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Eiji Satoh, Kaho Hirano, Taiga Sato,
Eiki Shimada, Ayana Sumiyoshi,
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Kakeru Yamaguchi, and Sora Yamamoto

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1 Kanayagawa, Fukushima-shi, 960-1296 Japan

Welfare impact of subsidies in oligopolistic markets: Evidence from Japan's gasoline market*

Eiji Satoh[†], Kaho Hirano, Taiga Sato, Eiki Shimada, Ayana Sumiyoshi, Satoshi Takahashi, Hiroshi Tamaki, Kakeru Yamaguchi, Sora Yamamoto

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Abstract

This study empirically examines the welfare effect of gasoline subsidies in Japan by modeling oligopolistic behavior in the gasoline market. Employing the parameters estimated by the model, we conducted a simulation analysis that incorporated the external costs associated with automobile use. The total deadweight loss in 2022 is approximately 1133.1 billion yen. This result suggests that pricing gasoline below marginal costs is inefficient because gasoline subsidies result in overconsumption and increase externality costs.

Keywords: externality, gasoline, oligopolistic markets, subsidy, welfare
JEL classifications: H25, H23, Q41, and L13

1 Introduction

Subsidizing gasoline for automobile use accelerates environmental problems. The sustained use of gasoline-powered vehicles results in worsening local air pollution and global warming, and leads to loss of life due to traffic congestion and accidents. These externalities are significant, and the current government policies that affect them should be discussed. In 2014, 16 countries subsidized gasoline (Davis, 2017). Demand for gasoline-powered vehicles is relatively inelastic, implying that the consumer surplus of automobile users is drastically reduced when gasoline prices increase sharply. Furthermore, the number of fuel producers in domestic markets is usually low, resulting in oligopolistic markets. The excessive markup arising from the exercise of market power causes producer cost inefficiency (Martin, 1988). Although higher prices might eliminate

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[†]Faculty of Economics and Business Administration, Fukushima University. Address: 1 Kanayagawa, Fukushima City, Fukushima Prefecture 960-1296, Japan. Phone: 81-(0)24-548-8452. E-mail: esatoh@econ.fukushima-u.ac.jp

overconsumption and decrease negative externalities, deadweight losses can also arise from excessive markups. With historic rises in crude oil prices beginning in October 2021, the Japanese government decided to subsidize gasoline in 2022. However, the external costs of gasoline subsidies are less emphasized in policy discussions.

This study empirically examines the welfare effect of gasoline subsidies in Japan by modeling oligopolistic behavior in the gasoline market. Employing the parameters estimated by the model, we conducted a simulation analysis that incorporated the external costs associated with automobile use. The subsidy achieved an increase in consumer and producer surpluses (671.69 and 29.519 billion yen, respectively). However, the welfare improvement sacrifices not only government expenditure (1454.6 billion yen) but also additional external costs (379.70 billion yen) caused by increased gasoline consumption. As a result, the total deadweight loss in 2022 was approximately 1133.1 billion yen. This suggests that pricing gasoline below the marginal costs is inefficient because gasoline subsidies result in overconsumption and increase externality costs.

This study extends the literature on fuel subsidies and welfare with respect to external costs. Davis (2014) estimated the economic costs of global road sector subsidies for gasoline using the long-run elasticity of transportation fuels. Coady et al. (2017) focused on global energy subsidies and estimated the social welfare changes from subsidy removal. These models are based on the price elasticity of demand, but do not consider supply side behaviors and market equilibrium. Prices under subsidy removal would not be observed prices minus subsidies but would be determined in the market equilibrium. Furthermore, a few domestic firms produce gasoline. We assume an oligopoly market based on the microeconomic foundation, according to Bresnahan (1982). Adetutu and Weyman-Jones (2019) used an econometric model based on Bresnahan (1982) to analyze fuel subsidies in 68 developing countries. Fuel subsidies in developing countries may be based for political reasons and may aim to help low-income households.

In response to the economic pain brought on by COVID-19, many countries enhanced their economic relief packages, and Japan expanded numerous subsidy programs; however, it is possible that they lost economic efficiency. For example, Honda et al. (2023) showed that business support programs prevented firm exits but also propped up firms that were not viable in the long run. Kotera and Schmittmann (2022) focused on government support cushioning the hit to labor markets and showed that job mobility decreased during the pandemic, especially among the most affected industries, and reflected fewer job openings as well as skill mismatches and the emphasis of policy support on maintaining employment. One of the subsidy programs to relieve the economic pain brought on by COVID-19 in Japan is the gasoline subsidy program. However, gasoline consumption causes external costs. We empirically examined the subsidy effect.

The remainder of this paper is organized as follows: Section 2 provides a brief overview of Japan's gasoline subsidies. Section 3 explains the theoretical model, and Section 4 presents the estimation results. Section 5 discusses the simulation analysis. Section 6 concludes.

Figure 1: Retail gasoline prices and crude oil prices, 2010-2022

Source: Oil Information Center and Agency for Natural Resources and Energy under the Ministry of Economy, Trade, and Industry.

2 Japan's gasoline market and subsidies

2.1 Overview of Japan's gasoline market

Domestic oil refiners and primary oil distribution dominate Japan's gasoline market.[1] Japan lacks significant domestic reserves and imports substantial quantities of crude oil, which is converted into gasoline in coastal refineries. Five domestic oil refiners and primary oil distributors sell their own branded gasoline at affiliated retail gas stations. In the retail gasoline market, gasoline accounted for 78.8% of oil refiners' total sales volume between July 2014 and June 2015. Therefore, Japan's gasoline market can be considered oligopolistic.

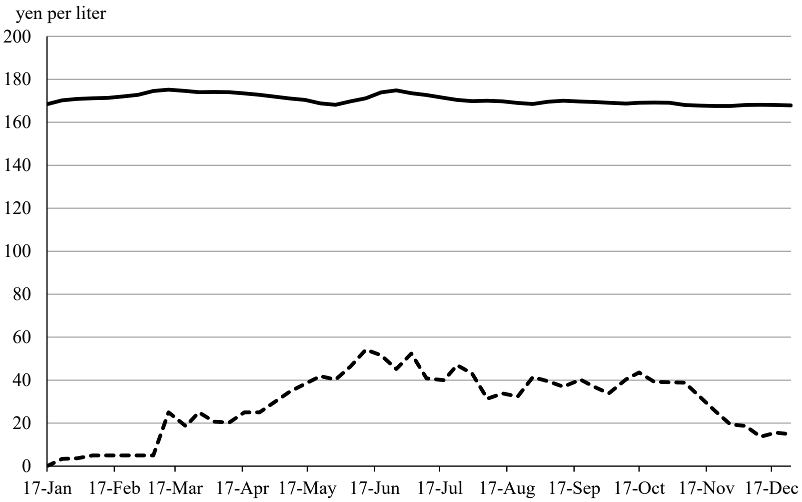
Retail gasoline prices are highly correlated with crude oil prices. Figure 1 shows the monthly average crude oil and retail gasoline prices from 2010 to 2020. From 2010 to 2019, the trend in crude oil prices was similar to that of retail gasoline prices. However, in 2020, crude oil prices sharply increased and decreased, whereas retail gasoline prices increased and decreased slightly.

2.2 Gasoline subsidies

Japan implemented a subsidy program for oil wholesalers to maintain the average retail price of gasoline at 168 yen per liter (yen/ℓ). This program intended

[1] Japan Fair Trade Commission (2016) reports practices in the gasoline industry, and the Petroleum Association of Japan (2022) oversees Japan's gasoline industry. For industry details see Japan Fair Trade Commission (2016) and Petroleum Association of Japan (2022).

Figure 2: Retail gasoline prices and subsidy in 2022



Data source: Oil Information Center and World bank.

to quickly stop the economic pain brought on by COVID-19, preventing gasoline and other fuel prices from increasing dramatically. In January 2022, the national average gasoline price exceeded 170 yen/ℓ. The government provided subsidies to oil wholesalers of up to 5 yen/ℓ from late January. In March 2022, they raised the subsidy ceiling to 25 yen/ℓ if the national average gasoline price exceeded 172 yen/ℓ. Beginning April 28, the government expanded their subsidy program. When the national average price of gasoline exceeded 168 yen/ℓ, they paid subsidies to oil wholesalers of up to 35 yen/ℓ. Furthermore, if the compensated average gasoline price exceeded 168 yen/ℓ, the subsidy was provided.

Figure 2 shows the trends in gasoline prices and subsidies in 2022, when the weekly average retail gasoline prices were mostly over 168 yen/ℓ. The price range was within 10 yen, the maximum weekly average retail gasoline prices was 175.2 yen/ℓ and the minimum was 167.6 yen/ℓ. The monthly average subsidy per liter was 22.75 yen in April and exceeded 35 yen from May.[2] From May to November, the subsidy as a percentage of prices exceeded 15%, and the subsidy substantially reduced gasoline tax to less than one-third since the gasoline tax was 53.8 yen/ℓ.

[2]Data on weekly gasoline subsidy amount is unavailable. Thus, we calculate gasoline subsidies according to the assessment method of subsidy payments by the Agency for Natural Resources and Energy (ANRE) under the Ministry of Economy, Trade and Industry (METI).

3 Theoretical model

3.1 Demand and supply

To analyze the behavior of the gasoline market in Japan, we constructed a model of the supply and demand of gasoline and estimated its parameters. Gasoline is classified into regular and high-octane gasoline, according to its octane rating. In Japan, most gas stations sell regular and high-octane gasoline but segment their markets accordingly. Thus, regular gasoline can be considered a homogeneous product.

Following Bresnahan (1982), we assume a linear demand function and marginal cost function, and the market demand function is

$$Q_t = \alpha_0 + \alpha_1 P_t + \alpha_2 X_t + u_t^D, \tag{1}$$

where Q_t is the regular gasoline consumption, P_t is the regular gasoline price, X_t is a set of exogenous variables that determine demand, and u_t^D is an error term. The marginal cost of gasoline supply is

$$MC_t = \beta_0 + \beta_1 W_t + \beta_2 S_t + u_t^S,$$

where W_t is the cost determinant S_t is the gasoline subsidy, and u_t^S is the error term.

Each firm maximizes its static profits by equating the marginal revenue to the marginal costs. The marginal revenue function is

$$MR(Q_t) = P_t + \lambda Q_t P_t',$$

where λ is an indicator of the extent to which firms can increase prices, restricting output, $0 \leq \lambda \leq 1$. This implies that the parameter should be interpreted as an indicator of market power. Using marginal revenue, we obtain the first condition that characterizes profit maximization:

$$\begin{aligned}
P_t + \lambda Q_t P_t' &= \beta_0 + \beta_1 W_t + \beta_2 S_t + u_t^S \\
P_t &= \beta_0 + \beta_1 W_t + \beta_2 S_t - \lambda Q_t P_t' + u_t^S \\
P_t &= \beta_0 + \beta_1 W_t + \beta_2 S_t - \frac{\lambda}{\alpha_1} Q_t + u_t^S. \qquad (2)
\end{aligned}$$

We then estimate Equations (1) and (2) as a simultaneous equation model.

3.2 Welfare analysis

Using the parameters estimated using Equations (1) and (2), we derive welfare implications. Our models allow us to compare the actual market equilibrium with the counterfactual market equilibrium that could have occurred if a gasoline subsidy had not been implemented. The counterfactual equilibrium generates consumer and producer surpluses, thus we can calculate the change in efficiency.

Let P^* and P^c denote the observed and counterfactual equilibrium prices, respectively, and let Q^* and Q^c denote the consumption levels corresponding to these prices. The change to the counterfactual market equilibrium in consumer and producer surpluses is given by

$$\Delta CS = (P^* - P^c)Q^c + \frac{1}{2}(P^* - P^c)(Q^* - Q^c). \tag{3}$$

and

$$\Delta PS = (P^c - MC^c)Q^c - (P^* - MC)Q^*, \tag{4}$$

where MC^c is the marginal cost under the implemented gasoline subsidy. Furthermore, gasoline consumption can lead to substantial external costs due to automobile usage. Gasoline subsidies encourage gasoline consumption, leading to substantial external costs. Therefore, the change in efficiency with no gasoline subsidy is

$$\Delta SS = \Delta CS + \Delta PS + S_t \cdot Q^* - MED \cdot (Q^c - Q^*),$$

where MED is the marginal external damage.

4 Empirical Analysis

4.1 Specification and data

We obtained the following data on gasoline prices and consumption: Gasoline price P is the monthly average regular gasoline price in Japan. The Oil Information Center was used as the data source. Gasoline consumption Q is the monthly regular gasoline sales to consumers, wholesalers, and retailers. The data was collected from the Agency for Natural Resources and Energy (ANRE) "Mineral resources and petroleum products statistics." Furthermore, the data on gasoline subsidies S were calculated according to the assessment method of subsidy payments by the ANRE.

We consider the following exogenous variables that determine demand and costs: The control variables of the demand function are $Temp$, *Traffic*, and $Covid$. Vehicle fuel economy depends on the temperature, weather, and other driving conditions. Therefore, temperature has an influence on gasoline consumption. Most drivers use their car air conditioners in summer and winter rather than in spring and autumn. This indicates a nonlinear relationship between temperature and gasoline consumption. To capture this nonlinear relationship, we constructed and estimated two specifications: (1) $Temp$ and $Temp^2$, (2) $|Temp - 20|$. The temperature, as a standard atmospheric condition defined in the fuel consumption rate test (JC08 mode), is 20°C. $Temp$ is the average monthly temperature in Tokyo. The data were sourced from the Japan Meteorological Agency. *Traffic* is daily average traffic volume on the metropolitan expressway, which is obtained from Metropolitan Expressway

Table 1: Basic statistics

Variable	Mean	Std. Dev.	Min	Max
Q	4637.0	469.77	3311.4	5767.2
P	145.65	13.996	112.58	174.60
S	2.1833	8.6320	0	49.363
$Temp$	16.519	7.6196	4.7000	29.600
$\|Temp - 20\|$	7.0359	4.5198	0	15.300
Traffic	989.35	78.126	670.44	1173.2
$Covid$	185.56	752.69	0	6173.1
$Dubai$	75.456	25.324	23.270	122.28
$Exchange$	104.63	15.098	76.720	147.16
$Wage$	100.18	1.8116	95.300	103.70

Company Limited. When traffic volume increases, traffic congestion may occasionally occur, resulting in increased gasoline consumption. $Covid$ represents the number of newly confirmed COVID-19 cases. The data source was the Ministry of Health, Labor, and Welfare (MHLW). As the number of COVID-19 cases increases, people refrain from going out, leading to a decrease in gasoline consumption.

The determinants of costs are $Dubai$, $Exchange$, and $Wage$. $Dubai$ is the monthly crude oil price obtained from the World Bank. Most crude oil in Japan is imported from the Middle East. Since crude oil prices are on a dollar basis, we add the exchange rate (yen/dollar) $Exchange$, which is from Bank of Japan. $Wage$ is contractual cash earnings indices obtained from MHLW "Monthly Labor Survey."

Table 1 summarizes their basic statistics.

4.2 Estimation results

Table 2 presents estimation results for two specifications. Both Model 1 and Model 2 use the full information maximum likelihood method to estimate Equations .(1) and (2). The difference between Model 1 and Model 2 is an explanatory variable about temperature. Model 1 uses $Temp$ and $Temp^2$, and Model 2 uses $|Temp - 20|$. The two results are nearly identical. The following discussion, therefore, focuses on the results for Model 1.

The estimation results of the demand function reveal the following. First, the coefficient of P is negative at the 1% significance level. This indicates that a higher price has a negative impact on gasoline consumption, which is consistent with consumers reducing the quantity purchased if the price increases while other demand shifters stayed fixed. Second, the coefficients of $Temp$ and $Temp^2$ are statistically significant at the 1% level. The sign of $Temp$ is negative, while the sign of $Temp^2$ is positive, implying that the relationship of temperature and gasoline consumption is convex downward and gasoline consumption is minimum at approximately 19°C as expected. Third, the coefficient of Traffic is positive

Table 2: Estimation results: demand function and pricing equation

	Model 1		Model 2	
(Demand function)		Robust		Robust
	Coef.	Std. err.	Coef.	Std. err.
P	-7.0189^{***}	(1.2273)	-7.4140^{***}	(1.1888)
$Temp$	-137.60^{***}	(27.233)		
$Temp^2$	3.6134^{***}	(0.6451)		
$\|Temp - 20\|$			55.472^{***}	(9.5758)
$Traffic$	3.4948^{***}	(0.2484)	3.3955^{***}	(0.2522)
$Covid$	-0.0273^{*}	(0.0143)	-0.0231^{*}	(0.0127)
Const.	2632.7	(428.37)	1318.3^{***}	(352.71)
Year Dummies	Yes		Yes	
Month Dummies	Yes		Yes	
(Pricing equation)		Robust		Robust
	Coef.	Std. err.	Coef.	Std. err.
Q	-0.0031^{**}	(0.0014)	-0.0030^{**}	(0.0014)
$Dubai$	0.5058^{***}	(0.0345)	0.5054^{***}	(0.0345)
$Exchange$	0.5903^{***}	(0.0619)	0.5927^{***}	(0.0618)
$Wage$	2.7972^{***}	(0.3960)	2.8061^{***}	(0.3956)
S	-0.4786^{***}	(0.0676)	-0.4802^{***}	(0.0675)
Const.	-213.65^{***}	(39.272)	-215.28^{***}	(39.105)
Year Dummies	Yes		Yes	
Month Dummies	Yes		Yes	

Notes: ***, **, and * denote significance at 0.01, 0.05, and 0.10, respectively.

and significant. This indicates that greater traffic volume on the metropolitan expressway increases gasoline consumption. Finally, the coefficient $Covid$ is negative and significant, suggesting that an increasing number of COVID-19 cases causes a decrease in gasoline consumption.

Looking at the estimation results of the pricing equation, first, coefficient Q in the pricing equation (Equation (2)) is negative at the 5% significance level. Since the estimated parameter α_1 in Equation (1) is 7.0189, the parameter λ is 0.0220, consistent with $0 \leq \lambda \leq 1$. The result implies that firms set prices close to their marginal costs. Second, the coefficient S is negative at the 1% significance level, implying that gasoline subsidies reduce marginal costs. Coefficient refers to the pass-through of subsidies to retail prices. Because the absolute value is less than 1, subsidy payments result in an incomplete decrease in retail prices. Finally, the coefficients $Dubai$, $Exchange$, and $Wage$ are all positive at the 1% significance level. This indicates that crude oil prices, exchange rates, and cash earnings increase the marginal costs.

5 Simulation Analysis

5.1 Counterfactual equilibrium

This section explores the counterfactual scenario with no gasoline subsidies. Using the results estimated from Equations (1) and (2), we calculate the counterfactual equilibrium. The following simultaneous equations can be solved to obtain price P^c and consumption levels Q^c in the counterfactual equilibrium:

$$Q_t^c = \hat{\alpha}_0 + \hat{\alpha}_1 P_t^c + \hat{\alpha}_2 X_t + \widehat{u^D}_t$$
$$P_t^c = \hat{\beta}_0 + \hat{\beta}_1 W_t - \frac{\hat{\lambda}}{\hat{\alpha}_1} Q_t^c + \widehat{u^S}_t,$$

where $\hat{\alpha}_0$, $\hat{\alpha}_1$, $\hat{\alpha}_2$ are the estimated parameters of Equation (1), $\widehat{u^D}_t$ is the residual of Equation (1), $\hat{\beta}_0$, $\hat{\beta}_1$, and $-\frac{\hat{\lambda}}{\hat{\alpha}_1}$ are the estimated parameters of Equation (2) and $\widehat{u^S}_t$ is the residual of Equation (2). Since the estimated coefficient S is negative, no gasoline subsidies would raise marginal costs, leading to higher equilibrium prices compared to observable prices. Substituting the calculated price P^c and consumption level Q^c into Equations (3) and (4), changes in the consumer and producer surpluses can be simulated.

Table 3 summarizes the estimates of the counterfactual equilibrium and changes in consumer and producer surpluses. The column labels refer to the underlying specifications listed in Table 2. Both specifications yielded similar results. The discussion below focuses on the results of Model 1.

Under the counterfactual equilibrium, the average price is higher than the actual average price in 2022. While the actual average price in 2022 is 170.53 yen/ℓ and actual average consumption is 4.2044 billion ℓ, the average price in the counterfactual equilibrium is 183.82 yen/ℓ and the average consumption is 4.1111 billion ℓ. Therefore, changing to the counterfactual market equilibrium

Table 3: Estimates of counterfactual equilibrium and welfare

	Model 1	Model 2
P (yen $/\ell$)	170.53	170.53
P^c (yen $/\ell$)	183.82	183.86
Q (billion ℓ)	4.2044	4.2044
Q^c (billion ℓ)	4.1111	4.1056
ΔCS (billion yen)	-671.69	-673.19
ΔPS (billion yen)	-29.519	-30.022
$S \cdot Q$ (billion yen)	1454.6	1454.6

Notes: Column labels refer to the underlying specifications shown in Table 2. In 2022, P^* and Q^* are the average observed values and and P^c and Q^c are the average values in the counterfactual equilibrium. ΔCS, ΔPS, and $S \cdot Q$ are the total value in 2022.

could reduce consumer and producer surpluses by 671.69 and 29.519 billion yen, respectively. Since the total subsidies for regular gasoline $S \cdot Q^*$ is 1454.6 billion yen, eliminating the gasoline subsidy would save 753.39 billion yen worth of surplus.

5.2 Externality

Gasoline consumption causes negative externalities including local and global air pollution, traffic noise, congestion, and accidents. We roughly estimated the externality costs, which decrease gasoline consumption.

5.2.1 Local air pollution

One of the toxic substances emitted by automobile exhausts is PM2.5, which has been identified as a cause of cancer. The World Bank (2022) estimated the 2019 annual cost of health damages from PM2.5 in Japan. We calculated the cost of PM2.5 from automobile use by multiplying the World Bank's estimates by the 2019 exchange rate and the ratio of PM2.5 caused by automobiles.[3] We divided the costs by the gasoline consumption in 2019 and obtained the cost per gasoline consumption. Changing to the counterfactual market equilibrium would save 70.976 billion yen from the cost of gasoline consumption of PM2.5.

5.2.2 Global air pollution

Gasoline vehicles emit carbon dioxide, causing global warming. Rennert et al. (2022) estimated that the social cost of carbon dioxide emission is \$185 per tCO2 (2020 USD). We measured the cost of carbon dioxide emission from gasoline consumption by multiplying Rennert's estimates by the 2020 average exchange rates and the automobile carbon dioxide emission factor. Thus, no

[3] The ratio of PM2.5 generated by automobiles is obtained from the 12th Meeting for Bilateral Cooperation on PM2.5, Between Japan and the Republic of Korea, 2021.

gasoline subsidies could save 51.349 billion yen from the cost of carbon dioxide emissions from gasoline consumption.

5.2.3 Traffic noise

We calculated the external cost of traffic noise as the estimated cost of noise multiplied by the population exposed to road traffic noise, based on the noise level. Tagusari and Matsui (2021) estimated the population exposed to road traffic noise in Japan in 2015. Mizutani et al. (2011) determined the approximate cost of noise by vehicular transport. We divided this external cost by the gasoline consumption in 2015 and obtained the external cost per gasoline consumption. Changing to the counterfactual market equilibrium would reduce the external cost of traffic noise by 8.4667 billion yen.

5.2.4 Traffic congestion

The Ministry of Land, Infrastructure, Transport, and Tourism uses probe data from 2012 to estimate congestion time loss in Japan. We calculated the cost of traffic congestion as the product of the congestion time loss and the contractual cash earnings per hour obtained from MHLW "Monthly Labor Survey." We divided the costs by the gasoline consumption in 2012 and obtained the cost per gasoline consumption. Changing to the counterfactual market equilibrium would save 183.16 billion yen from the cost of traffic congestion.

5.2.5 Traffic accidents

The Cabinet Office and Government of Japan (2017) reported that financial costs from traffic accidents in FY2016, excluding compensation, were 3482 billion yen. We divided the costs by the gasoline consumption in FY2016, and obtained the cost per gasoline consumption. No gasoline subsidies could save 65.747 billion yen from the external costs of traffic accidents.

5.3 Discussion

Table 4 summarizes the estimated externality costs and welfare. In our estimated externalities, the share of global warming is larger than that estimated by Mizutani et al. (2011). Improving the scientific basis and comprehensive evidence implies a higher social cost of CO2 (Rennert et al., 2022).

The change in efficiency from no gasoline subsidies could save 1133.1 billion yen. Under the counterfactual equilibrium, the average price would be higher, and average consumption would shrink. No gasoline subsidies would reduce the consumer and producer surpluses. Furthermore, the externality costs caused by lower gasoline consumption and total subsidies would be saved. While the surplus decrease is 671.69 billion yen (consumer surplus) and 29.519 billion yen (producer surplus), the surplus increases are 1454.6 billion yen (total subsidies) and 379.70 billion yen (externality costs). Therefore, gasoline subsidies result

Table 4: Estimates of externalities costs and social welfare

	Model 1		Model 2	
ΔCS	-671.69		-673.19	
ΔPS	-29.519		-30.022	
$S \cdot Q$	1454.6		1454.6	
$-MED \cdot (Q^c - Q^*)$	379.70	(100.0)	402.31	(100.0)
Local air pollution (PM2.5)	70.977	(18.7)	75.203	(18.7)
Global air pollution (CO2)	51.349	(13.5)	54.407	(13.5)
Traffic noise	8.4667	(2.2)	8.9709	(2.2)
Traffic congestion	183.16	(48.2)	194.07	(48.2)
Traffic accidents	65.747	(17.3)	69.662	(17.3)
ΔSS	1133.1		1153.7	

Notes: Column labels refer to the underlying specifications listed in Table 2. In 2022, Q^* is the average observed value and Q^c is the average value in the counterfactual equilibrium. ΔCS, ΔPS, $S \cdot Q$, and ΔSS are the total value in 2022. MED is the marginal external damage. The percentages of social costs are shown in parentheses.
Unit: billion yen

in 1133.1 billion yen in deadweight loss. This loss represents 13.15% of total regular gasoline sales and 0.203% of Japan's nominal GDP in 2022.

This suggests that pricing gasoline below marginal costs is inefficient although consumer and producer surpluses improve. When firms set prices close to their marginal costs, their low markups should not cause producer cost inefficiency. Furthermore, higher prices could eliminate overconsumption and decrease negative externalities. Unless the markups arising from the exercise of market power are significant, they could cause slight producer cost inefficiency and deadweight losses.

6 Concluding Remarks

By modeling oligopoly behavior in the gasoline market, this study empirically examined the welfare effect of Japan's gasoline subsidy. In the counterfactual scenario with no subsidies, welfare effects were calculated using a simulation exercise. The subsidy achieved an increase in consumer and producer surpluses (671.69 billion yen and 29.519 billion yen, respectively). However, the welfare improvement sacrifices not only government expenditure (1454.6 billion yen) but also additional external costs (379.70 billion yen) caused by increased gasoline consumption. Therefore, the total deadweight loss in 2022 was approximately 1133.1 billion yen. This suggests that pricing gasoline below the marginal costs is inefficient because gasoline subsidies result in overconsumption and increase externality costs.

Our study has several limitations. First, our estimated externality costs depend crucially on the estimated timing and assumptions. For example, in line with Parry et al. (2007), who found that marginal external damages are \$1.11 per gallon, externality costs caused by increased gasoline consumption would be 47.84 billion yen. Our estimated costs of traffic congestion and accidents are based on data from more than five years ago. Estimated externality costs should be based on up-to-date data. Second, our theoretical model assumes that gasoline suppliers integrate wholesalers with retailers. Retail prices depend on inventory volume, implying that price-setting laggardly reflects gasoline subsidies. Future theoretical models should construct more detailed and vertically separated gasoline markets.

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