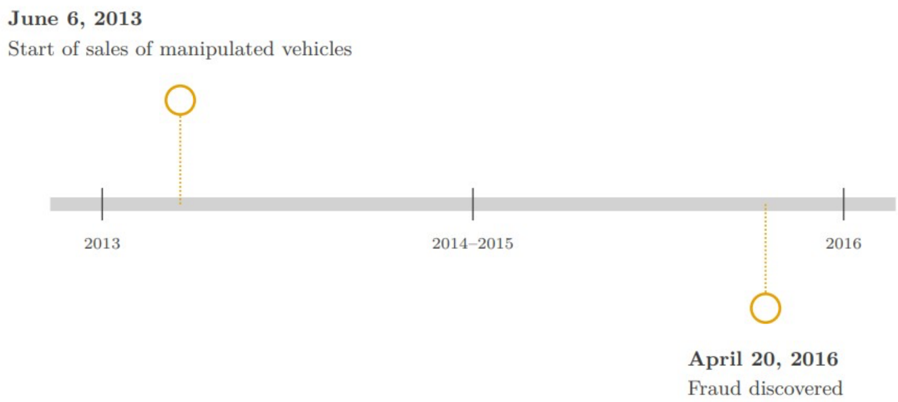

Figure 1. Timeline of the Mitsubishi Motors fuel-economy fraud (June 2013–April 2016)

Source: Author's compilation based on official investigation reports.

Note: Figure 1 illustrates the timeline of the misconduct, including the introduction of the manipulated models in June 2013 and the public disclosure of the irregularities on April 20, 2016. It highlights the period during which consumers make purchase decisions based on overstated fuel economy information.

3. Related Literature

This study examines how fraudulent performance information distorts consumer beliefs before detection and, in turn, affects demand allocation, consumer welfare, and environmental externalities. This study relates to several strands of literature: (i) studies on corporate misconduct and information disclosure; (ii) research on consumer misperception and welfare; (iii) the role of fuel economy and energy information in automobile demand; and (iv) the impact of misconduct on market competition and demand allocation.

3.1 Corporate Misconduct and Market Outcomes

A large body of literature examines the economic consequences of corporate misconduct, focusing primarily on market reactions following public disclosure. Existing studies document substantial declines in firm value, stock prices, and product demand after scandals such as the Volkswagen emissions case (e.g., Dura, 2019; Barth et al., 2022; Bachmann et al., 2023). These studies provide important evidence that markets discipline corporate misconduct through reputational and financial penalties once the information becomes public. The documented declines in firm value and product demand indicate that disclosure triggers substantial adjustments in consumer behavior and market outcomes. However, while this literature highlights the role of market discipline after disclosure, it provides limited insight into how misconduct affects resource allocation while it remains undetected. Prior to public revelation, consumers continue to make decisions based on distorted product information, potentially generating misallocation and welfare losses that are not captured by post-disclosure analyses. Understanding these pre-detection effects is therefore essential for evaluating the full economic consequences of corporate misconduct.

3.2 Consumer Misperception and Welfare

Previous studies examine how imperfect information and misperceptions affect consumer behavior and welfare. Chetty et al. (2009) show that tax salience influences consumer responses, demonstrating that limited attention and misperception can distort market outcomes. Hastings and Shapiro (2013) provide evidence that misperceived prices and product attributes lead to inefficient choices and welfare losses.

For durable goods and energy use, consumers must evaluate future operating costs at the time of purchase, and expected fuel expenses are often capitalized on vehicle prices and willingness to pay. Allcott and Wozny (2014) quantify consumer misperceptions about fuel costs in the automobile market and estimated the associated welfare losses. Moreover, studies in other markets including health insurance document substantial welfare losses stemming from suboptimal choices owing to information friction (Abaluck and Gruber, 2011; Handel and Kolstad, 2015). More recently, Alé-Chilet et al. (2025) use a structural demand framework to examine how firms' strategic responses to environmental regulations can distort consumer choices prior to detection.

These studies establish that consumer misperceptions can distort allocation and reduce welfare. However, most existing studies focus on cognitive biases, limited attention, or regulatory responses, rather than intentional misinformation. Additionally, empirical evidence on welfare losses arising from firms' fraudulent performance claims remains limited.

This present study examines such a case of fuel economy misreporting. By overstating fuel efficiency, the affected vehicles appeared to offer lower lifetime operating costs, thereby increasing their perceived value at the time of purchase. This setting allows us to examine how firm-induced misperceptions, rather than purely behavioral biases, affect demand allocation, consumer welfare, and environmental outcomes.

3.3 Fuel Economy Information and Vehicle Demand

Numerous studies have examined the roles of fuel economy and energy performance in vehicle demand. Survey-based evidence suggests that consumers may not fully account for lifetime fuel costs when making vehicle purchase decisions, reflecting their limited attention or imperfect evaluation of future operating expenses (Turrentine and Kurani, 2007). Meanwhile, market-based studies indicate that the fuel economy is still economically relevant to consumer choice.

Using transaction data, Busse, Knittel, and Zettelmeyer (2013) show that changes in gasoline prices affect vehicle prices, consistent with the notion that expected future fuel costs are capitalized into consumer willingness to pay. Similarly, Sallee, West, and Fan (2016) find that used vehicle prices reflect the present value of the expected fuel savings. These findings indicate that the fuel economy influences demand through its effect on perceived operating costs, despite incomplete consumer optimization.

The importance of fuel economy may also vary across consumers depending on driving intensity, fuel price expectations, and preferences for operating cost savings. Such heterogeneity implies that incorrect or distorted fuel economy information can unevenly affect different consumers and generate substantial aggregate demand responses.

In summary, existing evidence indicates that fuel economy is a key determinant of vehicle demand. However, empirical evidence on how market allocation and environmental outcomes respond when firms intentionally distort fuel economy information is limited.

3.4 Misconduct, Competition, and Demand Reallocation

Several studies examine how corporate misconduct affects competition and demand allocation across products. In differentiated product markets, quality misrepresentation shifts the perceived utility of the affected product upward, thereby expanding residual demand and diverting consumers from competing products (Reynaert and Sallee, 2021). Theoretically, such distortions alter the competitive landscape by changing the relative product attractiveness and may affect firms' pricing and positioning decisions. Competing firms may respond strategically by adjusting their prices, product characteristics, and marketing efforts to mitigate demand losses.

Empirical evidence on demand reallocation focuses primarily on the period following public disclosure. For instance, Bachmann et al. (2023) show that the Volkswagen emissions scandal led consumers to substitute with competing vehicles, while Hasan et al. (2019) find that registrations of affected models declined, but overall market demand remained relatively stable. These studies provide key evidence on reputational spillovers and competitive responses after misconduct becomes publicly known.

However, how demand reallocation occurs while misinformation remains undisclosed remains understudied. In a pre-detection environment, consumers do not penalize the firm for misconduct, but rather demand shifts arise because distorted performance information increases the perceived quality of the affected products. Therefore, this present study can isolate how firm-provided misinformation reallocates demand across competing models and alters market competition even in the absence of reputation effects.

3.5 Contribution of This Study

Existing literature indicates that (i) corporate misconduct affects market outcomes after disclosure, (ii) consumer misperceptions can generate welfare losses, and (iii) fuel economy information plays an important role in vehicle demand. However, little empirical evidence regarding how fraudulent performance information affects consumer behavior and market allocation before the misreporting is disclosed. Prior studies offer limited evidence of how persistent firm-provided misinformation reallocates demand across competing products, distorts consumer welfare, and generates environmental externalities in pre-detection settings.

This study contributes to the existing literature in three ways. First, it provides market-level evidence of the economic consequences of intentional fuel economy misreporting before public disclosure, thus isolating a condition under which consumer beliefs are distorted without reputational effects. Second, the analysis employs a structural demand framework to quantify the resulting changes in demand allocation and consumer surplus, allowing the welfare effects of misinformation to be evaluated using counterfactual performance information. Third, this study links demand distortions to environmental outcomes by estimating the additional CO_2 emissions generated via excess fuel consumption.

By integrating demand estimation, welfare analysis, and environmental impact assessment, this study comprehensively evaluates the social costs associated with inaccurate firm information. These results indicate that misinformation can simultaneously distort market competition, reduce consumer welfare, and weaken the effectiveness of performance-based environmental policies.

4. Conceptual Framework: Demand Distortion and Welfare under Misreported Performance

This study proposes a simple conceptual framework to illustrate how fuel economy misreporting affects market outcomes and consumer welfare. The framework uniquely hypothesizes that misreporting does not change production technology or costs, but instead affects market outcomes by distorting consumers' perceived product quality.

Let q denote the quantity of vehicles sold and p the market price. Consumer willingness to pay is represented by the inverse demand function $p = D(q)$. When accurate fuel economy information is available, willingness to pay is modeled as follows:

$$p = D^{true}(q).$$

Let q^* denote the equilibrium quantity under accurate information and $\tilde{q}$ denote the equilibrium quantity when the fuel economy is overstated and consumers form biased performance beliefs.

If fuel economy is overstated, consumers perceive vehicle performance to be higher than its true level. Consequently, consumers are willing to pay a higher price for any given quantity. Therefore, the perceived demand based on the reported information is the following:

$$p = D^{rep}(q),$$

where

$$D^{rep}(q) > D^{true}(q)$$

for all q. This assumption reflects a systematic upward bias in perceived product quality owing to misreporting.

On the supply side, fuel economy misreporting does not affect the production technology or marginal costs. Therefore, the supply function is assumed to remain unchanged:

$$p = S(q).$$

This assumption is appropriate for the present analysis, which focuses on short-run market outcomes during a period in which misreported fuel economy affects consumer beliefs. While firms may adjust prices or product characteristics in the longer run, the framework abstracts from such supply-side responses to isolate the demand-side distortion generated by incorrect performance information.

Under accurate information, the market equilibrium is determined as

$$D^{true}(q^*) = S(q^*).$$

When misreporting occurs, the market equilibrium is determined by the following intersection of perceived demand and supply:

$$D^{rep}(\tilde{q}) = S(\tilde{q}).$$

Because perceived demand exceeds true demand, the equilibrium quantity increases:

$$\tilde{q} > q^*.$$

Thus, misreporting leads to additional transactions in the range $[q^*, \tilde{q}]$ that would not occur under accurate information.

For these additional units, consumers' true marginal benefit is given by $D^{true}(q)$, whereas the market price reflects the marginal cost along the supply curve $S(q)$. As $S(q) > D^{true}(q)$, over this range, these transactions generate a welfare loss. The deadweight loss is then given by

$$\int_{q^*}^{\tilde{q}} [S(q) - D^{true}(q)]\, dq > 0.$$

which represents the loss in total surplus arising from overconsumption when demand is distorted upward by misperceived product performance. This framework illustrates the efficiency loss associated with excessive consumption relative to allocation under correct information.

In addition to the aggregate efficiency loss, misreported performance information may generate distributional effects across consumers. For instance, consumers with higher expected driving intensity or greater sensitivity to operating costs may experience greater welfare losses. Our empirical analysis focuses on the aggregate consumer-surplus effect.

However, in the empirical analysis, the welfare measure focuses on the consumer surplus component of this distortion. Specifically, the analysis computes the changes in the expected consumer surplus using the logit inclusive-value formula under correctly reported and perceived fuel economy. Thus, although the conceptual framework describes the total surplus (deadweight loss), the empirical results quantify the consumer welfare loss implied by distorted consumer choices.

Figure 2 illustrates this mechanism. The misreported fuel economy shifts perceived demand upward from $D^{true}(q)$ to $D^{rep}(q)$, increasing the equilibrium quantity from $q^*$to $\tilde{q}$. The shaded area between the supply and true demand curves over the interval $[q^*, \tilde{q}]$ represents the welfare loss resulting from excess purchases under distorted information.

Based on this framework, the empirical analysis identifies how misreported fuel economy affects vehicle demand and the extent to which it reallocated purchases across products. The estimated demand distortions are then used to quantify the resulting change in consumer welfare and the increase in CO_2 emissions associated with excess vehicle usage.

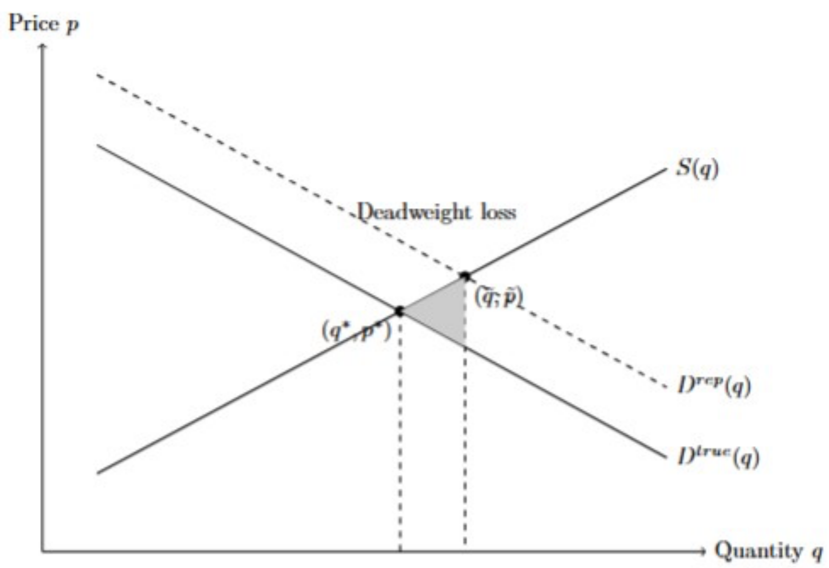

Figure 2. Demand Distortion and Welfare Loss under Fuel Economy Misreporting

Notes: The solid downward-sloping curve $D^{true}(q)$ represents the true demand based on accurate fuel economy information, whereas the dashed curve $D^{rep}(q)$ represents the perceived demand when the fuel economy is overstated. The upward-sloping curve $S(q)$ denotes the supply (marginal cost) curve unaffected by misreporting. Misreported performance shifts perceived demand upward, increasing the market equilibrium from (q^*, p^*) to $(\tilde{q}, \tilde{p})$. The shaded area between the supply and true demand curves over the interval $[q^*, \tilde{q}]$ represents the deadweight loss resulting from excess purchases under distorted information.

5. Data

This study utilizes monthly panel data on the Japanese passenger vehicle market covering the period from January 2005 to April 2016. The dataset comprises 30,880 observations at the vehicle–month level. The sample period includes the introduction of the manipulated models in June 2013 and ends just before the public disclosure of the misconduct on April 20, 2016. By focusing on the pre-disclosure period, we can capture the effects of misreported fuel economy on consumer behavior, demand allocation, consumer welfare, and associated environmental externalities without confounding results from reputation effects or post-disclosure adjustments.

As the market share of imported vehicles is small (5.6 percent of new vehicle sales in 2012; Japan Automobile Inspection and Registration Information Association, 2024) and their product cycles and regulatory environments differ from those of domestic manufacturers, they are excluded from the analysis. The analysis focuses on vehicles produced by Japanese manufacturers to ensure a more homogeneous competitive environment. Although this restriction may limit the external validity of the results, imported vehicles account for only a negligible share of the mini-car segment, suggesting that the main findings are representative of the contextual market conditions.

Table 1 reports summary statistics for the main variables. All variables are defined at the monthly level, and each observation corresponds to a vehicle model in a given month. A vehicle model is defined at the nameplate–generation level, such that major model redesigns (full model changes) are treated as distinct products. The dataset includes information on sales, price, fuel economy, power-to-weight ratio, vehicle size, gasoline prices, and policy-related indicators. Vehicle characteristics, including engine size, vehicle dimensions, and power specifications, are obtained from manufacturers' official catalogs and the publicly available automotive database Goo-net, operated by Proto Corporation. The variable *Fraud* is a binary indicator equal to one for vehicle models with a discrepancy between reported and actual fuel economy identified during the period in which fuel economy misreporting occurred, and zero otherwise. The variables *Tax* and *Subsidy* indicate eligibility for eco-car tax reductions and purchase subsidy programs, respectively. Fraudulent models account for approximately 0.5 percent of the vehicle–month observations. This figure reflects the share of model–time cells rather than economic market size. However, in terms of units sold these models account for approximately 2 percent of total vehicle sales during the sample period, indicating that the affected segment is limited in scope but economically meaningful.

For the affected models, corrected fuel economy values are obtained from the official post-investigation figures released by the Ministry of Land, Infrastructure, Transport, and Tourism following the disclosure of the misconduct. These corrected values replace the reported fuel economy values for the affected models when constructing the counterfactual scenario, whereas the reported values are retained for all unaffected models.

Table 1. Summary statistics

Variable	Mean	Std. Dev.	Min	Max
Sales (units)	1575.207	3084.51	0	45496
Price (million yen)	2.3271	1.7448	0.555	13.0129
Reported fuel economy (km/L)(fuel)	16.2422	5.493	5.5	40.000
Power-to-weight ratio (kW/kg) (Hppw)	0.073	0.027	0.033	0.233
Vehicle volume (m^3) (Size)	11.415	2.478	5.849	19.154
Gasoline price (yen/liter) (Gas Price)	142.261	16.102	107.709	188.426
Fraud (Fraud)	0.005	0.071	0	1
Tax eligibility (Tax)	0.254	0.435	0	1
Subsidy eligibility (Subsidy)	0.107	0.309	0	1
Observations		30,880		

Notes: This table reports the summary statistics for the vehicle–month panel used in the analysis. Sales denote monthly unit sales for each vehicle model. Price is the manufacturer's suggested retail price in million yen. Fuel economy refers to the officially reported fuel efficiency (km/L). Gasoline price is the monthly national average retail price (yen/liter). *Fraud* is a dummy variable equal to one for vehicle models with identified discrepancies between reported and actual fuel economy. *Tax* indicates eligibility for eco-car tax reductions, and *Subsidy* indicates eligibility for purchase subsidy programs. The sample covers January 2005 to April 2016.

Vehicle sales data for the period 2005-2016 are obtained from the Japan Mini Vehicles Association and Japan Automobile Dealers Association. Information on vehicle characteristics is collected from publicly available catalog data provided by Goo-net. Because sales data are available only at the model level and multiple trim levels may exist within a model, each vehicle model is represented by a single specification. Specifically, the vehicle attributes are defined based on the lowest-priced base trim. This approach improves comparability across models and over time, as higher trims often include additional equipment that increases the vehicle weight without proportionate changes in fuel efficiency. Additionally, base trims are consistently available across models and periods. The vehicle demand literature typically represents each model by a single set of characteristics (e.g., Reynaert, 2021). Moreover, because variation across trims within a model is limited relative to variation across models, this aggregation is unlikely to materially affect the estimated demand responses.

Figure 3 presents the time-series evolution of fraudulent and non-fraudulent vehicles sales. Although the two groups differ in sales levels, both exhibit relatively stable trends prior to 2013, with no evidence of differential pre-trends before the manipulated models are introduced. After 2013, sales of fraudulent vehicles increase compared to those of non-fraudulent models. These patterns are consistent with the identification strategy, suggesting that the introduction of manipulated fuel economy information coincides with changes in market outcomes.

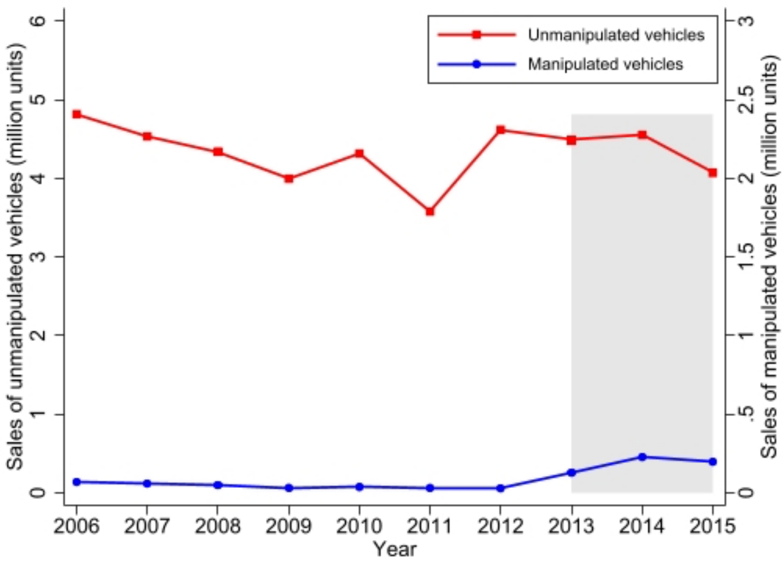

Figure 3. Sales trends for manipulated and unmanipulated vehicles

Notes: The figure plots the annual aggregate sales for the manipulated and unmanipulated vehicle models in 2006–2015. Manipulated vehicles refer to models with an overstated fuel economy. The shaded area indicates the period after 2013, when the manipulated models are introduced. Prior to 2013, the sales of manipulated vehicles remain low and relatively stable, with no clear differential trend compared with unmanipulated vehicles. After 2013, sales of manipulated vehicles increase, suggesting a demand shift associated with misreported fuel economy.

The main identifying feature of this setting is that the fuel economy manipulation did not alter the physical performance, design, or production costs of the affected vehicles. Instead, the misconduct involved the manipulation of testing data, which distorted consumers' perceived fuel efficiency while the supply conditions remained unchanged. Therefore, the resulting variation can be interpreted as a demand-side information shock.

The study estimates a structural demand model for the Japanese passenger vehicle market and compares the market outcomes between manipulated and non-manipulated models. This structural approach allows consumer preferences for vehicle attributes to be explicitly recovered from observed purchase behavior, making it possible to evaluate how the distorted fuel economy information affects consumer choice and welfare.

Because the misconduct remained undisclosed during the sample period, the observed demand changes are unlikely to reflect reputation effects or information updates. Additionally, the empirical specification controls for observable vehicle characteristics, as well as model and time fixed effects, thereby accounting for persistent quality differences across vehicles and aggregate demand fluctuations. These institutional and empirical features provide a suitable environment for identifying the impact of perceived quality distortions on demand and welfare.

6. Empirical Analysis

6.1 Empirical Strategy

To evaluate how misreported fuel economy affects vehicle demand and the associated environmental outcomes, this study estimates an aggregate logit demand model following Berry (1994) and Konishi and Zhao (2017).

The Berry framework's main advantage is that it allows the mean utility of each product, typically unobserved, to be recovered from the observed market shares. Specifically, it exploits the relationship between a vehicle's market share and the share of the outside option. This inversion enables inference of the average attractiveness (mean utility) of each vehicle from aggregate purchase data without requiring individual-level choice information.

Although automobiles are durable goods and purchase decisions are inherently dynamic, we adopt a static discrete-choice framework. The outside option is interpreted as the choice not to purchase a new vehicle in a given month, which includes continued use of an existing vehicle or postponing replacement. Accordingly, the model captures the choice between purchasing a specific vehicle model and postponing the purchase in the current period. This static approximation focuses on short-run substitution patterns across vehicle models and is widely used in empirical automobile demand studies for tractability.

The estimation equation is derived by taking the logarithm of the ratio of the market share of product i to the share of the outside option. Let s_{ift} denote the market share of the vehicle model i produced by manufacturer f in month t, and let s_{0t} denote the share of the outside option in market t. The outside option represents the decision to not purchase a new passenger vehicle. A market is defined as the new national passenger vehicle market in month t.

The baseline estimating equation is as

$$\ln(s_{ift}) - \ln(s_{0t}) = \beta_0 + \beta_1 \text{Fraud}_{ift} - \alpha p_{ift} + \sum_k \beta_k x_{ift} + \sum_l \gamma_l T_{ift} + \rho_f + \sigma_t + \varepsilon_{ift}. \quad (1)$$

where i denotes vehicle models, f manufacturers, and t months. The dependent variable is the mean utility of vehicle i in market t. The variable p_{ift} denotes vehicle price. Vector x_{ift} includes observable vehicle characteristics such as actual (true) fuel economy, power-to-weight ratio, and vehicle size. The variable Fraud_{ift} is a dummy variable indicating whether the vehicle model is subject to fuel economy manipulation. Vector T_{ift} includes policy variables such as eligibility for eco-car tax reductions and purchase subsidies. Manufacturer fixed effects (ρ_f) control for time-invariant brand-level characteristics including overall brand reputation, design philosophy, and perceived reliability. Time fixed effects (σ_t) capture aggregate demand shocks common to all vehicles in a given month, such as macroeconomic conditions, seasonal factors, or changes in fuel prices.

One potential concern is that unobserved product quality may vary over time at the model level. However, in the present setting, misconduct involves the manipulation of the reported fuel economy without any change in the physical performance or production technology of the affected vehicles. This institutional feature mitigates concerns about the time-varying unobserved quality, enabling analysis that isolates demand shifts driven by incorrect performance information. The error term ε_{ift} represents unobserved demand shocks and measurement errors that are not captured by observable characteristics or fixed effects. As unobserved demand shocks may be correlated across multiple models produced by the same manufacturer, standard errors are clustered at the model level.

The dependent variable is generated from product-level and outside-option market shares. Let s_{ift} denote the market share of the vehicle model i produced by manufacturer f in month t.

Product share is defined as

$$s_{ift} = \frac{q_{ift}}{M_t}, i = 1, \dots, I_t,$$

where q_{ift} represents the unit sales of model $i$and M_t denotes the potential market size in month t. The outside-option share is defined as

$$s_{0t} = \frac{M_t - \sum_{i=1}^{I_t} q_{ift}}{M_t}.$$

The outside option represents households that do not purchase a new vehicle within month t or that postpone their purchase decision. The potential market size M_t is measured using the number of households reported in the Basic Resident Register published by the Ministry of Internal Affairs and Communications.

To capture the effect of fuel economy manipulation, the key explanatory variable is $Fraud_{ift}$, a dummy variable equal to one if model i is subject to manipulated fuel economy reporting in month t, and zero otherwise. Vehicle price p_{ift} is included to estimate the demand function. Additionally, vector X_{ift} comprises observable vehicle characteristics such as fuel economy, power-to-weight ratio, and vehicle size. As environmental policies may affect vehicle demand, policy variables are also included. Specifically, Tax_{ift} equals one if the model is eligible for eco-car tax reductions in month t, and $Subsidy_{ift}$ equals one if the model is eligible for purchase subsidies during the subsidy periods (April 2009–September 2010 and December 2011–September 2012).

The potential endogeneity of vehicle prices is a major concern in estimating the demand equation. Prices may correlate with the unobserved product quality or demand shocks, resulting in biased estimates. To address this issue, the analysis employs two distinct instrumental variable (IV) approaches. Using multiple identification strategies allowed us to assess whether the results were robust against alternative sources of exogenous price variations.

Berry–Levinsohn–Pakes Instruments

The first approach uses the standard Berry–Levinsohn–Pakes (BLP) instruments (Berry et al., 1995). The BLP instruments are constructed based on the characteristics of competing products in the same market. These instruments exploit the idea that the characteristics of rival products affect a model's equilibrium price through competitive interactions but are unlikely to be correlated with the unobserved demand shock for the product itself. Therefore, the instruments are constructed based on the characteristics of other products on the market:

$$Z_{ift}^{BLP,Other} = \sum_{k \in J_{ft}, k \neq i} X_{kft}, Z_{ift}^{BLP,Rival} = \sum_{k \notin J_{ft}} X_{kft},$$

where J_{ft} denotes the set of products produced by manufacturer f in month t. The first instrument captures the composition of a manufacturer's product lineup, whereas the second reflects the characteristics of the competing products produced by rival firms. These variables affect pricing through competitive and product-line considerations but are assumed to be uncorrelated with product-specific unobserved demand shocks.

Lewbel Heteroskedasticity-Based Instruments

As an alternative identification strategy, the analysis employs the heteroskedasticity-based IV method proposed by Lewbel (2012). The Lewbel (2012) identification strategy relies on the presence of heteroskedasticity in the first-stage error term and assumes that exogenous product characteristics are uncorrelated with unobserved demand shocks. Under these conditions, higher-order moments in the data can generate valid instruments for endogenous prices. This approach yields internal instruments using the covariance structure of the error terms when external instruments are limited.

In the first stage, vehicle prices are regressed on exogenous product characteristics, policy variables, and manufacturer- and time-fixed effects. Let $\hat{v}_{ift}$denote the residual of the regression. The instruments are then constructed as follows:

$$z_{j,ift} = (X_{j,ift} - \check{X}_j)\hat{v}_{ift},$$

where $\check{X}_j$ is the sample mean of exogenous variable X_j. These instruments exploit heteroskedasticity in the pricing equation to yield variations that are correlated with price but orthogonal to the demand error term. The validity of this approach relies on two conditions: (i) the presence of heteroskedasticity in the price equation and (ii) exogeneity of the underlying product characteristics with respect to unobserved demand shocks.

Besides the exogeneity of observed product characteristics, a related concern is that fuel economy misreporting may be correlated with unobserved product quality or demand conditions. The demand specification includes product fixed effects, which control for time-invariant unobserved quality differences across models and time fixed effects that absorb common market-level demand shocks. These controls mitigate the concerns that the estimated effects are driven by persistent product characteristics, rather than the causal impact of fuel economy misreporting.

6.2 Evaluation of Consumer Welfare and Environmental Externalities

Using the estimated demand parameters, we evaluate the impact of fuel economy manipulations on consumer welfare and environmental externalities. First, we compute the consumer surplus for each market (in months) based on the estimated mean utilities.

6.2.1 Mean Utility and Consumer Surplus

In the aggregate logit model, the mean utility of the vehicle model i produced by manufacturer f in month t is as follows:

$$\delta_{ift} = \beta_0 + \beta_1 \text{Fraud}_{ift} - \alpha p_{ift} + X'_{ift}\beta + T'_{ift}\gamma + \rho_f + \sigma_t.$$

Following Berry (1994), consumer surplus in market t is computed using the inclusive value:

$$CS_t = \frac{1}{\alpha} \ln \left(1 + \sum_{i=1}^{I_t} \exp\ (\delta_{ift}) \right).$$

The term "1" inside the logarithm represents the outside option of not purchasing any vehicle. This option captures the consumer's participation decision, reflecting the choice to postpone or not make a purchase in month t. Therefore, the consumer surplus measure represents the expected utility gain from choosing among the available vehicle options relative to the outside alternative.

This expression is derived under the standard logit demand framework, assuming that individual-specific preference shocks follow an independent extreme value distribution and that the marginal utility of income is constant across consumers. The outside option is normalized to yield zero mean utility, corresponding to the constant term "1" in the surplus formula.

The welfare measure used in this study is based on the standard logit consumer surplus formula and represents the change in expected utility evaluated under correctly perceived product attributes. This measure should be interpreted as an ex-ante consumer surplus metric that reflects the welfare that consumers obtain if the fuel economy was accurately reported at the time of purchase.

Therefore, the difference between surplus under reported and true fuel economy captures both welfare loss from inefficient substitution across products and the elimination of "illusory" utility arising from misperceived performance. Following the standard approach in the consumer misperception literature, welfare is evaluated based on utility under the correct performance information. Therefore, utility gains arising solely from incorrect beliefs about product performance are not treated as welfare improvements, as they do not reflect actual consumption benefits.

6.2.2 Counterfactual Consumer Surplus without Fuel Economy Manipulation

To evaluate the effect of the manipulation, we construct a counterfactual scenario in which the reported fuel economy is replaced by true fuel efficiency. Let $Fuel_{ift}^{reported}$ denote the observed (manipulated) value and $Fuel_{ift}^{true}$ the corrected value. The counterfactual mean utility is defined as

$$\delta_{ift}^{true} = \delta_{ift} + \beta_{fuel}\left(Fuel_{ift}^{true} - Fuel_{ift}^{reported}\right).$$

Consumer surplus under the counterfactual scenario is as follows:

$$CS_t^{true} = \frac{1}{\alpha}\ln\left(1 + \sum_{i=1}^{I_t} \exp\ (\delta_{ift}^{true})\right).$$

The per-household welfare loss due to fuel economy manipulation in month t is given by

$$CW_t^{loss} = CS_t - CS_t^{true}.$$

To obtain the market-level welfare loss, the per-household loss is multiplied by the potential market size M_t:

$$CW_t^{loss,market} = M_t \times CW_t^{loss}.$$

The cumulative consumer welfare loss over the manipulation period is computed by summing the monthly losses as follows:

$$CW_{total}^{loss} = \sum_{t \in T_{fraud}} M_t\ CW_t^{loss}.$$

The welfare measure in this study represents a flow loss: each month is treated as a separate market, and the cumulative welfare loss is obtained by aggregating monthly losses over the manipulation period.

The Fraud dummy captures residual demand differences for affected models that are not fully explained by observed characteristics, including fuel economy.

During the fraud period, the reported fuel economy constitutes the information set available to consumers, while the true fuel economy is unobserved at the time of purchase. The welfare calculations therefore compare the consumer surplus generated under perceived (reported) attributes with the surplus that would have arisen if true performance had been correctly disclosed.

The Fraud indicator is intended to capture time-varying residual demand factors unrelated to fuel economy information, such as unobserved quality changes, marketing intensity, brand-specific demand shifts, or other attributes correlated with the affected models. To isolate the effect of corrected fuel economy information, the Fraud indicator is held constant in the counterfactual analysis. This ensures that the welfare calculation reflects only the demand response to changes in performance beliefs, rather than confounding effects from other contemporaneous demand shifts.

6.2.3 Counterfactual Market Shares and Sales

Based on the estimated mean utilities, the predicted market share of vehicle model i in month t is given by

$$s_{ift} = \frac{\exp(\delta_{ift})}{1 + \sum_{j=1}^{I_t} \exp(\delta_{jft})}.$$

Similarly, the following is the counterfactual market share under the scenario without fuel economy manipulation:

$$s_{ift}^{true} = \frac{\exp(\delta_{ift}^{true})}{1 + \sum_{j=1}^{I_t} \exp(\delta_{jft}^{true})}.$$

The constant term "1" in the denominator represents the outside option, corresponding with the decision not to purchase a new vehicle. Therefore, households choose from among all vehicle models, as well as the option of not purchasing. Predicted market shares are converted into quantities using the potential market size, which is defined as the total number of households making purchase decisions. Observed sales are used to measure realized market outcomes, whereas the potential market size translates model-based demand shares into theoretical market quantities.

Let M_t denote the potential market size (number of households) in month t. The predicted sales based on the observed (reported) fuel economy and counterfactual sales without manipulation are as follows:

$$q_{ift}^{rep} = M_t s_{ift}, q_{ift}^{true} = M_t s_{ift}^{true}.$$

The potential market size M_t is used within the aggregate logit framework to evaluate theoretical demand under alternative scenarios. By contrast, let Q_t denote the total number of vehicles sold in month t. To relate the estimated share changes to the observed market outcomes, the counterfactual quantity changes are rescaled using the observed total vehicle sales in each month.

The change in sales attributable to fuel economy manipulation for each model is defined as follows:

$$\Delta q_{ift} = q_{ift}^{rep} - q_{ift}^{true}.$$

Aggregating across products yields the total change in market sales:

$$\Delta Q_t = \sum_{i=1}^{I_t} \Delta q_{ift}.$$

This decomposition allows examination of whether the effects of manipulation reflect an expansion of total market demand or reallocation of sales across vehicle models. Changes in sales are further aggregated by manufacturer and fraud status to quantify how manipulation impacts the distribution of demand between manipulated and non-manipulated vehicles.

6.2.4 Environmental Impact: CO_2 Emissions

Fuel economy manipulation increases CO_2 emissions through higher fuel consumption over the lifetime of affected vehicles. To quantify the environmental impact, we compute the cumulative excess emissions associated with fraudulent vehicles over the usage period.

Let Ddenote annual driving distance and κ the CO_2 emission factor per liter of gasoline. The emission factor is set to 2.32 kg-CO_2 per liter, based on official statistics from the Ministry of the Environment (2023). The annual CO_2 emissions per vehicle of model i sold in month t are defined as

$$CO2_{ift}^{car} = \frac{D}{FuelEff_{ift}} \kappa.$$

The excess annual emissions per vehicle owing to to fuel economy manipulation are calculated as follows:

$$\Delta CO2_{ift}^{car} = CO2_{ift}^{true} - CO2_{ift}^{reported} = D\kappa \left(\frac{1}{FuelEff_{ift}^{true}} - \frac{1}{FuelEff_{ift}^{reported}} \right).$$

Multiplying this per-vehicle excess by the number of fraudulent vehicles sold yields the additional emissions generated in month t

$$\Delta CO2_t = \sum_{i \in F} q_{ift} \ \Delta CO2_{ift}^{car},$$

where F denotes the set of manipulated vehicle models. For non-manipulated vehicles, $\Delta CO2_{ift}^{car} = 0$. Assuming that fraudulent vehicles remain in use for an average of L years, the cumulative excess emissions over the manipulation period are given by:

$$\Delta CO2^{total} = \sum_{t \in T_{fraud}} \sum_{i \in F} q_{ift} \, \Delta CO2_{ift}^{car} \times L.$$

For simplicity, cumulative emissions are not discounted over time.

7. Empirical Results: Demand, Welfare, and Environmental Effects

We quantify the effects of fuel economy misreporting on demand allocation, consumer welfare, and environmental externalities using the estimated aggregate logit model. First, we examine how misreporting affects product-level demand. Then, we evaluate the associated changes in the consumer surplus based on the estimated demand structure. Next, we estimate the additional CO_2 emissions attributable to misreporting and assess the magnitude of the environmental externalities. Finally, we conduct sensitivity analyses with respect to assumptions regarding the annual driving distance to examine whether the main conclusions are contingent upon specific parameter choices.

7.1 Demand Effects of Fuel Economy Misreporting

Table 2 reports the estimation results for the demand equation. Column (1) presents ordinary least squares (OLS) estimates that treat price as exogenous. Because vehicle prices may be correlated with unobserved product quality or demand shocks, the price coefficient in this specification may suffer from endogeneity bias. Therefore, the OLS results are reported for comparison only and not interpreted as the preferred estimates.

Column (2) reports IVs estimates using BLP instruments. Although the estimated price coefficient has the expected negative sign and is broadly consistent with the OLS estimate, the standard errors are relatively large, suggesting limited precision. In specifications that include both manufacturer and time fixed effects, product characteristic-based BLP instruments may have limited variation, which can weaken identification. Accordingly, the results in Column (2) are considered robustness checks.

Column (3) reports the estimates using Lewbel's (2012) heteroskedasticity-based IV approach. This specification addresses price endogeneity, while providing precise estimates. The weak identification tests indicate sufficient instrument strength. The estimated price coefficient is negative and statistically significant, indicating that higher prices reduce demand. More importantly, the coefficient for the fraud indicator is positive and statistically significant across specifications. The magnitude is stable across the estimation methods, suggesting that the demand-increasing effect associated with a misreported fuel economy is not driven by price endogeneity or instrument choice.

These results are consistent with the interpretation that fuel economy misreporting increases the perceived utility of the affected models and thereby shifts demand toward these vehicles. Because the preferred specification controls for price endogeneity, the demand effect is unlikely to reflect unobserved price advantages or omitted product quality. However, it suggests that distorted performance information influences consumer choices.

An increase in demand for fraudulent vehicles implies a relative reduction in demand for competing models. This pattern indicates distortion in market allocation. Next, we evaluate the implications of this demand reallocation for consumer welfare and environmental outcomes.

Table 2. Estimation Results for the Demand Function (OLS and IV)

	(1)	(2)	(3)
	OLS	IV: BLP	IV:Lewbel
Price	-0.419***	-0.486	-0.326***
	(0.074)	(0.380)	(0.011)
Fuel	0.0791***	0.0790***	0.0791***

	(0.025)	(0.004)	(0.004)
Hppw	-2.395	-0.215	-5.375***
	(3.998)	(12.29)	(0.599)
Size	0.103**	0.116	0.0853***
	(0.0473)	(0.0732)	(0.0075)
Fraud	1.730***	1.744***	1.711***
	(0.212)	(0.162)	(0.145)
Subsidy	0.310**	0.299***	0.325***
	(0.140)	(0.0857)	(0.0530)
Tax	0.943***	0.961***	0.919***
	(0.185)	(0.104)	(0.035)
Constant	-13.11***	-13.27***	-12.88***
	(0.963)	(0.981)	(0.227)
Manufacturer Fe	Yes	Yes	Yes
Time Fe	Yes	Yes	Yes
Under identification Test (p-value)		0	0
Weak Identification Test (F-stat)		52	56
Observations	25,006	25,006	25,006
R-squared	0.313	0.312	0.313

Notes: The dependent variable is the log of the product market share relative to the outside option. The robust standard errors clustered at the model level are reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. For the IV specifications, the Kleibergen–Paap LM test rejects the null hypothesis of under identification ($p < 0.001$). The Kleibergen–Paap Wald F statistics exceed the Stock–Yogo (2005) critical values for a maximal 10% IV size distortion, suggesting that weak instrument concerns are unlikely to affect the main results.

7.2 Impact of Fuel-Efficiency Fraud on Consumer Welfare and Market Allocation

We further evaluate the impact of fuel-efficiency fraud on consumer welfare based on the aforementioned demand estimates. Specifically, consumer surplus is compared between the observed environment using the reported fuel economy (reported) and a counterfactual scenario in which fraudulent overstatement is removed (true).

Comparing the monthly consumer surplus shows that the average level under the reported fuel economy is slightly higher than that under the counterfactual scenario based on the true fuel economy.

This estimated difference implies an average welfare loss of approximately 0.0003 for logit consumer surplus. This result indicates that fuel efficiency misreporting leads consumers to overestimate the product utility, resulting in a systematic distortion in consumer welfare. Because vehicle prices are measured in millions of yen, the consumer surplus is also expressed in million-yen units. Therefore, the estimated difference corresponds to a welfare loss of approximately 300 yen per household per month.

To obtain the aggregate effect, this per-household loss is multiplied by the potential market size, which is defined as the number of households in each month. The potential market size is measured using the number of households reported in the Basic Resident Register (Ministry of Internal Affairs and Communications, 2024), which averages approximately 52–53 million households during the sample period. The resulting aggregate consumer welfare loss averages approximately 16 billion yen per month during the fraud period. Summing the monthly losses from June 2013 to April 2016 (35 months) yields a cumulative consumer welfare loss of approximately 560 billion yen.

Cumulatively, this corresponds to a welfare loss of approximately 10,000–11,000 yen per household over the entire period. Although welfare loss at the individual level is modest, the aggregate impact is economically significant given the large automobile market. Importantly, the aggregate loss reflects systematic distortions in consumer choices indicated by the structural demand estimates and resulting misallocation of purchases across vehicle models.

Furthermore, changes in sales volumes are examined using the predicted market shares rescaled to match the observed market size. Aggregating the counterfactual quantity changes over the fraud period indicates that fuel-efficiency misreporting increased the cumulative sales of the affected vehicles by approximately 175,000 units relative to the scenario with corrected fuel economy. This figure represents the net increase in purchases attributable to misreported fuel economy rather than the total sales of the affected models.

These results indicate that fraudulent information not only reallocates demand toward manipulated vehicles but also expands overall market demand. In the counterfactual scenario, a substantial portion of these additional purchases would have remained in the outside option (i.e., households would have postponed or avoided purchasing a new vehicle). Thus, misreporting induces additional entry into the new vehicle market. Such market expansion reflects purchase decisions based on overstated expected operating cost savings, implying overconsumption relative to efficient allocation. By encouraging additional vehicle purchases, fuel efficiency misreporting generates inefficiency in both demand allocation and total consumption, contributing to increased environmental externalities.

7.3 Increase in CO_2 Emissions Attributable to Fuel-Efficiency Fraud

The emissions calculation is based on the observed sales volumes of the affected vehicles rather than the marginal change in sales estimated from demand counterfactuals. Thus, the estimated environmental impact reflects the additional fuel consumption of the full stock of vehicles, whose fuel economy is overstated.

Using the actual sales volumes of fraudulent vehicles, this study assesses the impact of the gap between reported and true fuel efficiency on CO_2 emissions during the vehicle-use phase. Specifically, for each fraudulent model, the total lifetime driving distance is calculated by multiplying the number of vehicles sold by the assumed annual mileage with the expected vehicle lifetime. The assumptions regarding the annual mileage are based on the Ministry of Land, Infrastructure, Transport and Tourism's (2024) *Automobile Transport Statistics* and *Automobile Fuel Consumption Survey*, and the baseline vehicle lifetime is set to ten years. Additional CO_2 emissions attributable to fuel-efficiency fraud are then obtained by comparing emissions calculated using reported fuel efficiency with those based on true fuel efficiency and aggregating the difference over the vehicle lifetime.

The estimated increase in CO_2 emissions amounts to approximately 5.6×10^8 kg (approximately 560,000 tons). Valuing these emissions using the carbon price yields a social cost of approximately 5.6 billion yen under a price of 10,000 yen per ton and 11.2 billion yen under that of 20,000 yen per ton. The carbon price range used in this study reflects the standard values employed in policy evaluations based on the Social Cost of Carbon (SCC) by Japan's Ministry of the Environment and international estimates (Interagency Working Group on Social Cost of Greenhouse Gases, 2021; Ministry of the Environment, 2021). These results suggest that fuel-efficiency fraud generates non-negligible environmental externalities during the vehicle-use stage.

Importantly, this estimate captures excess CO_2 emissions during the usage phase conditional on the observed stock of manipulated vehicles, and does not represent the change in aggregate market-level emissions relative to a no-fraud equilibrium. Therefore, the estimated emission increase should be interpreted as reflecting environmental externalities during the vehicle-use stage attributable to misreported fuel efficiency for vehicles that were actually sold, rather than a full general-equilibrium assessment of how fuel-efficiency fraud altered total emissions in the new car market.

To examine the robustness of these estimates, sensitivity analyses are conducted with respect to assumptions regarding vehicle lifetime and annual driving distance. **Table 3** reports cumulative CO_2 emissions under alternative scenarios, including vehicle lifetimes of 8, 10, and 12 years and annual mileage adjusted by ±10 percent from the baseline. Across all combinations of assumptions, the estimated cumulative emissions attributable to fraud range from approximately 400,000 to 740,000 tons. These values remain close to the baseline estimate of approximately 560,000 tons, indicating that the magnitude of environmental damage is quantitatively robust to plausible variations in usage assumptions. Although fraudulent vehicles accounted for only a small proportion of total sales, the resulting aggregate emissions were economically nonnegligible.

Table 3. Sensitivity Analysis of Cumulative CO_2 Emissions: Vehicle Lifetime and Annual Mileage

Vehicle lifetime	Annual mileage (−10%)	Baseline mileage	Annual mileage (+10%)
8 years	402 thousand tons	447 thousand tons	492 thousand tons
10 years	503 thousand tons	559 thousand tons	615 thousand tons
12 years	604 thousand tons	671 thousand tons	738 thousand tons

Notes: Values represent cumulative CO_2 emissions over the vehicle lifetime (thousand tons). The baseline scenario assumes a vehicle lifetime of 10 years and average annual mileage. In the ±10% scenario, only annual mileage is varied; all other assumptions remain unchanged.

8. Extensions and Robustness Checks

8.1 Environmental Policy Interaction: The Effect of the Eco-Car Tax on Fraudulent Vehicles

We evaluate how the eco-car tax interacts with fuel efficiency fraud, and its implications for demand distortion. According to the IV-Lewbel estimates reported in Column (3) of Table 4, the coefficient for *Fraud* is 2.331, whereas that for the interaction term *Fraud* × *Tax* is −0.663. This implies that when the eco-car tax applies, the demand-shifting effect of fraud decreases to 2.331 − 0.663 = 1.668. Therefore, rather than amplifying the demand advantage of fraudulent vehicles, the tax policy partially offsets the demand distortion caused by fraud, reducing the fraud-induced demand premium by approximately 0.66 log-odds points.

A similar pattern emerges from the IV-BLP specification reported in Column (2) of Table 4. In this case, the coefficient for *Fraud* is 2.422 and that for the interaction term is −0.555, implying a net fraud effect of 2.422 − 0.555 = 1.867 when the tax applies. Across the estimation methods, the eco-car tax consistently reduces the relative demand advantage of fraudulent vehicles by approximately

0.55 log-odds points, and the interaction effect is statistically significant in all cases. These results suggest that the policy does not strengthen preferential treatment of fraudulent vehicles but instead mitigates the additional demand generated by misreported fuel efficiency. Although fraudulent vehicles continue to enjoy a demand advantage even when the tax is applied, the magnitude of this advantage is substantially smaller than in the absence of the policy.

The interaction effect is identified from the within-model time variation in tax eligibility among manipulated vehicles. During the sample period, the affected models were not always eligible for the eco-car tax program, as eligibility depended on evolving fuel efficiency standards and policy thresholds. From the data, both taxed and untaxed observations are made for fraudulent vehicles (72 and 89 model-month observations, respectively), allowing the main Fraud effect and Fraud × Tax interaction to be separately identified from within-model variation rather than relying on cross-sectional differences or functional-form extrapolation.

From a behavioral perspective, this finding is not immediately obvious. Consumers were unaware of the fraud at the time of purchase; therefore, in principle, the tax incentive would be expected to have similar demand effects for both fraudulent and non-fraudulent vehicles. Therefore, the smaller marginal response observed for fraudulent vehicles may reflect a saturation effect; because their perceived fuel efficiency was already overstated, the demand for these vehicles had been elevated prior to the application of the tax. Consequently, the scope of the additional demand stimulation through tax incentives is relatively limited.

Overall, the results indicate that the environmental policy did not exacerbate the market distortion caused by fraudulent information and may have partially attenuated the resulting misallocation.

Table 4. Demand Effects of Fuel-Efficiency Fraud and the Eco-Car Tax

	(1)	(2)	(3)
	OLS	IV:BLP	IV:Lewbel
Price	-0.419***	-0.500	-0.326**
	(0.074)	(0.382)	(0.015)
Fuel	0.079***	0.079***	0.079***
	(0.025)	(0.0039)	(0.0040)
Hppw	-2.394	0.234	-5.376***
	(3.998)	(12.38)	(0.599)

Size	0.103*	0.118	0.0853***
	(0.0473)	(0.0737)	(0.0075)
Fraud	2.379***	2.422***	2.331***
	(0.275)	(0.234)	(0.123)
Fraud×Tax	-0.694**	-0.722***	-0.663***
	(0.239)	(0.238)	(0.196)
Subsidy	0.309**	0.296***	0.325***
	(0.140)	(0.0862)	(0.053)
Tax	0.944***	0.965***	0.920***
	(0.185)	(0.105)	(0.0359)
Constant	-13.11***	-13.31***	-12.88***
	(0.963)	(0.988)	(0.227)
Manufacturer Fe	Yes	Yes	Yes
Time Fe	Yes	Yes	Yes
Under identification Test (p-value)		0	0
Weak Identification Test (F-stat)		51.977	55.986
Observations	25,006	25,006	25,006
R-squared	0.313	0.312	0.312

Notes: This table reports estimates of the demand effects of fuel efficiency fraud and its interaction with the eco-car tax. Column (1) presents OLS estimates. Column (2) reports IV estimates based on BLP-type instruments (IV-BLP), and Column (3) reports the estimates using the heteroskedasticity-based internal instruments proposed by Lewbel (2012) (IV-Lewbel). *Fraud* is a dummy variable that indicates vehicles subject to fuel-efficiency fraud. *Fraud* × *Tax* captures the differential effect of the eco-car tax on fraudulent vehicles. All specifications control for vehicle price, fuel efficiency, horsepower-to-weight ratio, vehicle size, subsidy eligibility, and tax variables and include manufacturer and time fixed effects. For the IV specifications, tests for under identification and weak instruments are reported at the bottom of the table. Robust standard errors are reported in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

8.2 Robustness to Alternative Specifications

We further examine whether the main results are sensitive to specific modeling choices or assumptions. To this end, several alternative specifications are estimated as part of the sensitivity analysis. Table 5 reports the results of the modified time effects and set of IVs.

Column (1) of **Table 5** replaces the time fixed effects used in the baseline specification with monthly gasoline prices as an explicit control variable. This specification captures the impact of macro-level fuel price fluctuations on automobile demand in a more structured manner. The estimated coefficient for *Fraud* remains positive and statistically significant, and its magnitude is broadly consistent with the baseline estimates. This finding indicates that the main results are not driven by aggregate shocks absorbed by time fixed effects and remain robust when fuel price variation is explicitly accounted for.

Column (2) of **Table 5** introduces a more stringent time control by including manufacturer-by-time fixed effects (Maker × Time FE). This specification flexibly controls for time-varying manufacturer-specific factors, such as model renewal cycles, sales strategies, and advertising activities. Despite this demanding specification, the estimated coefficient for *Fraud* remains positive and highly significant, suggesting that the results are unlikely to be driven by manufacturer-specific time trends or shocks.

Column (3) modifies Lewbel's (2012) internal instruments by excluding instruments generated from the subsidy and tax variables. This specification tests whether the identification relies excessively on specific instruments. The estimated *Fraud* coefficient remains stable in both sign and magnitude, and the first-stage F-statistic continues to indicate strong identification. These results suggest that the main findings are not sensitive to the specific choice of instrument.

Overall, the positive effect of fuel efficiency fraud on vehicle demand is consistently observed across alternative treatments of time effects and different instrument sets. These robustness checks support the conclusion that the baseline results are not driven by a particular specification and reflect a stable empirical relationship.

Table 5. Robustness to Alternative Specifications

	(1)	(2)	(3)
	IV:Lewbel	IV:Lewbel	IV:Lewbel
Price	-0.0326***	-0.0316**	-0.0325*
	(0.0114)	(0.0109)	(0.0114)
Fuel	0.0855***	0.0820***	0.0791***
	(0.0039)	(0.0041)	(0.0040)
Hppw	-5.221***	-5.632***	-5.416***
	(0.605)	(0.593)	(0.594)

	(1)	(2)	(3)
Size	0.0876***	0.0921***	0.0851***
	(0.0075)	(0.0075)	(0.0075)
Fraud	1.598***	2.145***	1.711***
	(0.150)	(0.158)	(0.145)
Subsidy	0.266***	0.351***	0.325***
	(0.0343)	(0.0555)	(0.0530)
Tax	0.379***	0.889***	0.918***
	(0.0323)	(0.0360)	(0.0359)
GasPrice	-0.0051***		
	(0.0007)		
Constant	-12.37***	-16.12***	-12.88***
	(0.176)	(0.747)	(0.227)
Manufacturer Fe	Yes		Yes
Time Fe			Yes
Manufacturer*Time Fe		Yes	
Under identification Test (p-value)	0	0	0
Weak Identification Test (F-stat)	56.364	59.897	87.703
Observations	25,006	25,006	25,006
R-squared	0.263	0.336	0.312

Notes: This table reports IV estimates based on Lewbel's (2012) approach. Column (1) replaces the time fixed effects with monthly gasoline prices to explicitly control for aggregate demand shocks. Column (2) includes manufacturer-by-time fixed effects to flexibly account for the unobserved manufacturer-specific factors that vary over time. Column (3) modifies the instrument set by excluding the instruments constructed from the subsidy and tax variables. All the specifications include the same set of vehicle characteristics and policy controls as those in the baseline model. Robust standard errors are reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

9. Conclusion

This study quantitatively evaluates the economic and environmental consequences of fuel efficiency fraud in the Japanese automobile market. Focusing on the period before detection, we examine how misreported performance information affects consumer choice, demand allocation, consumer welfare, and environmental externalities. Additionally, the study constructs a structural demand framework to analyze market outcomes before the fraud became publicly known and thus isolates the effects of distorted information rather than post-disclosure reputation responses.

The empirical results show that vehicles subject to fuel efficiency fraud exhibited significantly higher demand, even after controlling for prices, product characteristics, and policy variables. This demand effect remains robust when price endogeneity is addressed using IV methods, suggesting that misreported fuel efficiency distorted consumers' perceived utility and increased the market attractiveness of the affected models.

Counterfactual simulations indicate that fuel efficiency fraud not only reallocated demand from non-fraudulent vehicles to fraudulent ones, but also modestly expanded total market demand. This misallocation, driven by consumer decisions based on inaccurate information, led to a measurable loss in consumer welfare. Although welfare loss at the individual level is modest, the aggregate loss over the fraud period is economically meaningful, amounting to approximately 560 billion yen (approximately 10,000–11,000 yen per household).

The analysis also documents the environmental consequences. Based on the observed sales of affected vehicles and the gap between reported and true fuel economy, the cumulative increase in CO_2 emissions during the vehicle-use phase is estimated to have reached approximately 560,000 tons. By using standard estimates of the social cost of carbon for the valuation, this corresponds to the environmental damages of the order of several billion yen. Sensitivity analyses varying according to vehicle lifetime and annual mileage indicate that the magnitude of these emissions remains quantitatively robust to plausible usage assumptions.

Additionally, this study examines the interaction between fuel efficiency fraud and the eco-car tax. While the results suggest that the tax did not amplify the demand advantage of fraudulent vehicles, it partially offset the additional demand generated by misreported fuel efficiency, thereby mitigating the resulting market distortion but not eliminating it. This finding implies that, while the policy itself did not exacerbate the effects of fraud, the effectiveness of performance-based environmental policies critically depends on the reliability of the underlying product information.

Collectively, these findings suggest that quality fraud generates broader social costs beyond firm-level losses, thereby affecting consumer welfare, market efficiency, and environmental outcomes. More broadly, the results highlight that the credibility of firm-provided performance information is essential for the efficient functioning of markets and the effectiveness of environmental and performance-based regulatory policies.

This study has several limitations. First, the analysis focuses on emissions during the vehicle-use phase and does not consider potential spillovers to secondary markets. Second, the study does not examine how consumers update their beliefs or adjust their behavior after fraud is disclosed. These issues are important topics for future research. Despite these limitations, this study provides empirical evidence that distorted performance information can simultaneously affect market allocation, welfare, and environmental outcomes, offering policy-relevant insights into the design of disclosure systems and the enforcement of environmental regulations.

Funding:

This work was supported by Zengin Foundation for Studies on Economics and Finance; and Research Grant, Shikishima Foundation for Academic and Cultural Promotion.

Acknowledgements:

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