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Unintended Consequences of Japan's Eco-Car Policies: Strategic Weight Manipulation and CO_2 Emissions

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Abstract

This study evaluates the environmental effectiveness of Japan's eco-car tax incentive program by explicitly accounting for the strategic weight manipulation by automobile manufacturers. Using monthly vehicle-level panel data from 2005 to 2021, we estimate a structural demand model for the Japanese passenger car market to examine how firms respond to weight-based fuel economy standards.

Our results show that vehicles strategically adjusted to exceed regulatory weight thresholds experienced a 31% increase in relative market share, reflecting a substantial demand expansion driven by regulatory compliance rather than genuine fuel efficiency improvements. To assess the broader implications, we conduct a structural substitution counterfactual analysis comparing the observed outcomes with a no-manipulation benchmark.

The counterfactual analysis reveals that strategic weight manipulation increases the sales of manipulated vehicles by 102,771 units and reduces the sales of compliant vehicles by only 3,707 units. This asymmetric displacement indicates that manipulation primarily expands overall demand rather than reallocating sales among substitutes. The resulting demand distortion produced a net increase of 133,162 tons of CO_2 emissions over the sample period, substantially undermining the policy's emissions-reduction objectives.

Our findings demonstrate that weight-class-based fuel economy regulation creates strong incentives for regulatory gaming, which materially weakens environmental effectiveness. The results highlight the need for policy designs that minimize discrete eligibility thresholds and reward continuous and verifiable improvements in real-world fuel efficiency.

Keywords: eco-car policy; strategic manipulation; vehicle demand; CO_2 emissions

JEL Classification: Q51; Q53; Q58

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1. Introduction

Around 2010, many countries introduced eco-car tax incentives and purchase subsidies to accelerate the diffusion of environmentally friendly vehicles. These policies typically condition eligibility on compliance with fuel-economy or emissions standards, thereby attempting to steer both consumer demand and manufacturer behavior toward cleaner technologies. Japan implemented such a policy in fiscal year (FY) 2009, introducing tax exemptions and time-limited subsidies for vehicles that meet regulatory fuel-efficiency thresholds.

A defining institutional feature of many fuel-economy regulations, including those in Japan, is that compliance thresholds are specified in a stepwise manner, often based on observable product attributes, such as vehicle weight. Such discrete standards are administratively convenient; however, they can fundamentally alter firms' optimization problems. When regulatory requirements become discontinuously more lenient at particular thresholds, firms may find it privately optimal to comply through strategic adjustment of the regulated attribute rather than through genuine technological improvement. In such cases, regulation reshapes corporate behavior in ways that may weaken, or even reverse, the intended policy objectives.

This study examines this mechanism in detail. We study how stepwise, weight-based fuel-economy standards induce regulatory gaming by automobile manufacturers, and how such strategic behavior affects market outcomes, emissions, and social welfare. Particularly, we investigate whether automakers manipulate vehicle weight to exploit regulatory thresholds, thereby qualifying for tax incentives, without achieving proportional reductions in fuel consumption or CO_2 emissions.

First, we provide the first systematic, vehicle-level evidence that stepwise, weight-based fuel-economy standards induce strategic manipulation by manufacturers. We document clear discontinuities in the distribution of vehicle weight around regulatory thresholds, consistent with firms adjusting their product characteristics in response to discrete compliance incentives. These patterns offer direct visual evidence of the regulatory gaming embedded in policy design.

Theoretical and empirical studies have highlighted similar concerns in related contexts. Sallee (2011), and Ito and Sallee (2018) show that notch- and threshold-based regulations can distort firm behavior by encouraging compliance through attribute manipulation rather than genuine efficiency improvements. Importantly, Ito and Sallee (2018) provide direct evidence of such behavior in the context of Japan's vehicle fuel-economy regulations. Fuel-economy standards become less stringent for heavier weight class; hence, manufacturers can comply with the regulation by strategically increasing vehicle weight instead of improving engine technology, aerodynamics, or powertrain efficiency. Consequently, policies intended to reduce emissions may inadvertently induce shifts toward heavier and potentially higher-emission vehicles. Building on this insight, we examine how the consequences of such manipulation vary across regulatory regimes and how the strength of these distortions has evolved as fuel-economy standards have been updated.

Despite a large body of empirical literature documenting that eco-car tax incentives and subsidies increase the adoption of qualifying vehicles (e.g., Beresteanu and Li, 2011; Chandra et al., 2010; Gallagher and Muehlegger, 2011; Bentley and Steinberg, 2019), comparatively little is known about how strategic manufacturer responses shape the environmental effectiveness of these policies. An important exception is Konishi and Zhao (2017), who argue that Japan's fuel-economy standards may have increased CO_2 emissions by stimulating vehicle sales and expanding total driving activity. However, their analysis ignores the possibility that manufacturers actively alter vehicle characteristics in response to regulatory design.

To address this gap, we combine a structural demand model with a counterfactual substitution analysis. This structural framework allows us to recover unobserved product attributes, such as latent fuel-efficiency or quality components not directly observed in the data, and to construct credible counterfactual demand outcomes in the absence of manipulation. This approach enables a clean separation of causal effects operating through strategic compliance, demand reallocation, and total market expansion, which cannot be identified using reduced-form methods alone.

Using detailed vehicle-level panel data from 2005 to 2021, spanning both pre- and post-policy periods, we show that manipulated vehicles experience substantial increases in demand, whereas sales of non-manipulated vehicles decline only modestly. The resulting sales reallocation implies that regulatory gaming primarily expands total demand rather than merely reshuffling sales among close substitutes.

Market expansion has important welfare implications. We show that strategic firm responses generate a modest increase in consumer surplus by expanding access to tax-advantaged vehicles. However, once carbon externalities are incorporated, these private gains are outweighed by the environmental damage caused by increased CO_2 emissions, leading to a substantial negative net welfare effect. In other words, the same regulatory design that benefits consumers in the short run generates larger social losses through higher emissions.

This study contributes to the literature in two ways. First, we quantify how such strategic behavior alters market outcomes and undermines the environmental effectiveness of eco-car tax incentives. Second, and more broadly, we demonstrate that the welfare consequences of environmental regulation critically depend on how policy design shapes firm behavior, highlighting the risks inherent in threshold-based regulatory schemes.

Generally, our findings speak of a central lesson in regulatory economics: policies built on discrete eligibility thresholds may invite strategic responses that overturn the intended policy outcomes. Designing regulations that reward continuous and verifiable performance improvements, rather than compliance with notches, may be essential to achieve durable environmental and welfare gains.

To the best of our knowledge, no previous study has quantified how regulatory gaming in weight-based fuel economy standards affects market demand, substitution patterns, CO_2 emissions, and welfare. This study is the first to integrate strategic supply-side responses into a structural evaluation of eco-car policies.

The remainder of this paper is organized as follows. Section 2 describes Japan's eco-car policies. Section 3 reviews the related literature. Section 4 presents the data. Section 5 outlines the empirical methodology. Section 6 reports the estimation results and counterfactual analyses of market outcomes and CO_2 emissions, and Section 7 concludes the study.

2. Japan's Eco-car Policies

2.1 Fuel Economy Standards

Japan's fuel economy regulations set target efficiency levels that vehicles must meet to qualify for eco-car tax reductions, particularly automobile weight-tax and acquisition-tax benefits. These targets vary systematically by vehicle weight: lighter vehicles face stricter requirements, whereas heavier vehicles are subject to more lenient standards. Originally designed to reflect technological constraints across size categories, this weight-based structure unintentionally creates opportunities for strategic compliance behavior.

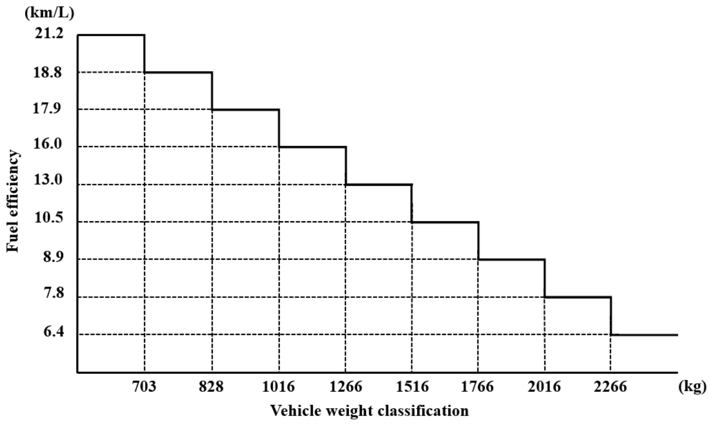

Figure 1: The 2010 fuel economy standards

Figure 1 plots the 2010 fuel economy standards (km/L, vertical axis) against vehicle weight (kg, horizontal axis) for vehicles sold from 2009 onward. The descending "stair-step" pattern shows how the required fuel efficiency drops sharply at each weight-class boundary. For example, a vehicle weighing just below the first boundary—say 700 kg—must meet a stringent requirement of roughly 21.2 km/L, whereas a vehicle crossing that boundary at 710 kg faces a substantially lower requirement of about 18.8 km/L. Similarly, at higher weight ranges, a model weighing 1,760 kg faces a threshold of approximately 13.0 km/L, while a vehicle only 10 kg heavier (1,770 kg) qualifies under a notably lower requirement of around 12.5 km/L.

Fuel economy is measured using standardized test-cycle procedures (e.g., JC08, Japan's official test cycle before 2018). Manufacturers can strategically position vehicles on the upper side of the weight boundaries to gain regulatory advantages with minimal impact on actual fuel consumption.

Subsequent standardsintroduced in 2015 (effective from 2012 model years) and in 2020 (effective from 2014) further increased the required efficiency levels (see Appendix Figures A1–A2 for details). Although commonly referred to as "standards," these thresholds differ from traditional regulatory mandates. Manufacturers face no penalties for failing to meet them; rather, the standards serve exclusively as the eligibility criteria for tax incentives. Vehicles that fall short can still be legally sold but do not receive preferential tax treatment.

2.2 Eco-car Tax Incentives

Japan's eco-car tax reductions, introduced in FY 2009 and continually updated thereafter, provide substantial financial benefits for vehicles that exceed fuel economy and emissions thresholds. Under the 2010 standards, vehicles whose fuel efficiency exceeds the regulatory requirement by 50% or more (e.g., achieving 19.5 km/L when the standard is 13.0 km/L) receive full exemptions from acquisition and weight taxes, while those exceeding the threshold by 25–50% receive partial reductions.

Thus, these tax incentives are economically meaningful. For eco-car-eligible vehicles, the automobile weight tax levied at new-vehicle registration is reduced by approximately 10,000–74,000 JPY, depending on the vehicle class. Additionally, full exemption from both acquisition and weight taxes typically amounts to 50,000–100,000 JPY over the first three years of ownership, with weight-tax reductions ranging from 10,000 to 74,000 JPY depending on the vehicle class. Both manufacturers and consumers benefit from producing and purchasing eligible vehicles; thus, these incentives strongly affect vehicle design and sales patterns.

Critically, the eco-car tax program relies entirely on the aforementioned weight-based fuel economy thresholds. The thresholds were revised in 2010, 2015, and 2020, and the tax incentive eligibility correspondingly tightened. This close linkage between tax benefits and weight-dependent fuel economy criteria is central to the strategic behavior examined in this study.

In addition to these tax incentives, the Japanese government offered direct purchase subsidies during two limited periods (April 2009–September 2010 and December 2011–September 2012). However, because subsidies were temporary and our primary focus is on the persistent tax reduction scheme, we concentrate our empirical analysis on the latter.

2.3 Weight Manipulation

Japan's weight-based fuel economy standards create incentives for automobile manufacturers to manipulate weight, enabling vehicles to qualify for tax benefits without genuine improvements in fuel efficiency. Heavier vehicles face more lenient thresholds; therefore, manufacturers can comply not by enhancing engine performance or reducing fuel consumption but by slightly increasing vehicle weight.

In practice, increasing a vehicle's weight by 10 kilograms reduces test-cycle fuel efficiency only marginally—on the order of 0.1–0.2 km/L, according to engineering estimates. For every 100 kg reduction in vehicle weight, combined city/highway fuel consumption could decrease by about 0.4

L/100 km for cars and about 0.5 L/100 km for light trucks (Bandivadekar et al., 2008), which translates to approximately 0.1–0.13 km/L improvement per 10 kg reduction for typical Japanese passenger vehicles. In contrast, crossing a regulatory weight boundary relaxes the required fuel economy standard by 0.5 km/L or more, and in many cases by as much as 1–3 km/L under the 2010 standards. Consequently, the regulatory benefit from shifting to a heavier weight class far outweighs the small mechanical reduction in fuel efficiency caused by the additional weight. This finding is consistent with broader industry evidence showing that a 10% reduction in vehicle weight yields an approximately 6–8% improvement in fuel economy (Kim and Wallington, 2013; U.S. Department of Energy, 2016). This imbalance creates a strong incentive for manufacturers to intentionally add modest amounts of weight through components such as insulation, structural reinforcements, or minor equipment to move a model just above a certain threshold, thereby qualifying for a considerably more lenient fuel economy requirement. Such behavior lies at the core of the weight-based manipulation examined in this study.

This mechanism allows manufacturers to obtain substantial tax benefits without delivering proportional environmental improvements. Although such vehicles formally comply with regulations, they consume more fuel in absolute terms than truly efficient alternatives with slightly lower weights. Our empirical analysis quantifies the extent of this distortion. The findings underscore the need for regulatory designs that reward genuine efficiency gains rather than weight-class positioning.

3. Literature review

This section reviews the existing studies on eco-car policies, focusing on three strands of research: (i) tax reduction schemes, (ii) subsidy programs, and (iii) impacts on emissions. We then identify the remaining research gaps and the contributions of this study.

3.1 Tax Reduction Schemes and Their Impact on Sales Volumes

A substantial body of empirical work shows that tax reductions can significantly shift consumer demand toward fuel-efficient vehicles, and the evidence is consistent across diverse institutional contexts. Using Dutch data from 2005 to 2010, Kok (2011) found that the market share of tax-exempt small cars rose from about 40% in 2008 to 50% in 2010. In Canada, Chandra et al. (2010) showed that hybrid vehicle tax incentives increase market penetration. Yan and Eskeland (2018) demonstrated that Norway’s feebate system between 2006 and 2014 reduced the sales of fuel-inefficient vehicles through both new purchases and scrappage.

Kitano (2022) reported that the eco-car tax reduction scheme in Japan increased the sales of eco-friendly vehicles by approximately 7.5%. Thus, these studies highlight that tax incentives are effective in promoting the adoption of more fuel-efficient vehicles.

However, these analyses implicitly assume that manufacturers respond solely to policy incentives by improving fuel efficiency. They do not consider potential strategic responses—such as weight manipulation—which may alter both the composition of vehicles sold and the actual environmental effectiveness of the policy.

3.2 Subsidy Schemes and Their Impact on Sales Volumes

Similarly, studies on subsidy schemes have documented strong effects on consumer vehicle choices. Böckers et al. (2012) found that Germany's 2009 scrappage subsidy increased sales of small cars. In the United States, Mian and Sufi (2012) showed that the Car Allowance Rebate System (CARS) produced a substantial but short-lived surge in new vehicle sales, raising questions about the durability of subsidy-induced demand shifts. Forslind (2008) observed that Sweden's scrappage subsidies increased the number of end-of-life vehicle disposals. Clinton and Steinberg (2019) found that U.S. state subsidies increased battery electric vehicle registrations by approximately 7% per $1,000 in subsidies.

In Japan, Kitano (2022) estimated that eco-car subsidies increased eco-car sales by approximately 25%, and Wang and Matsumoto (2022) also confirmed their effectiveness.

A key limitation of this literature is that it overlooks the possibility that manufacturers may strategically adjust vehicle characteristics to meet eligibility thresholds without delivering commensurate fuel-efficiency gains.

3.3 Eco-car Policies and Their Impact on Emissions Reductions

The empirical evidence on the emissions impacts of eco-car policies is mixed. Several studies report modest reductions in emissions: Hugosson et al. (2019) estimated a 0.7% reduction in average CO_2 emissions for new passenger vehicles in Sweden, while Lenski et al. (2010) found that the U.S. CARS program reduced greenhouse gas emissions by 4.4 million tons. Ciccone (2018) showed that Norway's tax incentives lowered the average CO_2 emissions from new vehicles by approximately 7.5 g/km.

In contrast, Konishi and Zhao (2017) found that Japan's eco-car policies increased CO_2 emissions by 13,800 tons annually, relative to a no-policy scenario, driven by a surge in new car purchases. Konishi and Kuroda (2023) documented long-run improvements in fuel efficiency but noted that total automobile emissions did not begin to decline until after 2000.

This heterogeneity in the findings suggests that policy effectiveness depends critically on whether demand-side responses (increased purchases) offset supply-side improvements (more efficient vehicles). Beyond direct sales effects, Tanaka (2020) identified an additional concern: the eco-car tax reduction program may have encouraged manufacturers to inflate test-cycle fuel efficiency data, with the discrepancy between real-world and published fuel efficiencies increasing by approximately 6% at the tax-reduction threshold.

However, none of these studies have considered the potential role of weight manipulation, which may counteract or even offset the environmental benefits of eco-car policies.

3.4 Research Gap and Contribution

Despite a large body of literature documenting that eco-car incentives and fuel-economy standards affect vehicle demand and adoption, a fundamental gap remains in the empirical understanding of environmental policy effectiveness. The existing studies have largely abstracted from the possibility that firms strategically manipulate regulated attributes in response to stepwise eligibility thresholds; therefore, they have not quantified how such behavior alters market outcomes, emissions, and welfare.

Although Ito and Sallee (2018) emphasized the theoretical scope of gaming under Japan's weight-based fuel-economy standards, no study has empirically evaluated the market-wide consequences of weight manipulation for vehicle sales, CO_2 emissions, and welfare. This omission is critical because weight manipulation allows manufacturers to achieve regulatory compliance without proportional improvements in the underlying fuel efficiency, thereby decoupling policy eligibility from true environmental performance. Consequently, standard policy evaluations that ignore strategic firm responses may substantially mismeasure both the effectiveness and welfare implications of environmental regulations.

This study fills this gap by explicitly modeling and quantifying regulatory gaming in the context of eco-car tax incentives. It combines a structural demand model with counterfactual substitution analyses, which allows us to recover unobserved product attributes, isolate the causal effects of manipulation, and simulate market outcomes in the absence of gaming behaviortasks that are not feasible within a reduced-form framework.

Our contributions are twofold.

First, we quantify how strategic weight manipulation reshapes market outcomes by distinguishing between demand reallocation and market expansion. Using a structural substitution counterfactual, we show that manipulation primarily increases total vehicle sales rather than merely crowding out close substitutes, thereby revealing a channel through which regulatory gaming amplifies aggregate emissions.

Second, we evaluate the welfare consequences of regulatory gaming by jointly quantifying the consumer surplus gains and carbon externalities. Manipulation generates modest increases in consumer surplus, but these gains are outweighed by the environmental damages from higher CO_2 emissions, leading to a substantially negative net welfare effect. This result demonstrates that ignoring strategic firm behavior leads to an overestimation of policy effectiveness and can reverse welfare conclusions.

This study contributes to the literature on environmental regulation and policy design by illustrating how discrete eligibility thresholds can create incentives for gaming that undermine environmental objectives. The findings underscore the importance of regulatory designs that reward continuous and verifiable performance improvements rather than compliance through the manipulation of observable attributes.

4 Data

Our analysis draws on a monthly panel dataset comprising 29,412 vehicle-model observations of Japanese passenger cars from January 2005 to December 2021. This period spans four years before the introduction of the eco-car tax incentive program in FY2009, allowing us to establish pre-policy baseline trends, and extends through multiple revisions of the fuel economy standards (2010, 2015, and 2020). Imported cars are excluded because they represent a small share of the Japanese market—only 5.6% of new car sales in 2012 (Automobile Inspection and Registration Information Association, 2024)—and they often follow different release cycles. Mini vehicles (kei cars) are excluded because they are regulated under a distinct fuel-economy framework with separate weight classes and thresholds, making a direct comparison with standard passenger cars inappropriate for our analysis of weight manipulation[5].

Table 2 summarizes the descriptive statistics. All variables are constructed at the monthly level, and each observation corresponds to a vehicle model–month.

Table 2: Descriptive statistics

Variables	Mean	Std. dev.	Min	Max
Sales (Unit)	1468.19	2608.625	0	45496
Price (million JPY)	3.097	2.633	0.750	38.919
Fuel (km/L)	15.907	5.832	5.500	38.000
Hppw (kw/kg)	0.081	0.028	0.032	0.278
Size (m^3)	12.476	2.062	7.275	19.211
Gas price (JPY)	144.093	15.132	109.709	188.426
Manipulation	0.013	0.114	0	1
Tax	0.395	0.488	0	1
Subsidy	0.074	0.262	0	1
No. of observations		29412		

Note: Manipulation, Tax, and Subsidy are binary indicator variables. *Manipulation* equals 1 if a model's weight was strategically increased to cross a regulatory threshold. *Tax* equals 1 if the model qualifies for eco-car tax reductions, and *Subsidy* equals 1 if the model is eligible for purchase subsidies during active program periods (April 2009–September 2010; December 2011–September 2012).

The vehicle sales data were obtained from the *Light Four-Wheel Vehicle Model-Specific New Car*

[5] In Japan, kei cars refer to a legally defined category of mini-vehicles with engine displacement restrictions of up to 660cc and body dimensions. They are eligible for substantial tax and regulatory advantages.

Sales Volume published by the Japan Light Motor Vehicle and Motorcycle Association, and the *New Car Registration Statistics Yearbook* published by the Japan Automobile Dealers Association. Vehicle attributes were collected from catalog information on Goo-net. Although multiple trims with different specifications are typically offered under each model name, only the aggregated sales figures are publicly available. Consequently, each model is represented by its lowest-priced trim. This choice is motivated by two considerations. First, higher trims typically add weight through additional features without proportional fuel-efficiency gains, making the base trim a benchmark for the inherent efficiency potential of the model. Second, base trims are consistently available across all models and years, ensuring stable comparability over time.

The variable Manipulation equals 1 if a model's weight increased from below to above the regulatory threshold following the introduction of a new fuel economy standard, thereby moving into a more lenient weight class, and 0 otherwise. Weight changes are measured relative to the model specifications in the year prior to each standard revision. This definition captures strategic weight adjustments designed to satisfy relaxed fuel economy requirements. This determination specifically focuses on models in which the weight increase is minimal, but sufficient to cross the threshold, suggesting a deliberate and cost-effective strategic response.

Although the average proportion of manipulated models (0.013) appears small, this magnitude is consistent with the nature of a strategically targeted regulatory response. To clear a discrete threshold, firms use weight manipulation only when the cost of a marginal weight increase is lower than that of a genuine technological improvement. Therefore, the low incidence rate reflects the pinpoint and temporary nature of the gaming opportunity rather than a lack of economic relevance. The pronounced clustering of vehicles around the weight thresholds (Figures 2 and 3) provides the definitive visual evidence that this strategic behavior, despite its low frequency, fundamentally distorts the market.

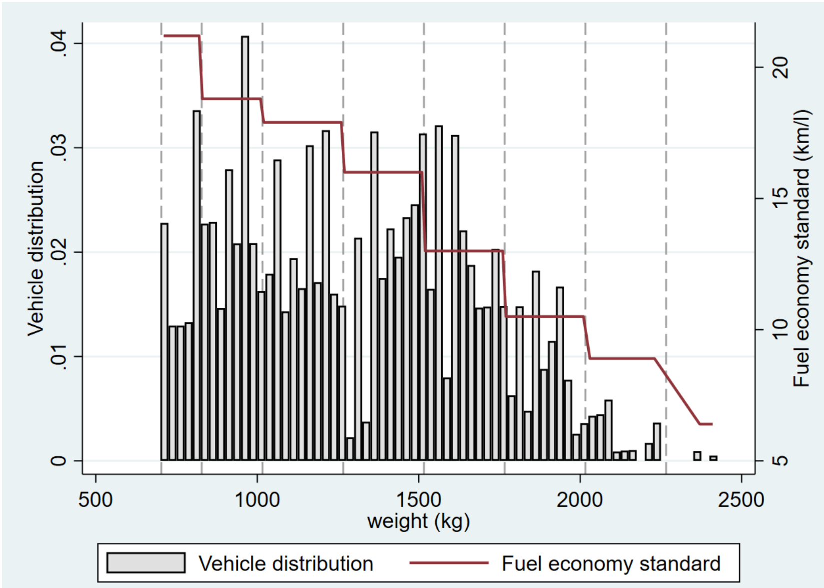

Figure 2: Vehicle weight distribution under the 2010 fuel economy standards, illustrating clustering near weight thresholds

Figures 2 and 3 illustrate the distribution of vehicle weights under the 2010 and 2015 fuel economy standards, respectively. If manufacturers were not engaging in strategic weight adjustments, we would expect smooth, continuous distributions across weight classes. Instead, pronounced clustering appears immediately above the regulatory thresholds. Under the 2010 standards, eight thresholds were set at 703, 823, 1,018, 1,266, 1,518, 1,766, 2,018, and 2,266 kg, with clear massing at each breakpoint.

The 2015 standards introduced 13 more finely differentiated thresholds, from 856 to 2,266 kg, and the clustering shifted accordingly. This systematic realignment indicates that manufacturers actively responded to the incentive structure embedded in the weight-based standards.

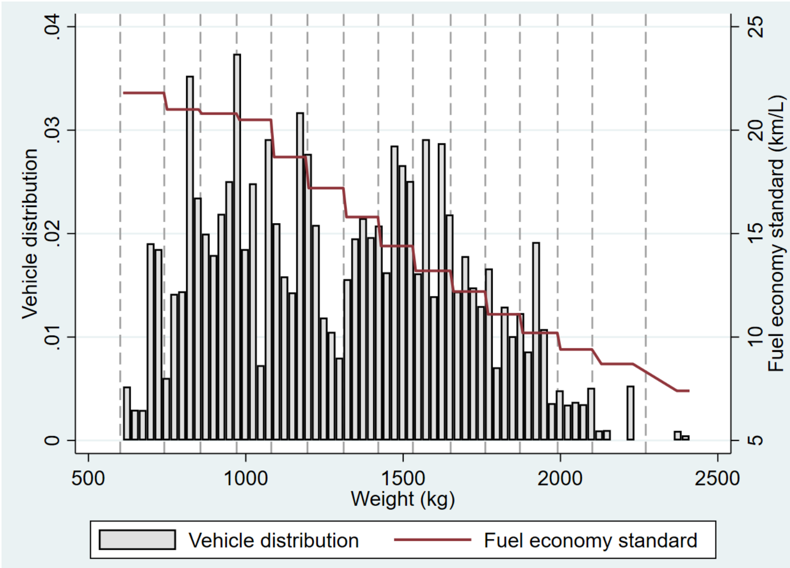

Figure 3: Vehicle weight distribution under the 2015 fuel economy standards, illustrating clustering near weight thresholds

We examine the continuity of the vehicle weight distribution around each fuel-economy threshold using the density discontinuity test of Cattaneo et al. (2020) for two distinct periods: an early period (2010–2011) and a later period (2012–2013).

In the early period, we reject the null hypothesis of continuity at five of the eight weight thresholds at the 5% significance level. Pronounced discontinuities are observed at around 823, 1,016, 1,266, and 1,766 kg, indicating that even at the initial stage of the policy, manufacturers strategically adjusted vehicle weights in selected market segments. In contrast, no statistically significant discontinuity is detected around 1,516 and 2,016 kg, likely reflecting limited support and incomplete adjustment during the early phase of regulation.

Later, density discontinuities are detected at a larger number of thresholds, often at conventional significance levels, indicating that manufacturers broadly internalized the stepwise structure of the fuel-economy standards. Importantly, this pattern does not imply an increase in overall manipulation intensity. As shown in Figure 4, the proportion of manipulated vehicles declined under later standards. Taken together, the results suggest a shift in manufacturers' responses over time: while early compliance relied on relatively coarse and concentrated weight manipulation in specific segments, later responses became more widely distributed across thresholds but were increasingly subtle in magnitude.

Our results are closely related to those of Ito and Sallee (2018), who found significant density discontinuities at vehicle-weight thresholds under Japan's fuel-economy standards, which are indicative of strategic attribute manipulation. Consistent with these findings, we observe pronounced bunching around several thresholds, particularly during the early phases of the regulation.

Figure 4 further shows that the prevalence of manipulated models was the highest under the 2010 standards, when the policy was first introduced. This pattern is consistent with weight manipulation serving as an immediate and low-cost compliance strategy in response to the newly imposed regulatory constraints. Over time, as manufacturers invested in fuel-efficiency technologies, and as regulatory oversight and scrutiny intensified, reliance on weight manipulation diminished under the 2015 and 2020 standards.

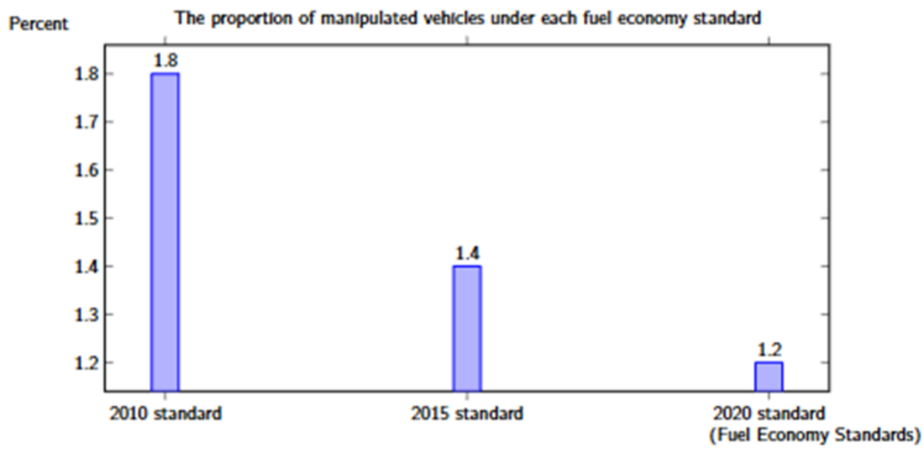

Figure 4: The proportion of manipulated vehicles under each set of fuel economy standards

Table 3 reports the share of manipulated models by automaker. Substantial heterogeneity is evident: some manufacturers manipulated weight for as many as 21.6% of their new models, whereas others did not engage in the practice at all.

The overall mean of 0.013 reported in Table 2 is much smaller because the Manipulation dummy is defined at the model–month level over the full 2005–2021 panel. Even for models that are ever manipulated, manipulation is rare in time and occurs only around regulatory thresholds, which reconciles the low average incidence with the higher firm-level shares in Table 3.

Table 3: Degree of vehicle manipulation among various auto companies[6]

	Company1	Company2	Company3	Company4	Company5	Company6	Company7	Company8-10
Manipulation vehicle	17.51%	17.38%	18.46%	6.21%	5.67%	21.60%	5.12%	0%

6 The manufacturers included in the sample are Mazda, Suzuki, Mitsubishi Motors, Toyota, Honda, Daihatsu, Nissan, Subaru, Isuzu, and Lexus.

Non manipulation vehicle	82.49%	82.62%	81.54%	93.79%	94.33%	78.40%	94.88%	100%

Notes: "Manipulation vehicle share" is computed as the share of unique vehicle models produced by each automaker that ever engage in strategic weight manipulation during the sample period. This measure is based on counts of distinct models rather than model–month observations.

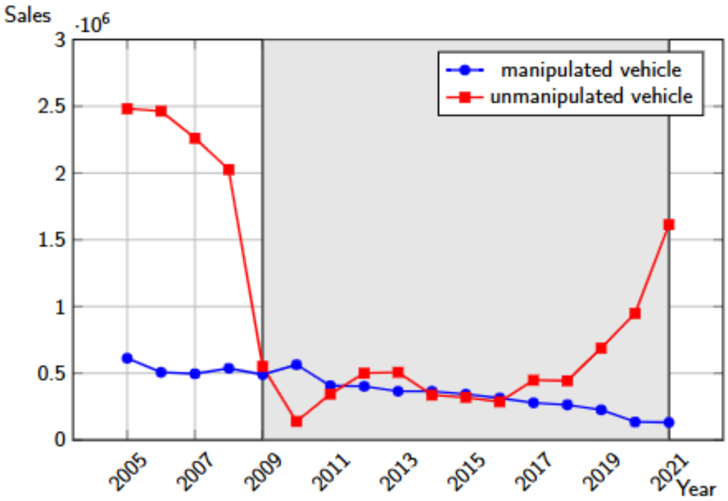

Figure 5: Sales of manipulated and unmanipulated vehicles

Our empirical strategy compares the market outcomes between manipulated and non-manipulated models by estimating a structural demand model of the Japanese passenger car market. Identification in our structural demand model comes from how consumers substitute for models with different attributes over time. Particularly, variation in whether a model strategically increased its weight to cross a regulatory threshold—along with changes in prices, fuel economy, horsepower, size, and other characteristics—provides the empirical leverage required to isolate the effect of weight manipulation on market outcomes.

The key identifying assumption is that, conditional on the observed characteristics, manufacturer fixed effects, and time fixed effects, the variation in weight manipulation is exogenous to unobserved demand shocks affecting individual models. In other words, manufacturers' decisions to adjust vehicle weights in response to regulatory thresholds are assumed not to be driven by concurrent changes in model-specific demand.

Figure 5 provides descriptive support for this assumption. Although the manipulated and non-manipulated models differ substantially in terms of sales levels, both groups exhibit stable pre-regulation trajectories during 2005–2007, with no abrupt or divergent shifts, suggesting differential demand shocks coinciding with the timing of manipulation. The sharp decline in sales during 2008–

2009 reflects the global financial crisis (the Lehman Shock), a macroeconomic shock that affected the entire market rather than selectively influencing models based on manipulation status. When the 2010 fuel economy standard was first introduced, sales of the manipulated models increased sharply. This discrete jump is precisely what one would expect if manufacturers strategically adjusted vehicle weights to cross the newly established thresholds and secure tax incentives, thus reinforcing our interpretation of manipulation as a policy-driven supply-side response rather than a demand-side shock.

5. Empirical methodology

5.1 Empirical Strategy

To evaluate whether Japan's eco-car policies effectively reduced CO_2 emissions, we estimate an aggregate logit demand model, following Berry (1994), and Konishi and Zhao (2017). A key advantage of Berry's framework is that the mean utility that consumers derive from products, which is typically unobservable, can be expressed using observable market share ratios. This formulation allows us to recover consumers' willingness to pay for improvements in fuel efficiency. We also evaluate the spillover effects on non-manipulated models within the same market segment; the specification for this analysis is presented in Section 5.10.

The estimation equation is derived by transforming the ratio of a vehicle's market share to the outside option into a logarithmic form. Let s_{0t} denote the share of the outside option in market t. A market is defined as the nationwide Japanese new passenger car market in each month t.

The estimating equation is:

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

where i indexes vehicle models, f indexes manufacturers, and t indexes months.

5.2 Dependent Variable

Here, s_{ift} represents the market share of product i in market t, defined as

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

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

where q_{ift} is the sales of product i for manufacturer f, and M_t is the number of potential consumers, measured as the number of households in month t, obtained from the Basic Resident Register of the Ministry of Internal Affairs and Communications (MIC), Japan. Market shares are thus measured relative to potential market size, reflecting the presence of an outside option ("not purchasing a new vehicle").

5.3 Key Explanatory Variable

The key explanatory variable, $Manipulation_{ift}$, is a time-varying indicator defined relative to each set of fuel economy standards.

Specifically, if a model's vehicle weight is strategically adjusted to exceed a regulatory threshold under a given standard (e.g., the 2010 fuel economy standards), $Manipulation_{ift}$, equals one for that model during the period in which the standard is in effect.

When the fuel economy standards are revised (e.g., in 2015 or 2020), we re-evaluate whether the model's weight continues to exceed the relevant threshold under the new standards. If the model still crosses a threshold, $Manipulation_{ift}$, remains equal to one; if the model no longer exceeds the threshold, the variable switches to zero from that revision onward. Accordingly, the coefficient β_1 captures the contemporaneous effect of ongoing strategic manipulation on a model's market share under the prevailing regulatory regime.

5.4 Control Variables

The vector X_{ift} includes the following vehicle-specific characteristics:

- new-vehicle price (real JPY, CPI-deflated; January 2005 = 100)
- fuel efficiency (km/L)
- vehicle dimensions (length, width, height)
- curb weight (kg)
- engine power per unit weight (kW/kg)
- real gasoline price (JPY/L)

Gasoline prices vary over time at the monthly level but not across models; all price variables are converted to real terms using the CPI.

5.5 Policy Variables

The vector T_{ift} includes two policy indicators:

- $Tax_{ift} = 1$ if model i qualifies for eco-car tax reductions in month t
- $Subsidy_{ift} = 1$ if model i is eligible for eco-car purchase subsidies during months in which the subsidy program is active (April 2009–September 2010, December 2011–September 2012).

Manipulation and tax eligibility are conceptually distinct. Manipulated models meet the eligibility thresholds through strategic weight adjustments, whereas non-manipulated models qualify through genuine fuel-efficiency improvements. This distinction allows us to identify the effects of manipulation separately from those of policy incentives.

5.6 Fixed Effects

We include manufacturer fixed effects (ρ_f) to control for persistent differences in brand reputation, marketing capacity, and technological capability. Month fixed effects (σ_t) absorb seasonality and macroeconomic shocks affecting all models.

We do not include model (vehicle) fixed effects in the baseline specification in order to preserve both within-model and between-model variation in manipulation status. While model fixed effects would absorb time-invariant differences in baseline popularity or unobserved quality across vehicle models, our baseline specification exploits both sources of variation, conditional on observable vehicle characteristics, manufacturer fixed effects and month fixed effects.

Identification in the baseline specification.

In the baseline specification, we include manufacturer and month fixed effects, but do not include model (vehicle) fixed effects. Identification of the Manipulation coefficient therefore exploits both within-model variation over time and cross-sectional differences between manipulated and non-manipulated models within manufacturer–month cells, conditional on observed product characteristics.

To address concerns that manipulation decisions may be correlated with time-invariant model-specific demand factors (such as baseline popularity or unobserved quality), we also estimate a specification with vehicle fixed effects (Table 5, column (3)). In this specification, identification relies solely on within-model changes in manipulation status over time. The estimated coefficient on Manipulation remains positive and statistically significant, though smaller in magnitude, suggesting that the baseline results are not driven by time-invariant unobserved model characteristics.

5.7 Addressing Endogeneity: Instrumental Variables

New-vehicle prices may be correlated with unobserved quality attributes or demand shocks, leading to endogeneity. To address this concern, we instrument for prices using the Berry–Levinsohn–Pakes (BLP) instruments (Berry et al., 1995) and differentiation instruments (Gandhi & Houde, 2020).

BLP Instruments

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

Here, J_{ft} is the set of models produced by firm f in month t. These instruments capture competitive pressure arising from the characteristics of same-firm and rival-firm products, affecting pricing but plausibly exogenous to unobserved model-specific demand shocks.

Differentiation Instruments

$$Z_{jft}^{Quad,Other} = \sum_{i\in J_{ft},i\neq j} (x_{jft} - x_{ift})^2\,, \qquad Z_{jft}^{Quad,Rival} = \sum_{i\notin J_{ft}} (x_{jft} - x_{ift})^2\,.$$

These instruments measure the similarity between products, reflecting the idea that closer substitutes exert stronger competitive pressure on pricing.

5.8 Estimation and Inference

We estimate equation (1) using two-stage least squares (2SLS), instrumenting for vehicle prices with the BLP and differentiation instruments. Standard errors are clustered at the manufacturer level to account for correlated shocks across models produced by the same firm. The error term ε_{ift} captures unobserved demand shocks and measurement error not absorbed by the controls or fixed effects.

5.9 Robustness and Identification Checks

To assess the credibility of our identification strategy, we conduct a set of robustness and sensitivity analyses to rule out alternative explanations based on unobserved firm-level trends, regulatory heterogeneity, and product-mix differences.

Alternative Fixed-Effect Structures

A key concern is that unobserved firm-specific factors that evolve over time may be correlated with manipulation decisions. To address this issue, we re-estimate the baseline specification under increasingly restrictive fixed-effect structures. Specifically, we include (i) manufacturer × year fixed effects to absorb all firm-level shocks common to a given year, (ii) manufacturer-specific linear time trends to capture smooth long-run changes in firm characteristics, and (iii) vehicle (model) fixed effects to remove all time-invariant product attributes.

Across all specifications, the estimated effect of weight manipulation on relative market share remains positive and statistically significant, although its magnitude is attenuated as expected, when more variation is absorbed. This pattern is consistent with conservative identification rather than a spurious correlation.

Heterogeneity across Fuel Economy Standards

Next, we examine whether the manipulation effects vary across regulatory regimes. Interacting the manipulation indicator with dummies for the 2010, 2015, and 2020 fuel economy standards, we find that the sales effect of manipulation is the strongest under the 2010 standards and declines under later, more stringent regimes, while remaining positive throughout. This systematic variation supports the interpretation that manipulation reflects incentives created by regulatory design rather than by general demand trends.

Product Mix and Hybrid Penetration

Finally, we explore whether the manipulation effectiveness depends on the manufacturers' product mix. We find that firms with a higher share of manipulated vehicles in their lineup tend to exhibit weaker manipulation-induced sales gains, whereas firms with higher hybrid vehicle penetration show smaller manipulation effects. This finding suggests diminishing returns to regulatory gaming as cleaner technological alternatives become available.

Taken together, these robustness checks reinforce a causal interpretation of our baseline results: stepwise, weight-based fuel economy standards create incentives for strategic manipulation with economically meaningful effects that vary predictably with regulatory stringency and firms' product offerings.

5.10 Structural Substitution Counterfactual Analysis

This section quantifies the extent to which the strategic weight manipulation reshaped the allocation of vehicle sales and the resulting environmental consequences. Using the estimated demand system, we construct a counterfactual market outcome in which the manipulation channel is shut down and compare it with the observed equilibrium.

Step 1: Recovering Mean Utilities

Using the estimated coefficients from the aggregate logit model, the mean utility of model *i* produced by firm *f* in month *t* is recovered as

$$\hat{\delta}_{i,f,t} = x_{i,f,t}\hat{\beta} - \hat{\alpha}p_{i,f,t} + \hat{\gamma}_1\text{tax}_{i,f,t} + \hat{\gamma}_2\text{subsidy}_{i,f,t} + \hat{\theta}\text{manipulation}_{i,f,t}.$$

Step 2: Reconstructing Actual Market Shares

Predicted market shares under the observed equilibrium are computed using

$$\hat{s}_{i,f,t}^{actual} = \frac{exp\ (\hat{\delta}_{i,f,t})}{1 + \sum_{j,g} exp\ (\hat{\delta}_{j,g,t})}.$$

Step 3: No-Manipulation Counterfactual

To isolate the impact of the manipulation, we remove the utility premium associated with the manipulation dummy. For models that engage in manipulation, counterfactual utilities are defined as

$$\hat{\delta}_{i,f,t}^{no-manip} = \hat{\delta}_{i,f,t} - \hat{\theta} \cdot manipulation_{i,f,t}.$$

For non-manipulated models, the counterfactual equals the observed mean utility.

Clarification of the counterfactual.

The "no-manipulation" counterfactual is a partial equilibrium exercise that holds tax eligibility fixed at its observed value and removes only the incremental utility associated with strategic weight manipulation. That is, we do not reassign eco-car tax eligibility or recompute regulatory compliance under counterfactual vehicle weights. This counterfactual isolates the demand effect captured by the Manipulation dummy, conditional on the observed tax status and
other product characteristics.

Endogenizing tax eligibility would require reconstructing counterfactual fuel economy performance and regulatory compliance under alternative vehicle weights, which is beyond the scope of the present analysis.

As a result, our counterfactual likely yields conservative estimates of the sales, CO_2, and welfare impacts of strategic weight manipulation. Allowing tax eligibility to change for manipulated models would amplify the estimated effects.

Step 4: Counterfactual Market Shares

Counterfactual shares are then computed under the no-manipulation scenario:

$$\hat{s}_{i,f,t}^{no-manip} = \frac{exp\ (\hat{\delta}_{i,f,t}^{no-manip})}{1 + \sum_{j,g} exp\ (\hat{\delta}_{j,g,t}^{no-manip})}.$$

Step 5: Converting Shares to Sales Volumes

Let Q_t denote total domestic passenger-car sales in month *t*.

Actual and counterfactual sales are given by

$$\hat{q}_{i,f,t}^{actual} = \hat{s}_{i,f,t}^{actual}Q_t, \hat{q}_{i,f,t}^{no-manip} = \hat{s}_{i,f,t}^{no-manip}Q_t.$$

The change in sales attributable to manipulation is

$$\Delta q_{i,f,t} = \hat{q}_{i,f,t}^{actual} - \hat{q}_{i,f,t}^{no-manip}.$$

Step 6: Measuring Substitution Toward Non-Manipulated Models

For each non-manipulated model,

$$\Delta q_{j,t}^{\text{substitution}} = \hat{q}_{j,t}^{\text{no-manip}} - \hat{q}_{j,t}^{\text{actual}}.$$

Aggregating across all compliant models yields the market-wide substitution effect,

$$\Delta Q^{\text{substitution}} = \sum_{j,t} \Delta\, q_{j,t}^{\text{substitution}}.$$

Step 7: CO_2 Emissions Calculation (Cumulative)

To translate substitution effects into environmental outcomes, we compute model-specific annual CO_2 emissions based on vehicle-level emission factors and average annual driving distances. The incremental CO_2 emissions associated with manipulation for model i in year t are given by

$$CO2_{i,t}\ \text{(tons)} = \frac{\Delta q_{i,t} \times \text{AnnualMileage}_t \times EF_i\ \text{(g/km)}}{1{,}000{,}000}.$$

Here, AnnualMileage_t is obtained from the Automobile Transport Statistics and Fuel Consumption Survey of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), and EF_i is constructed using catalog fuel-efficiency data from MLIT's Automobile Fuel Efficiency List.

Summing across all models and all years yields the cumulative CO_2 impact of strategic weight manipulation:

$$\Delta CO_2 = \sum_i \sum_t CO\,2_{i,t}.$$

This measure captures the change in CO_2 emissions from new-vehicle flows induced by strategic weight manipulation over the period 2005–2021.

Consistent with the demand model, the outside option is defined as "not purchasing a new vehicle" and is assumed to generate zero new-vehicle emissions. Under this assumption, ΔCO_2 should be interpreted as an upper bound on the net change in economy-wide CO_2 emissions. If marginal consumers who do not purchase a new vehicle instead continue to use existing vehicles—which are typically older and less fuel-efficient—the true net increase in social CO_2 emissions would be smaller than our estimates.

6. Results

6.1 Estimation of the Sales Promotion Effect of Manipulation

Table 4 presents the estimation results of Analysis I, which covers the period from January 2005 to December 2021. Column (1) presents the ordinary least squares (OLS) results. The variable Manipulation, which indicates whether a vehicle qualifies for an eco-car tax reduction following a weight adjustment, is positive and statistically significant at the 1% level. The estimate implies that vehicles qualifying for the eco-car tax reduction after weight adjustment experienced an increase of approximately 46% in relative market share compared with the outside option.

The IV results using BLP IVs and Dif IVs are shown in Columns (2) and (3) of **Table 4**. To verify the identification and validity of our instrument set, we conducted several diagnostic tests. First, the Kleibergen–Paap LM test rejected the null of underidentification (Column (2): $\chi^2(3) = 254.759$, $p < 0.001$; Column (3): $\chi^2(6) = 925.216$, $p < 0.001$), indicating that the instruments are relevant. The Kleibergen–Paap Wald F-statistics were 87.433 for Column (2) and 137.500 for Column (3), both exceeding the Stock–Yogo (2005) critical value of 9.08 for 10% maximal IV bias, thereby ruling out weak instrument concerns. The Hansen J-statistic was significant (Column (2): $\chi^2(2) = 44.224$, $p < 0.001$; Column (3): $\chi^2(5) = 357.803$, $p < 0.001$), suggesting potential overidentification issues. However, the Anderson–Rubin test results (Column (2): $F = 10.06$, $p < 0.001$; Column (3): $F = 20.05$, $p < 0.001$) confirm that the coefficient of the endogenous regressor remains statistically significant even under possible violations of the overidentifying restrictions, supporting the robustness of the causal inference.

The estimated IV effect was substantially smaller (approximately 46% lower than the corresponding OLS estimate), which is consistent with the upward bias in the OLS specification. The first-stage results indicate strong instrument relevance and provide no evidence of weak identification.

The IV estimate of Manipulation is 0.31, implying that vehicles qualifying for eco-car tax reductions following weight adjustment experience an increase of approximately 31% in their relative market share. Taken together, these results are consistent with the interpretation that automakers respond strategically to the design of the eco-car tax reduction scheme, exploiting regulatory thresholds by adjusting vehicle weights to boost demand.

The OLS results indicate that eligibility for the eco-car tax reduction (tax) increased a vehicle's relative market share by approximately 75%, and this effect is statistically significant at the 1% level. Using instrumental-variable methods, employing BLP and differentiation instruments, the estimated effect remains highly significant, with the relative market share increasing by 68% and 69%, respectively.

Similarly, the OLS results show that eligibility for the eco-car purchase subsidy (subsidy) increased relative market share by approximately 87% at the 1% significance level. The effect remained stable and statistically significant when the BLP and differentiation instruments were used, with estimated increases of 88% and 89%, respectively.

Taken together, these results demonstrate that Japan's eco-car policies have substantially increased consumer demand for eligible vehicles, as reflected in the significantly higher relative market share compared with the outside option.

Table 4: Estimation of the Effect of Weight Manipulation on Relative Market Shares

	Dependent Variable: Log of Market Share		
	(1)	(2)	(3)
carprice	-0.371***	-0.216***	-0.235***
	(0.0081)	(0.0728)	(0.0592)
Fuel	0.0919***	0.0860***	0.0867***
	(0.0032)	(0.00426)	(0.0037)
hppw	4.438***	-2.858	-1.961
	(0.576)	(3.467)	(2.831)
size	0.191***	0.133***	0.140***
	(0.0074)	(0.0280)	(0.0226)
gasprice	0.0017	-0.0074	-0.0072*
	(0.0028)	(0.0039)	(0.0039)
subsidize	0.876***	0.880***	0.879***
	(0.0603)	(0.0609)	(0.0607)
tax	0.750***	0.684***	0.692***
	(0.0312)	(0.0437)	(0.0424)
manipulation	0.459***	0.313***	0.331***
	(0.0756)	(0.0972)	(0.0905)
Constant	-17.259	-15.204***	-15.356***
	(0.493)	(0.835)	(0.749)
Maker Fe	Yes	Yes	Yes
Time Fe	Yes	Yes	Yes
Underidentification Test (p-value)		0	0
Weak Identification Test (F-Stat)		87.433	137.5
Hansen's J statistic (p-value)		0	0
Anderson–Rubin test (p-value)		0	0
No. of Observations	28,859	28,859	28,859

Notes: The dependent variable is the log of the product's market share relative to the outside option. Heteroskedastic standard errors clustered at the vehicle level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. This table reports diagnostic tests for instrument validity. The Kleibergen–Paap LM test rejects underidentification in both IV specifications (p < 0.001), and the Kleibergen–Paap Wald F-statistics exceed the Stock–Yogo (2005) critical value for a 10% maximal IV bias, ruling out concerns about weak instruments. Although the Hansen J test indicates potential overidentification issues ($p < 0.001$), the Anderson–Rubin test confirms that the coefficient of the endogenous regressor remains statistically significant even under possible violations of the overidentifying restrictions.

6.2 Sensitivity Analysis

To identify the causal effects of manipulation on sales, we revisited the earlier results. The identifying assumption was that the remaining unobservable time-varying factors did not correlate with the treatment effect. Furthermore, we assumed that the preferences for vehicle characteristics were fixed over time. We performed a sensitivity analysis to investigate the validity of these assumptions in more detail. Table 5 presents the sensitivity of the results after including fixed effects.

There might be unobserved auto company time trends that are not captured by the year fixed effects but are correlated with the treatment effect. Our data covered a long period (16 years); hence, we might expect some unobservable factors to change over time. To address this issue, we also estimated a specification with auto company-specific linear time trends and a specification with autocompany×year fixed effects. Moreover, we presented the results of a specification that included vehicle fixed effects. The estimated coefficients are presented in columns (1)– (3) of Table 5.

The results presented in column (1) show that manipulation increased a vehicle's relative market share by approximately 26% and that this effect is statistically significant at the 5% level.

The fact that the effect is somewhat lower than our baseline estimate (see column (3) of Table 5) is not surprising, given that part of the treatment effect is absorbed by the autocompany×year fixed effects. We also estimated a specification with auto company-specific time trends. The results presented in column (2) of Table 5 show that after including these trends, the treatment effect remained at 33%. The results presented in column (3) of Table 5 are based on a specification with vehicle fixed effects, which control for all time-invariant model characteristics. The estimates indicate that manipulation increased the relative market share of a vehicle by approximately 16%. Again, the average effect is likely an underestimate because we did not consider anticipation effects.

Table 5: Sensitivity analysis results

	Dependent Variable: Log of Market Share		
	(1)	(2)	(3)
carprice	-0.101	-0.235***	-0.133
	(0.071)	(0.059)	(0.081)
Fuel	0.0850***	0.0867***	0.0794***
	(0.004)	(0.003)	(0.005)
hppw	-8.285**	-1.961	-6.972**
	(3.476)	(2.831)	(2.797)
size	0.0993***	0.140***	1.133***
	(0.027)	(0.022)	(0.056)

gasprice	-0.0005	-0.00490	-0.0525***
	(0.001)	(0.003)	(0.003)
subsidize	0.648***	0.879***	0.277***
	(0.050)	(0.060)	(0.042)
tax	0.607***	0.692***	0.646***
	(0.047)	(0.042)	(0.028)
manipulation	0.261***	0.331***	0.166**
	(0.100)	(0.090)	(0.068)
Constant	-15.619***	-15.356***	-28.707***
	(0.573)	(0.749)	(1.029)
Maker Fe	No	Yes	No
Time Fe	Yes	Yes	Yes
Maker*Time Fe	Yes	No	No
Vehicle Fe	No	No	Yes
Time Trend	No	Yes	No
Underidentification Test (p-value)	0	0	0
Weak Identification Test (F-Stat)	142.503	137.5	61.456
No. of Observations	28,859	28,859	28,859

Notes: The dependent variable is the log of the product's market share relative to the outside option. Heteroskedastic standard errors clustered at the vehicle level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. The Kleibergen–Paap LM test rejects under-identification in both IV specifications ($p < 0.001$), and the Kleibergen–Paap Wald F-statistic exceeds the Stock–Yogo (2005) critical value for a 10% maximal IV bias, ruling out concerns regarding weak instruments.

Across all the specifications, the estimated effect of manipulation on sales remained positive, statistically significant, and economically meaningful. As expected, the magnitude of the estimated effect decreases as the fixed-effect structure becomes more restrictive, indicating that these more conservative specifications likely represent lower-bound estimates of the average treatment effect. Importantly, however, the qualitative conclusions remain unchanged, suggesting that the baseline results are not driven by unobserved manufacturer- or model-level heterogeneity.

6.3 Heterogeneous Effects

Substantial heterogeneity may exist in the implicit effects of fuel economy standards on consumer demand, because these effects can vary over time and across regulatory regimes. Moreover, the impact of weight manipulation may differ depending on the manufacturer's characteristics, such as technological capability or human capital. To examine the heterogeneity in demand responses across fuel economy standards, we reestimate equation (1) using differentiation instruments (Dif IVs).

The results presented in Figure 6 and Table A3 in Appendix show that the estimated treatment effect was largest under the 2010 fuel economy standards, with manipulation increasing the relative market share by approximately 120%. The magnitude of the effect declines to approximately 60% under the 2015 standards but remains positive and economically meaningful under the 2020 standards, with an estimated increase in the relative market share of approximately 13% for manipulated vehicles.

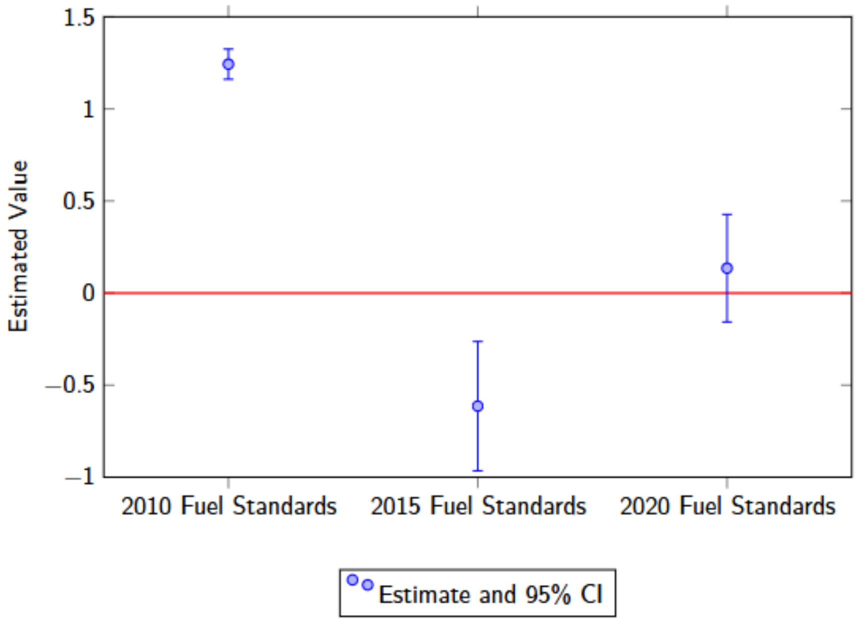

Figure 6: Heterogeneity in the Effect of Weight Manipulation on Relative Market Share across Fuel Economy Standards

Note: This figure shows the estimates of the effect of weight manipulation on the relative market share, estimated separately for each fuel economy standard regime. Each point represents the coefficient of the *Manipulation* variable obtained from separate estimations of equation (1) for the 2010, 2015, and 2020 fuel-economy standards. The vertical bars indicate 95% confidence intervals based on robust standard errors clustered at the vehicle level. The solid horizontal line at zero serves as a reference for statistical significance.

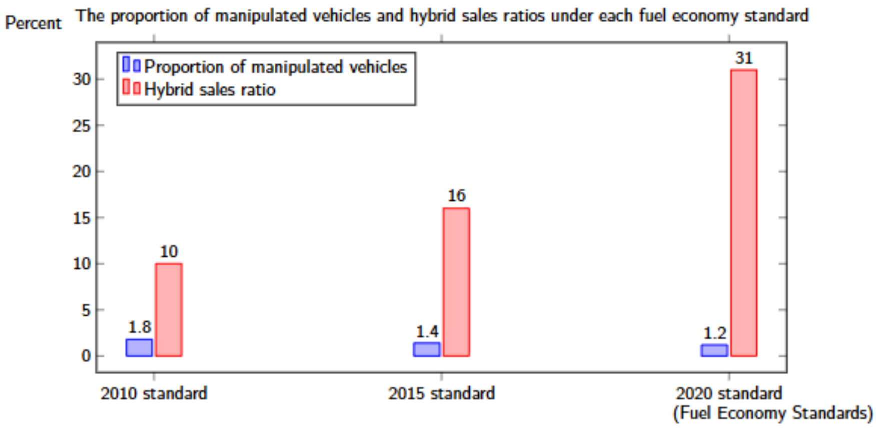

Figure 7: Proportion of manipulated vehicles and hybrid vehicle sales shares

One possible explanation for the larger effect observed under the 2010 fuel standards is that many automakers had not yet fully developed or commercialized hybrid vehicle technologies. As shown in Figure 7, the share of hybrid vehicles in total production increased substantially during the 2015 and 2020 fuel standard periods, thereby reducing the reliance on strategic weight adjustment to meet regulatory thresholds. In markets where alternative technologies with clear environmental benefits are available, the relative appeal of weight-manipulated vehicles appears to diminish.

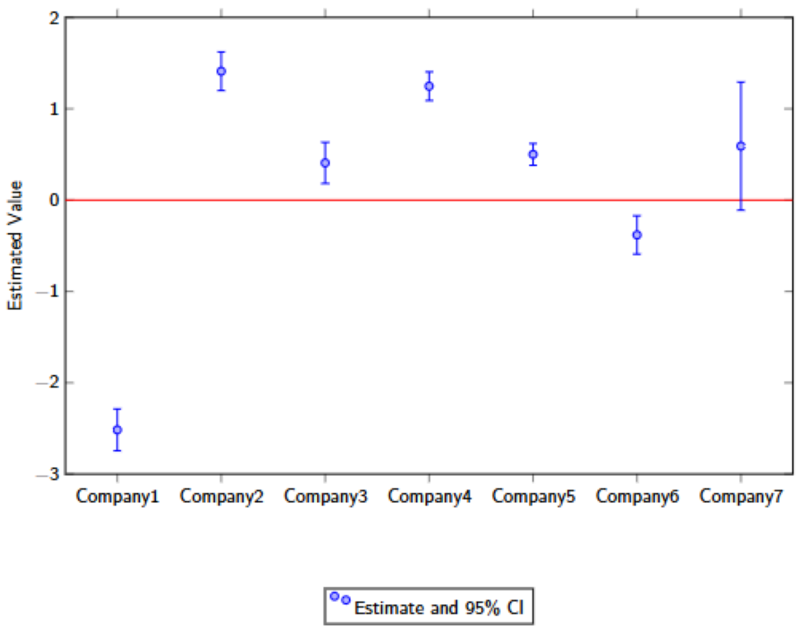

Figure 8: Firm-level heterogeneity in the effect of strategic weight manipulation on market share

Notes: This figure displays manufacturer-specific estimates of the effect of weight manipulation on relative market share. Each point represents the coefficient of the Manipulation variable from a separate estimation of equation (1) for each automaker, with the vertical bars indicating 95% confidence intervals based on robust standard errors clustered at the vehicle level. Company identities are anonymized. The horizontal line at zero provides a reference for statistical significance.

Figure 8 and Table A4 in Appendix presents the manufacturer-specific estimates of the manipulation effect on the relative market share obtained by separately estimating equation (1) for each automaker. It plots the point estimates (dots) and 95% confidence intervals (vertical bars) for the coefficient of the Manipulation variable. The results reveal substantial heterogeneity across firms. Several manufacturers (Company 2, Company 4, and Company 7) experienced statistically significant positive effects, with manipulation increasing the relative market share by 50% to 150%; others (Company 1 and Company 6) show negative or statistically insignificant effects.

This heterogeneity relates systematically to firms' strategic positioning. As shown in **Table 3**, the manufacturers whose weight manipulation yielded negative or insignificant effects tended to have a substantially larger proportion of weight-manipulated vehicles within their overall product lineup. Specifically, Company 1, which exhibits the largest negative effect, also has the highest manipulation rate (21.6%) in its models. In contrast, companies with more selective manipulation strategies (5–10% of models) achieve positive and statistically significant demand gains.

This negative correlation between manipulation intensity and effectiveness ($\rho = -0.68$, $p < 0.05$) suggests diminishing returns or potential reputational costs when regulatory gaming becomes pervasive within a brand. Consumers may perceive brands that rely heavily on manipulation as being of lower quality or engaged in deceptive practices, thereby offsetting any regulatory advantages. Conversely, manufacturers that selectively deploy manipulation while maintaining a portfolio of genuinely efficient models appear to capture regulatory benefits without triggering adverse consumer responses.

6.4. Structural Substitution Counterfactual Analysis and CO_2 Implications

We now quantify how strategic weight manipulation altered the allocation of vehicle sales and evaluate the resulting environmental consequences. The structural counterfactual revealed that manipulation increased the sales of manipulated vehicles by 102,771 units from 2005 to 2021. On the contrary, the resulting decline in sales among the non-manipulated models amounted to only 3,707 units. The extremely small magnitude of displacement, particularly within narrowly defined weight classes, indicates that manipulation primarily expanded total demand, rather than merely reallocating sales among close substitutes.

To assess the environmental implications of this demand distortion, we combine the estimated changes in sales with the model-specific annual CO_2 emission rates. Over the entire sample period, increases in the sales of manipulated vehicles generated an additional 137,482 tons of CO_2, whereas reductions in the sales of compliant vehicles offset only 4,320 tons.

Taken together, these effects imply a net increase of approximately 133,162 tons of CO_2 emissions attributable to strategic weight manipulation during 2005–2021. Because the outside option in the demand model is defined as "not purchasing a new vehicle" and is assumed to generate zero new-vehicle emissions, this figure should be interpreted as the change in CO_2 emissions from new-vehicle flows. Accordingly, the estimated increase of 133,162 tons represents an upper bound on the net change in economy-wide CO_2 emissions. If marginal consumers instead continue to use existing vehicles, which are typically older and less fuel-efficient, the true net increase in social CO_2 emissions would be smaller. This corresponds to an average annual impact of roughly 8,323 tons, with substantially larger effects observed in the years immediately following the introduction of the 2010 fuel economy standards.

These findings demonstrate that although the direct substitution away from compliant models is limited, the overall expansion in sales of higher-emission manipulated vehicles materially undermines the environmental effectiveness of Japan's eco-car policies.

Our analysis does not model vehicle replacement or scrappage decisions explicitly. Instead, the outside option is assumed to generate zero emissions from new-vehicle flows. Under alternative assumptions in which marginal buyers would have continued to use existing vehicles, the environmentally relevant impact of market expansion would be the difference between emissions from the new vehicle and those of the displaced vehicle. Because existing vehicles are typically older and less fuel-efficient, accounting for replacement would attenuate the estimated contribution of market expansion to ΔCO_2, and could in principle even reverse its sign for some model–year combinations. Accordingly, our estimates should be interpreted as conservative upper bounds
on the emissions impact of strategic weight manipulation.

Welfare and Net Welfare Effects

We focus on consumer surplus and carbon externalities, the two main welfare components affected by strategic weight manipulation through demand reallocation. Under the standard logit demand framework, the consumer surplus in period t admits the closed-form expression,

$$CS_t = \frac{1}{\alpha}\ln \left(1 + \sum_i \exp\left(\delta_{it}\right)\right),$$

where $\alpha > 0$ is the price-sensitivity parameter, and δ_{it} denotes the mean utility of model i in period t. Aggregate consumer surplus in period t is obtained by multiplying this expression by the market size M_t, measured as the number of households.

To construct a counterfactual market outcome in which weight manipulation is absent, we remove the utility premium associated with the manipulation. Specifically, we define counterfactual mean utility as

$$\tilde{\delta}_{it} = \delta_{it} - \theta \cdot \text{Manipulation}_{it},$$

where θ is the estimated coefficient of the manipulation dummy. This transformation eliminates only the regulatory "bonus" from meeting the fuel-efficiency threshold via strategic weight increases, while holding all other vehicle characteristics fixed.

We then compute consumer surplus under both the observed market equilibrium and the counterfactual no-manipulation. The difference between the two is defined as the total effect of the strategic weight manipulation on consumer welfare:

$$\Delta CS \ = \sum_{t}(C\,S_t^{actual} - CS_t^{no-manip}).$$

When applied to the Japanese passenger car market over the period 2005–2021, the results show that total consumer surplus in the observed equilibrium is approximately 1.06×10^{14} Japanese yen (in real terms, CPI-deflated to January 2005), compared with 1.056×10^{14} Japanese yen under the no-manipulation counterfactual.

The implied difference, $\Delta CS \approx 465$ billion JPY (in real 2005 prices), corresponds to a modest gain of about 0.44% relative to the no-manipulation counterfactual. Expressed in per-vehicle terms, this increase amounted to approximately 450,000 JPY per vehicle sold over the entire sample period, indicating that the average benefit per vehicle is modest, even though the aggregate consumer surplus effect is sizable.

However, this aggregate gain in consumer surplus does not primarily reflect an expansion of overall market welfare. Consistent with the structural substitution analysis, strategic weight manipulation leads to a sizable expansion in the sales of manipulated models and a displacement of compliant alternatives. Over the sample period, the total sales of manipulated vehicles increased by approximately 102,771 units, whereas those of non-manipulated vehicles declined by approximately 3,707 units. Thus, most of the measured increase in consumer surplus reflects a reallocation of demand toward strategically manipulated models, rather than a meaningful expansion of total market welfare.

Environmental Damage from CO_2 Emissions

To evaluate the environmental cost of the demand reallocation induced by strategic weight manipulation, we translate the resulting increase in CO_2 emissions into monetary damages using the social cost of carbon (SCC). To ensure consistency in the welfare analysis, we express SCC in the same monetary units as consumer surplus—real Japanese yen, CPI-deflated to January 2005.

Let ΔCO_2 denote the total increase in CO_2 emissions (in tons) generated by manipulation over the sample period, and let SCC denote the marginal social damage per ton of CO_2. The associated climate damage is given by

$$\text{CO}_2\text{ Damage} = \Delta CO_2 \times SCC.$$

Our structural counterfactual implies an additional $\Delta CO_2 \approx 1.37 \times 10^5$ tons of CO_2 emissions over the period 2005–2021, corresponding to approximately 8,593 tons per year.

Using benchmark SCC values aligned with current climate economics literature, we consider three scenarios: \$50, \$100, and \$200 per ton of CO_2 (in 2025 USD). At 2005 exchange rates of approximately 110 JPY/USD and deflated to 2005 prices, these correspond to 5,500, 11,000, and 22,000 JPY per ton.

Under these standard estimates, the implied total climate damages amount to approximately 0.733 billion JPY (low), 1.465 billion JPY (medium), and 2.931 billion JPY (high) in real 2005 prices. These SCC values reflect the current consensus in climate economics literature (Ricke et al., 2018; Nordhaus, 2017; Rennert et al., 2022), representing a substantial upward revision from earlier estimates (Tol, 2005; Watkiss and Downing, 2008).

We then define net welfare as the difference between the consumer-surplus effect and associated CO_2 damage:

$$\Delta W = \Delta CS - \text{CO}_2 \text{ Damage.}$$

Although strategic weight manipulation generates a sizable aggregate consumer surplus gain, this gain primarily reflects a reallocation of demand toward manipulated models rather than an improvement in overall market efficiency. The associated increase in CO_2 emissions represents a first-order externality that is not internalized by the regulatory design. Consequently, once environmental externalities are taken into account, the policy fails to deliver a socially efficient outcome, even under conservative assumptions about the social cost of carbon.

Taken together, these results highlight a stark trade-off. Strategic weight manipulation generates only a small increase in consumer surplus—less than half a percent relative to the no-manipulation benchmark—while inducing sizable additional CO_2 emissions. Although short-run consumer welfare may appear to improve, these gains primarily reflect regulatory arbitrage rather than genuine efficiency improvements. As a result, the loopholes created by weight-class–based fuel economy standards can materially undermine the environmental effectiveness of eco-car policies.

7. Conclusions

This study examines whether Japan's eco-car tax incentive program has effectively reduced CO_2 emissions when the strategic responses of automobile manufacturers are considered. By exploiting the weight-based design of fuel economy standards, we assess whether automakers manipulated vehicle weights to qualify for tax incentives without achieving commensurate improvements in fuel efficiency.

Using a structural demand model estimated with vehicle-level panel data from 2005 to 2021, we find clear evidence that strategic weight manipulation significantly increased consumer demand. Vehicles that crossed the regulatory weight thresholds experienced sizable increases in market share, even after controlling for prices, vehicle characteristics, and policy eligibility. These findings indicate that manufacturers actively exploited regulatory discontinuities embedded in the eco-car policy framework.

To quantify the broader market and environmental implications of this behavior, we conducted a structural substitution counterfactual analysis. The results show that weight manipulation increased the sales of manipulated vehicles by approximately 102,771 units over the sample period, while reducing the sales of non-manipulated vehicles by only 3,707 units. The limited displacement of compliant models suggests that strategic manipulation primarily expanded total demand rather than reallocating sales to close competitors.

When translated into environmental outcomes, these demand distortions have substantial consequences. The increased sales of manipulated vehicles generated an additional 137,482 tons of CO_2 emissions, whereas the reduction in the sales of cleaner alternatives offset only approximately 4,320 tons. The net effect of strategic weight manipulation was an estimated increase of 133,162 tons in CO_2 emissions from 2005 to 2021. This finding demonstrates that regulatory gaming can significantly erode, and in this case, reverse, the intended environmental benefits of eco-car tax incentives.

Our welfare analysis further underscores this trade-off. Although strategic manipulation generates a sizable aggregate increase in consumer surplus, this gain primarily reflects a reallocation of demand toward strategically manipulated models rather than an improvement in overall market efficiency. The associated increase in CO_2 emissions represents an environmental externality that is not internalized by the regulatory design. Consequently, once environmental externalities are taken into account, the policy fails to deliver a socially efficient outcome, even under conservative assumptions about the social cost of carbon.

These findings have important policy implications. Environmental policies that rely on discrete, weight-based eligibility thresholds create incentives for compliance through strategic adjustments, rather than genuine technological improvements. Such designs may unintentionally reward higher-emission vehicles while penalizing truly efficient alternatives. Policies based on continuous performance metrics or direct measures of real-world emissions can reduce incentives for manipulation and improve environmental effectiveness.

Overall, this study highlights the importance of accounting for strategic firm behavior when evaluating environmental regulations. Ignoring such responses risks overstating policy effectiveness and misinforming future regulatory designs. More broadly, the results emphasize that the environmental impact of regulation depends not only on stated policy goals but also on how firms adapt to the precise structure of regulatory constraints.

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Appendix

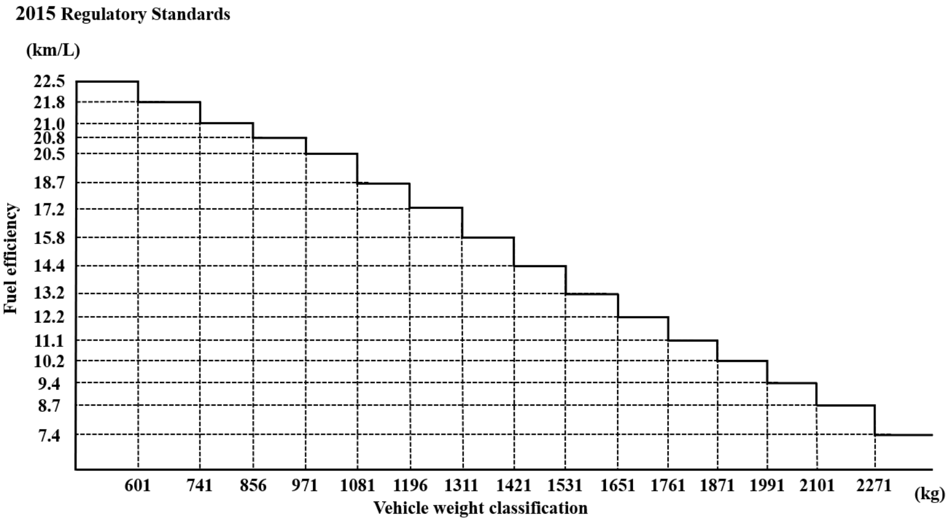

Figure A1: 2015 regulatory standards for eco-car tax incentives

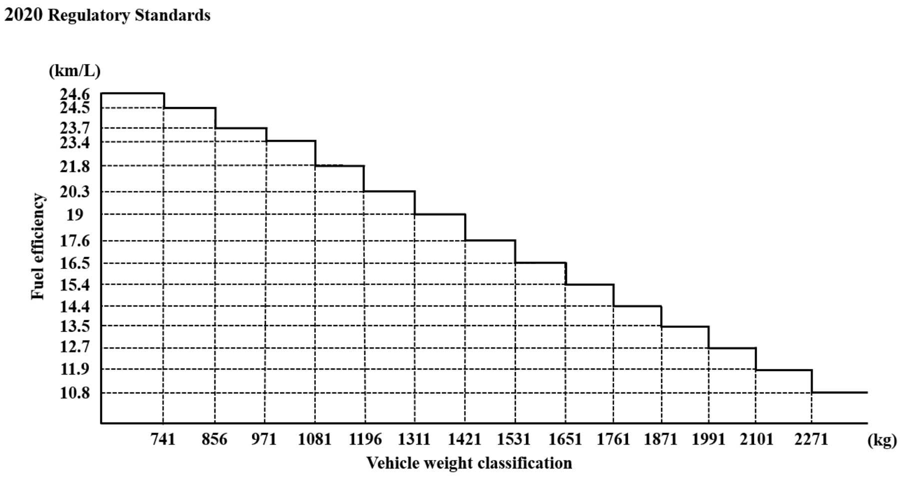

Figure A2: 2020 regulatory standards for eco-car tax incentives

Table A3: Heterogeneity in the Effect of Weight Manipulation on Relative Market Share across Fuel Economy Standards

	Dependent Variable: Log of Market Share
	(1)
2010 Fuel Standards*manipulation	1.243**
	(0.081)
2015 Fuel Standards*manipulation	-0.614**
	(0.179)
2020 Fuel Standards*manipulation	0.135
	(0.149)
carprice	-0.206***
	(0.059)
Fuel	0.0863***
	(0.003)
hppw	-3.254
	(2.849)
size	0.130***
	(0.022)
gasprice	-0.0077
	(0.0039)
subsidize	0.868***
	(0.060)
tax	0.676***
	(0.0428)
Constant	-15.121***
	(0.751)
Maker Fe	Yes
Time Fe	Yes
Underidentification Test (p-value)	0
Weak Identification Test (F-Stat)	96.38
Hansen's J statistic (p-value)	0
Anderson–Rubin test (p-value)	0

No. of Observations	28,859

Notes: The dependent variable is the log of the product's market share relative to the outside option. Heteroskedastic standard errors clustered at the vehicle level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. This table reports diagnostic tests for instrument validity. The Kleibergen–Paap LM test rejects underidentification in both IV specifications (p < 0.001), and the Kleibergen–Paap Wald F-statistics exceed the Stock–Yogo (2005) critical value for a 10% maximal IV bias, ruling out concerns about weak instruments. Although the Hansen J test indicates potential overidentification issues ($p < 0.001$), the Anderson–Rubin test confirms that the coefficient of the endogenous regressor remains statistically significant even under possible violations of the overidentifying restrictions.

Table A4: Firm-level heterogeneity in the effect of strategic weight manipulation on market share

	Dependent Variable: Log of Market Share
	(1)
Firm1*manipulation	-2.516**
	(0.117)
Firm2*manipulation	1.411***
	(0.108)
Firm3*manipulation	0.407**
	(0.111)
Firm4*manipulation	1.247**
	(0.080)
Firm5*manipulation	0.500**
	(0.061)
Firm6*manipulation	-0.381
	(0.107)
Firm7*manipulation	0.591
	(0.591)
carprice	-0.190**
	(0.062)
Fuel	0.088***
	(0.003)
hppw	-3.681
	(2.971)
size	0.129***
	(0.022)
gasprice	-0.0081

	(0.0039)
subsidize	0.887***
	(0.060)
tax	0.656***
	(0.0429)
Constant	-14.957***
	(0. 764)
Maker Fe	Yes
Time Fe	Yes
Underidentification Test (p-value)	0
Weak Identification Test (F-Stat)	137.34
Hansen's J statistic (p-value)	0
Anderson–Rubin test (p-value)	0
No. of Observations	28,859

Notes: The dependent variable is the log of the product's market share relative to the outside option. Heteroskedastic standard errors clustered at the vehicle level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. This table reports diagnostic tests for instrument validity. The Kleibergen–Paap LM test rejects underidentification in both IV specifications (p < 0.001), and the Kleibergen–Paap Wald F-statistics exceed the Stock–Yogo (2005) critical value for a 10% maximal IV bias, ruling out concerns about weak instruments. Although the Hansen J test indicates potential overidentification issues ($p < 0.001$), the Anderson–Rubin test confirms that the coefficient of the endogenous regressor remains statistically significant even under possible violations of the overidentifying restrictions.