DISCUSSION PAPER

June 2008 ■ RFF DP 08-15

Economic Analysis of a Japanese Air Pollution Regulation

An Optimal Retirement Problem under Vehicle Type Regulation in the NO_x–Particulate Matter Law

Kazuyuki Iwata and Toshi H. Arimura

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

Economic Analysis of a Japanese Air Pollution Regulation: An Optimal Retirement Problem under Vehicle Type Regulation in the NO_x–Particulate Matter Law

Kazuyuki Iwata and Toshi H. Arimura

Abstract

This paper empirically examines the vehicle type regulation that was introduced under the Automobile Nitrogen Oxides–Particulate Matter Law to mitigate air pollution problems in Japanese metropolitan areas. The vehicle type regulation effectively sets various timings of vehicle retirement by the first registration year and by type. However, there was no consideration of cost or efficiency in choosing the timing of retirement. We set and solve an optimal problem to maximize the social net benefit under the current framework of the vehicle type regulation. The analysis finds that the net benefit can increase by about 104 percent if the optimal retirement timing is chosen. Further, we confirm that even a simple alteration of retirement timing can increase the social net benefit by 13 percent. Thus, we confirm the importance of an ex-ante quantitative policy evaluation, a regulatory impact analysis, from the viewpoint of efficiency.

Key Words: air pollution, regulatory impact analysis, NO_x-PM law, cost–benefit analysis, optimal retirement model

JEL Classification Numbers: Q52, Q53, Q58

Contents

Economic Analysis of a Japanese Air Pollution Regulation: An Optimal Retirement Problem under Vehicle Type Regulation in the NO_x–Particulate Matter Law

Kazuyuki Iwata and Toshi H. Arimura [*]

1. Introduction

To mitigate air pollution in Japanese metropolitan areas, a variety of pollution regulations have been placed on stationary sources, such as facilities, and on mobile sources, such as automobiles. As a result, emission of sulfur dioxides has successfully been reduced. However, levels of nitrogen oxides (NO_x) did not improve through the 1980s. The increasing emissions from mobile sources were said to be a major reason. In response, in June 1992 the Japanese government introduced the Automobile NO_x Regulation Law to control automobile emissions.[1] This law targeted the metropolitan areas of Tokyo, Nagoya, and Osaka, which were designated as nonattainment areas.

Despite these efforts, the concentration of NO_x in metropolitan areas still did not improve in the 1990s. Among the roadside air pollution monitoring stations in the nonattainment areas, only 43 percent met the national ambient air quality standard for NO_x in 1998. The achievement of the environmental standard for particulate matter (PM) was even worse. Only 36 percent of the roadside air pollution monitoring stations achieved the ambient air quality standard for PM in 1998. The reason for these failures is considered to be the heavy usage of diesel trucks.

---

[*] Kazuyuki Iwata is a Ph.D. Candidate of Graduate School of Economics, Sophia University, Tokyo, Japan; and a Research Fellow of Japan Society for the Promotion of Science. Toshi H. Arimura is a Visiting Scholar of Resources for the Future, Washington, DC; a Visiting Associate Professor of George Mason University, Fairafx, Virginia; and an Assosiate Professor of Sophia University, Tokyo, Japan. We thank the Ministry of Internal Affairs and Communications for providing the data on vehicle registration. Kazuyuki Iwata is grateful for the financial support from Sonpo Japan Environmental Foundation for an earlier version of this project. Toshi H. Arimura appreciates financial support from the Economic and Social Research Institutes, Cabinet Office, Government of Japan, and for logistical support from the Kansai Institute for Social and Economic Research for an earlier version of this project. Toshi H. Arimura also thanks the Abe Fellowship. We appreciate comments from Yoshitsugu Kanemoto, Atsuo Kishimoto, Winston Harrington, Hibiki Akira, and seminar participants at Resources for the Future, the University of Tokyo, the Tokyo Institute of Technology, and APPAM.

[1] The official name of the law is "the Law concerning special measures for total emission reduction of Nitrogen Oxides from automobiles in specified areas."

Given these situations, the Automobile NO_x-PM Law (NO_x-PM Law),[2] a revised version of the Automobile NO_x Regulation Law, was legislated in 2001. This new law is intended to decrease the concentration of PM as well as NO_x in the nonattainment areas.

The NO_x-PM Law has a provision called the *vehicle type regulation*. The vehicle type regulation prohibits the use and registration of automobiles in the nonattainment areas, after certain grace periods, unless the automobiles satisfy the 2005 emissions standard, which is defined in the law. The 2005 emissions standard is more stringent than previous standards.[3]

The NO_x-PM Law is unique in enforcing the regulation on vehicles currently used. Most regulations on vehicles are enforced on newly sold vehicles; those already used by consumers or industries are exempted. For example, under earlier laws, stringent emissions standards were applicable only to new cars; owners of old vehicles with more polluting emissions intensity did not receive any penalty for using their older dirty vehicles. The regulation is called vehicle type regulation because the timing of the ban depends on vehicle type and the first registration year. For instance, a standard-size diesel truck newly registered in 1989 was banned in the nonattainment area in 2004, whereas a diesel passenger car newly registered in the same year could be used until 2005.

How was the timing of ban determined? The Ministry of Internal Affairs and Communications conducts regulatory impact analyses in Japan. An ex-post evaluation of the NO_x-PM Law by the Ministry reveals that there were no cost estimates of the regulation.[4] Thus, the timing of the ban for each vehicle type for each registration year was chosen without any analysis of cost or efficiency.

The vehicle type regulation exhibits an example of a command-and-control approach toward air pollution problems. Economic theory predicts that command-and-control regulations do not necessarily maximize the social welfare since there is no price mechanism to promote

---

[2] The official name of the law is "the Law concerning special measures for total emission reduction of Nitrogen Oxides and Particulate Matter from automobiles in specified areas" (revised June 2001). The Ministry of the Environment in Japan made a second revision of the NO_x-PM law in 2007 to solve the problems of high local pollution and of inflow vehicles from attainment areas.

[3] For instance, the emissions standard of diesel trucks of weight from 1.7 tons to 2.5 tons under the new law is 0.63 g/km for NO_x and 0.06 g/km for PM.

[4] One of the authors was involved with the Japanese government's ex-post evaluation of the NO_x-PM law (MIC 2006). The evaluation confirmed that there was no ex-ante and ex-post evaluation of the policy from the viewpoint of efficiency.

efficiency among polluters. On the other hand, economic theory claims that economic incentives such as a pollution tax can maximize the social welfare. However, the introduction of such a tax often is politically infeasible. Even if a tax can be introduced, the amount of the tax often is much lower than the marginal externality cost (MEC), which is necessary to maximize the social welfare.

This study proposes a third avenue. We examine the degree to which a regulator can increase social welfare by conducting a careful ex-ante regulatory impact analysis of alternative regulations. Although Arimura and Iwata (2008) found that the benefit of the current vehicle type regulation exceeds the cost, Arimura and Iwata (2006) found that there are deviations in marginal abatement cost across polluters. They imply that an alternative regulation could have achieved better social welfare just by adopting different enforcement timing. In this study, we examine how changes in years of ban for each vehicle type can increase the social welfare. Thus, we restrict the scope of the study to practical alternative command-and-control type regulations.

Several studies have examined the retirement of old vehicles as air pollution control policy. Lumbreras et al. (2008) show, with their simulation, that the renewal of old vehicles is an efficient way, among other regulations, of controlling air pollution problems. Other studies such as Dill (2004) and Alberini et al. (1995, 1996) examined voluntary retirement programs. This paper is the first study to examine a compulsory retirement program.

Section 2 outlines the vehicle type regulation with its background. This is followed in Section 3 by the model component estimating the cost of the regulation. Section 4 illustrates the model to measure the emissions reduction benefit due to the regulation. The solution to an optimizing problem is described with discussion in Section 5, and Section 6 concludes the paper.

2. Background of the NO_x-PM Law and the Compliance Methods

The NO_x-PM Law in Japan is unique in enforcing earlier replacement of older vehicles with new vehicles compliant with the new stringent emissions standards. The law sets the 2005 emissions target, the most stringent emissions vehicle standard for NO_x and PM to date. More importantly, after a grace period the regulation bans the use and the registration of older vehicles in the nonattainment areas unless they satisfy the 2005 emissions standard. For example, standard trucks initially sold in 1990 cannot be registered after 2005.

The timing of a ban depends on vehicle type. First, vehicles are divided into the following categories: trucks, buses, special-use vehicles, and passenger cars. Second, each category is divided into standard size and small size. Finally, passenger vehicles are divided into two groups depending on the frequency of legally required inspections; some passenger cars must be inspected every year while most passenger cars must be inspected every two years. Thus, vehicles are categorized into 10 types.

In addition, the timing of a ban depends on the first registration year. Vehicles registered before 2003 face the ban unless they satisfy the 2005 emissions target. Table 1 shows the terminal years for 10 vehicle types for each registration year.

Owners of old vehicles have several alternatives as compliance methods. First, the owners can just retire their old cars without a replacement. Surveys by the Japan Automobile Manufacturers Association (JAMA) (2005a, 2005b) found that only a few vehicle owners chose retirement for trucks. Second, they could replace their old vehicles with new ones complying with the stringent emissions standard. JAMA (2005a, 2005b) found that most of the truck owners chose to purchase the same type of new vehicles in response to the regulation. Thus, this paper focuses on the replacement with new vehicles of the same type as the compliance method.

Notably, diesel trucks are the most affected by vehicle type regulation under the NO_x-PM Law. Figure 1 illustrates the transition of the emissions standards for passenger cars and diesel trucks. While gasoline passenger vehicles have had to satisfy relatively stringent emissions targets for years, diesel trucks and passenger cars have faced less stringent emissions targets until recently. Even in the late 1990s, there was a still gap between gasoline vehicles and diesel vehicles in the stringency of the regulation. Thus, most old trucks must be replaced with new trucks. On the other hand, a relatively small share of passenger vehicles must be replaced because the emissions standards for passenger cars were already stringent in the later 1990s.

3. Cost of the Regulation

Following the discussion above, we focus on replacement with new vehicles as the compliance method. We compute the cost of the regulation in the following steps. First, for each registration year and each vehicle type, we identify how many vehicles are facing the replacement requirement. Second, we calculate the cost of the regulation per vehicle type. Finally, we sum costs over years and vehicle types.

3.1 Identification of Regulated Vehicles

We used the *Survey of Automobile Possession* (SAP)[5] by the Automobile Inspection and Registration Association to obtain information on the registered vehicles in March 2003. In SAP, about 3.9 million vehicles excluding gasoline passenger cars were identified in nonattainment areas. For each vehicle, we checked vehicle type and registration year. Further, we verified if the emissions intensity of each registered vehicle met the 2005 standards. If not, the car is subject to the regulation. Table 2 shows the number of vehicles facing the retirement requirement for each vehicle type in the nonattainment areas in 2003. The total number is approximately 2.6 million vehicles.

3.2 Compliance Cost per Vehicle

The compliance cost due to the regulation can be defined as the difference between the cost with and without the regulation. Figure 2 illustrates the effects of the regulation on vehicle owners. Without the regulation, a type m vehicle could be used for average life of L_m years. The regulation, however, enforces the replacement at year T_{rm} for a type m vehicle with the first registration year r. The regulation shortens the life of the vehicle by Y_{rm}, which we refer to as *reduced years*. Because the reduced year is a function of T_{rm} and L_m, we denote it as $Y_{rm}(T_{rm}, L_m)$. Under the current regulation, timing of replacement T_{rm} is defined as in Table 1. This study changes T_{rm} to maximize the net benefit of the regulation.

In estimating the cost of the regulation, we use the framework by Oka et al. (2007). The surveys by JAMA (2005a, 2005b) reveal that most owners do not change the vehicle type when replacing. Thus, we can safely assume that vehicle users do not change the vehicle type. Further, we assume that the vehicle prices are constant over time in spite of the regulation.

We expand the approach of Oka et al. (2007) by adding profit from the sales of the affected vehicles. The owners of vehicles can sell their vehicles to used car markets in attainment areas when they face the enforced retirement in the nonattainment areas. The regulation enforces the vehicle owners to sell their vehicles earlier than otherwise by the years of shortening. This early sale of used vehicles increases the profit because newer cars have higher values in the market. Therefore, we can define the compliance cost as the difference between the additional replacement cost and the additional profit on sale.

[5] This is an official record of vehicle registration used for tax purposes.

First, we define the replacement cost. We calculate the compliance cost at the timing of the replacement. Let P_{mw} be the purchasing price of vehicle type m with weight w. We have information on weight w because vehicle prices differ by weight even for the same vehicle type. Following Oka et al. (2007), we assume that prices do not change over time. With the regulation in place, the replacement cost is equal to the price of the new vehicle, P_{mw}, at the time of the replacement. The replaced vehicle, however, would have been used for $Y_{rm}(T_{rm}, L_m)$ more years if it were not for the regulation. Let i denote the interest rate. Then the replacement cost without the regulation, evaluated at the time of the ban, is the discounted present value of a new vehicle price, that is, $P_{mw}\exp(-i \times Y_{rm})$. Hence, the replacement cost $Cr_{rmw}^{T_{rm}}$ of type m vehicle that is banned in year T_{rm} is expressed as

$$Cr_{rmw}^{Trm} = P_{mw}\left[1 - \exp\{-i \times Y_{rm}(T_{rm}, L_m)\}\right] \tag{1}$$

Second, we define the profit from the sales to the used car market. The vehicle owners sell their old vehicles to used car markets $Y_{rm}(T_{rm}, L_m)$ years earlier with the regulation than without the regulation. As there is generally a negative correlation between vehicle price and age, owners gain the profit on sale by selling them with the regulation. Thus, we use the yearly average depreciation rate sr_m of vehicle type m provided by Kuroda et al. (1997) to incorporate the relation between vehicle price and age into our model. For example, they reveal that the yearly average depreciation rate of a standard truck is 25.7 percent. The difference between the profit on sale with and without the regulation, $Cs_{rmw}^{T_{rm}}$, evaluated at the time of ban T_{rm} can be calculated by using equation (2).

$$\begin{aligned} Cs_{rmw}^{T_{rm}} = {} & P_{mw}[\exp\{-sr_m \times (T_{rm} - r)\} \\ & - \exp\{-sr_m \times (T_{rm} + Y_{rm}(T_{rm}, L_m) - r)\} \times \exp\{-i \times Y_{rm}(T_{rm}, L_m)\}] \end{aligned} \tag{2}$$

The first and second terms in the brackets represent the profit on the sale of old vehicles evaluated at the time of ban with and without the regulation, respectively.

The compliance cost $C_{rmw}^{T_{rm}}$ is the difference between the replacement cost $Cr_{rmw}^{T_{rm}}$ and the profit on sale $Cs_{rmw}^{T_{rm}}$. Thus, it can be defined as the following equation:

$$C_{rmw}^{T_{rm}} = Cr_{rmw}^{T_{rm}} - Cs_{rmw}^{T_{rm}} \tag{3}$$

The calculation of the compliance costs in equations (1) and (2) requires the average life remaining of vehicles L_m when there is no regulation. We estimated L_m by using 2000 vehicle registration data to exclude the influence of the NO_x-PM Law, which was legislated in 2001. The results are shown in Table 3. The procedure is detailed in the appendix.

From Tables 1 and 3, we can obtain reduced years Y_{rm} under the current NO_x-PM Law. Table 4 exhibits the reduced years under the current vehicle type regulation. For instance, with the current regulation standard trucks registered in 1990 can be used until 2005, when the vehicle is 15 years old. The average life remaining for 15-year-old standard trucks is 4.84 years, which is the reduced year for the standard truck registered in 1990.

Truck prices by capacity load are collected from Japan Trucking Association (2004). Prices of passenger cars are obtained from the Japan Automobile Dealers Association (2000) for each vehicle type by taking sample means of each make.

3.3 Number of Replaced Vehicles

Table 2 identifies the number of vehicles in 2003 that did not comply with the 2005 emissions standard. However, some of them will not be affected by the vehicle type regulation for two reasons. First, some vehicles would be replaced before they face the terminal years due to other reasons such as mechanical failure or accidents as a natural part of the replacement process. We refer to this replacement as *natural replacement*.

Let $N_{rmwj}^{T_{rm}}$ represent the number of type m vehicles at T_{rm} in region j. Let the survival rate of a k-year-old vehicle be $s_m(k)$. Then, following the process of natural replacement, $N_{rmwj}^{T_{rm}}$ can be counted as follows:

$$N_{rmwj}^{T_{rm}} = N_{rmwj}^{2003} \times s_m(T_{rm} - r) / s_m(2003 - r) \tag{4}$$

For example, in 2003 there were 581,192 standard trucks with the first registration year of 1990 in nonattainment areas that were not compliant with the 2005 emissions standard. By the time they faced the ban in 2005, however, 70,949 of them would have been replaced as the result of the natural replacement process. Thus, only 510,243 vehicles would face the ban in 2005.

Second, a small portion of vehicle owners retire their vehicles without buying another vehicle when they face the registration ban by the vehicle type regulation. We use repurchasing rate rp_{mj} to capture the share of the vehicles to be replaced, that is, $(1 - rp_{mj})$ portion of vehicles are retired due to the regulation. Then, the number of vehicles replaced due to the regulation $NR_{rmwj}^{T_{rm}}$ can be defined as follows:

$$NR_{rmwj}^{T_{rm}} = rp_{mj} \times N_{rmwj}^{T_{rm}} \tag{5}$$

To capture regional differences, we computed rp_{mj} by region for each vehicle type from JAMA (2005a, 2005b). Because JAMA (2005a, 2005b) provide the information on small and standard trucks only, we assume that the repurchasing rates for buses and special-use vehicles are same as trucks and that the rates for passenger vehicles are equal to one.

3.4 Calculation of Total Cost

We calculate the compliance cost for each vehicle type, region, first registration year, and weight by year. Then, we sum the compliance cost over these components and compute the discounted present value of the cost evaluated at year 2004. Following a previous study, we assume that all the vehicles are retired after 21 years.[6] Thus, all the vehicles sold before the stringent emissions standard will be retired by 2024. Thus, total cost TC is defined as

$$TC = \sum_{t=2004}^{2024} \exp\{-i \times (t-2004)\} \sum_r \sum_m \sum_j \sum_w C^t_{rmw} \times NR^t_{rmwj} \tag{6}$$

We use a discount rate of 3 percent to calculate the total cost of repurchasing vehicles. The total cost of the current regulation was 521 billion yen.

3.5 Discussion of Cost Estimates

We would like to make some remarks on our cost estimates. First, our analysis does not include the maintenance cost in the calculation. Due to data limitations, we could not incorporate this point. If the maintenance cost rises as the vehicle ages, replacement of old vehicles will reduce maintenance costs (Spitzley et al. 2005). Thus, our cost may overestimate the true cost.

Second, some freight companies possessing multiple vehicles may use newer cars more often than older vehicles (Nomura 2002). Thus, if the owners replace their old vehicles with new ones, they are more likely to use newer vehicles, which have higher fuel economy than older ones. Thus, the operation cost becomes smaller when older vehicles are replaced. Due to the data restrictions, this aspect of the regulation was also not incorporated in the analysis. Again, there is a possibility of overestimation.

Finally, our analysis did not incorporate replacement with a used car as a compliance method because the price of used vehicles is unavailable. JAMA (2005a, 2005b) finds that the share is small. In this analysis, we assumed that all users replace their old vehicle with a new vehicle. However, they have the option of purchasing approved used vehicles. Since the prices of

[6] According to an interview with JAMA, this assumption is appropriate in Japan.

used vehicles are smaller than new ones, our calculation of the cost may overestimate the true cost.

Overall, if there is any bias in our estimate of the cost, our estimates are likely to overestimate cost. We believe that the amount of bias is limited.

4. Benefit: Health Benefit Due to the Emissions Reduction

As the benefit of the regulation, we estimate the health benefit due to the emissions reduction. To obtain the emissions reduction, we compute the emissions with and without the regulation. We must convert vehicle numbers to the emissions through the numbers of kilometers driven. We use the following equation to estimate emissions:

$$\text{Emissions}(g) = (\text{Emissions Intensity})(g/km) \times (\text{Mileage})(km/vehicle) \times (\text{Vehicle Numbers}) \quad (7)$$

Note that the vehicle type regulation reduces the emissions intensity. We estimate emissions by vehicle type, weight, and fuel type since the emissions intensities depend on all three of these factors.

We expand the model introduced in Arimura and Iwata (2008). More specifically, we change vehicle mileage depending on vehicle age. We use the adjusted rate of vehicle mileage to incorporate this assumption.

4.1 Emissions without the Regulation

First, as a baseline, we compute the emissions without the vehicle type regulation. Emissions standards for new vehicles have become more stringent over the years. Therefore, even without the vehicle type regulation, emissions will decrease due to the natural replacement process; older vehicle are replaced with newer ones that have lower emissions intensities.

We use e_{0mwf} to denote emissions intensity for type m vehicle with weight w and fuel type f (gasoline or diesel) that complies with the 2005 standard. Likewise, we use e_{rmwf} to refer to emissions intensity initially registered in year r, that is, emissions intensity for older vehicles, and thus, $e_{0mwf} < e_{rmwf}$ for the same type, weight, and fuel. Further, D_{mj} is used to denote mileage per vehicle in region j for vehicle type m. Then, without the regulation, emissions from type m vehicle with weight w and fuel type f in year t, $E^t_{o,rmwfj}$, can be computed as follows:

$$E^t_{o,rmwfj} = e_{rmwf} \times N^t_{rmwfj} \times D_{mj} + e_{0mwf} \times \left(N^{2003}_{rmwfj} - N^t_{rmwfj}\right) \times D_{mj} \quad (8)$$

Here N^{t}_{rmwfj} is the number of older vehicles still used in year t. Thus, the first term represents emissions from the existing older vehicles. In contrast, the term $N^{2003}_{rmwfj} - N^{t}_{rmwfj}$ represents the number of older vehicles being replaced with new ones due to natural replacement. Thus, the second term represents the emissions from newer vehicles.

4.2 Emissions with the Regulation

Emissions with the regulation, $E^{t}_{h,rmwfj}$ from type m vehicle with weight w and fuel type f in year t, are defined in equations (9a) and (9b). As equation (9a) represents annual emissions before all older vehicles face the registration ban, it is equivalent to (8). Equation (9b) represents annual emissions after the older vehicles are completely replaced with new ones. Thus, the emissions intensities used in (9b) are now e_{0mwf} only.

$$E^{t}_{h,rmwfj} = \left[e_{rmwf} \times N^{t}_{rmwfj} + e_{0mwf} \times \left(N^{2003}_{rmwfj} - N^{t}_{rmwfj}\right)\right] \times D_{mj} \qquad if \;\; T_{rm} > t \tag{9a}$$

$$E^{t}_{h,rmwfj} = \left[e_{0mwf} \times NR^{T_{rm}}_{rmwfj} + e_{0mwf} \times \left(N^{2003}_{rmwfj} - N^{T_{rm}}_{rmwfj}\right)\right] \times D_{mj} \times dr^{t}_{rmwfj} \qquad if \;\; T_{rm} \leq t \tag{9b}$$

Note that dr^{t}_{rmwfj} denotes the adjusted rate of vehicle mileage of vehicle type m with weight w and fuel type f in region j in year t. We need this term for the following reason.

Our model considers two compliance methods. The first method is to repurchase new vehicles and sell old ones. The second one is to dispose of old vehicles without repurchasing new ones. Therefore, the total number of vehicles in nonattainment areas will decrease due to the second compliance method. If we assume the mileage for each regulated vehicle is constant over time in the model, the adoption of the second compliance method decreases the total number of miles driven in the nonattainment areas. It is unlikely, however, that travel demand decreased because of the regulation. To handle this problem, in equation (10) we incorporate a constraint that the total number of miles driven is constant. That is, we increase mileage per vehicle as the number of vehicles decreases so that total vehicle mileage is constant over time.

Let $\overline{TD}_{rmwfj}$ represent the constant total amount of vehicle mileage. As we assume that $\overline{TD}_{rmwfj}$ is constant over time, dr^{t}_{rmwfj} varies subject to equation (10). The number of regulated vehicles after and before the timing of ban T_{rm} are described as $N^{2003}_{rmwfj} - N^{T_{rm}}_{rmwfj} + NR^{T_{rm}}_{rmwfj}$ and N^{2003}_{rmwfj} in equation (10), respectively. Therefore, the first and second equations in the right hand side of equation (10) represent the total amount of vehicle mileage after and before the banned year, respectively.

$$\overline{TD}_{rmwfj} = D_{mj} \times dr^{t}_{rmwfj} \times (N^{2003}_{rmwfj} - N^{T_{rm}}_{rmwfj} + NR^{T_{rm}}_{rmwfj}) \quad ,if\ T_{rm} \leq t$$
$$= D_{mj} \times N^{2003}_{rmwfj} \quad ,if\ T_{rm} > t \tag{10}$$

Since we choose T_{rm} to maximize the social net benefit, the timing of switching from (9a) to (9b) changes. If the ban comes earlier (T_{rm} becomes smaller), then the switching speeds up and so does the emissions reduction.

4.3 Emissions Reduction

In year t, the emissions reduction from vehicle type m registered in year r with weight w and fuel type f in region j, ER^{t}_{rmwfj}, is

$$ER^{t}_{rmwfj} = E^{t}_{o,rmwfj} - E^{t}_{h,rmwfj} \tag{11}$$

Thus, the emissions reduction in year t is given by summing equation (11) over the registration year, vehicle type, weight, fuel type, and region.

$$TER^{t} = \sum_{r}\sum_{m}\sum_{w}\sum_{f}\sum_{j} ER^{t}_{rmwfj} \tag{12}$$

We obtain mileage data from the Ministry of Land, Infrastructure, Transport and Tourism (2001) for each area. The emissions coefficient information is taken from Suri-Keikau Inc. (2005) by fuel type, vehicle type, regulation adoption year, and emissions intensity by speed for both NO_x and PM.

4.4 Health Benefit: Externality Benefit

To convert the emissions reduction into a monetary value, we use estimates from the literature. Table 5 exhibits the MEC estimates we use in our analysis. Koyama and Kishimoto **(**2001) estimate the median MEC of PM in Japan and show the upper and lower bounds of their estimates.

For the benefit of NO_x reduction, we use estimates from the European Union (NETCEN 2002) because to our knowledge there is no appropriate study in Japan. The study reports the MEC of NO_x in 15 European Union countries. Considering the high population density in Japan, we use the mean of the 15 countries as the lower bound of the estimates and use the highest value as the upper bound. We took the average of the upper and lower bounds as the median estimates for the MEC. In response to Viscusi and Aldy’s (2003) comment that estimates on the value of statistical life vary across studies, we also run the model with lower and upper bounds of the health benefit.

We use MEC^p to represent the average MEC for pollutant p (NO_x or PM). We assume a constant externality cost of the health problem. Then, the present discount value of the benefit of the emissions reduction TB, evaluated in 2004, is defined as follows:

$$TB = \sum_{t=2004}^{2024} \exp\{-i \times (t-2004)\} \sum_p [MEC^p \times TER^{t,p}_{rmwfj}] \tag{13}$$

We close this section with a discussion on the direction of potential bias in the benefit estimations. On one hand, the externality cost is likely to be smaller as the air becomes cleaner. In this regard, our estimates may overestimate the health benefit since we assume a constant MEC. This overestimation, however, becomes relevant in the future. Thus, in terms of the present discount value, the size of the overestimation is expected to be small.

On the other hand, our model does not incorporate any benefit of the emissions reduction other than a health benefit. For instance, reduction in PM is likely to improve visibility. From this viewpoint, our analysis may underestimate the benefit of the emissions reduction. Because we expect the size of the visibility benefit to be much smaller than the health benefit, we expect the bias in benefit estimates to be small.

5. Simulation of Alternative Policies

5.1 Optimal Retirement Model

Using the cost and benefit equations specified above, we set an optimal problem to maximize the social net benefit. We change the final year of vehicle usage T_{rm} to see how the net benefit changes. Figure 3 illustrates the structure of the model. The reduced year Y_{rm} is a function of T_{rm} and L_m, where T_{rm} is the final year of usage of the vehicle initially registered in year r and L_m is the average life of the vehicle for type m. Changing T_{rm} will change the timing of the replacement, which changes both the replacement cost $Cr^{T_{rm}}_{rmw}$ and the profit on sale $Cs^{T_{rm}}_{rmw}$ in (1) and (2), respectively. Further, it will change NR.

Changes in T_{rm} will also change the benefit of the regulation. First, it will change the timing that the old emissions intensity e_r in year r turns to the new emissions intensity e_0. This change of the emissions intensity will change the emissions with regulation $E^{t}_{h,rmwfj}$ and, in turn, will affect the emissions with the regulation and emissions reduction TER^t.

In this study, there are 10 vehicle types (m) and 19 years of registration period (r) subject to the regulation. Thus, there are 190 parameters (T_{rm}) from which to choose to maximize the net benefit under the current policy framework. The optimization problem is defined as

$$\underset{T_{rm}}{MAX}\{TB - TC\} \tag{14}$$

where TB and TC are defined in equations (13) and (6), respectively. The solution of the optimization with the point estimate of MEC is defined as optimal regulation (point estimate).

5.2 Result of Optimal Regulation (Point Estimate)

Table 6 exhibits the optimal retirement timing by vehicle type and registration years. We can point to the following findings. First, the simulation shows that most trucks should be replaced in 2004. This result comes from the fact that most diesel trucks have a high emissions intensity due to the lack of stringent emissions standards for diesel trucks (see Figure 1). Second, the model shows that old passenger vehicles should be exempted from the vehicle type regulation, while the optimal solution prohibits using newer passenger vehicles in 2004. This solution reflects the fact that the health benefit achieved from discarding newer vehicles is relatively larger than the cost because owners can sell them in used car markets at a high price.

Figures 4 and 5 show the emissions trajectories with the current regulation and with the optimal regulation. The emissions path without any regulation is also shown as a reference case (the triangle mark). Both emissions trajectories decline over time even without the vehicle type regulation because of the natural replacement process. The emissions under the current vehicle type regulation are marked as the square. The regulation accelerates the decline of the emissions. Our simulation shows that the emissions (marked by empty circles) should be reduced much faster than under the current regulation for both NO_x and PM.

The optimal regulation increases the net benefit dramatically. As the base case, we can compute the net benefit of the current regulation by using the current terminal years shown in Table 1. The resulting net benefit of the current regulation is 681.2 billion yen. With the optimization, the net benefit is 1,388.5 billion yen. Thus, it can increase the net benefit by more than 104 percent.

5.3 Uncertainty of Marginal Externality Cost

We showed one result of optimal regulation with a point estimate of MEC in the previous subsection. In the literature, the estimate of MEC is known to have much uncertainty. To account for the uncertainty, we solve the optimization problem with other MEC estimates by using a sensitivity analysis. In particular, we solve two optimization problems with the lower and upper bound estimates of MECs. Tables 7 and 8 describe the solutions of T_{rm} in the lower and upper bound estimates, respectively.

The final year of vehicle usage T_{rm} under the lower bound estimate persuades us to exempt older passenger vehicles and to accelerate the ban on using trucks. This result is similar to the point estimate.

We observe two differences from the results with the point estimate of MEC. First, the first registration years of exempted passenger vehicles changes. Second, some of the small older trucks are exempted from the vehicle type regulation. Figures 4 and 5, which illustrate the NO_x and PM emissions trajectories, also show that the pattern of both trajectories on lower bound estimation is close to the point estimate.

The optimal retirement timing under the upper bound estimate shows that it is efficient to exempt older passenger vehicles and to accelerate the banned timing of trucks. This result is also similar to the solutions with point and lower bound estimates. The first registration year of exempted passenger vehicles differs from the previous two optimal estimates. Under the upper bound estimate, the solution also suggests that it is preferable to accelerate emissions reduction more than the current regulation (Figures 4 and 5).

Increases in the social net benefit from the current regulation under the lower and upper bound estimates are described in Table 9. As the increases are 526.6 and 895.9 billion yen with the lower and upper bounds of MEC, respectively, we can conclude that the increase in social net benefit is huge whenever any MECs are used.

5.4 Robustness Check on Optimal Regulation

We made several assumptions in estimating the net benefit. These assumptions may affect our solution of the optimization problem and hence the estimates of the net benefit. Thus, in this subsection, we verify how the increase in social net benefit changes when we change the assumptions. If we could find that the social net benefit increases with alternative assumptions, we could robustly point out an important role of a regulatory impact analysis to improve the efficiency of command-and-control regulation.

Here we change three assumptions about the profit on sale $Cs_{rmw}^{T_{rm}}$, the repurchasing rate rp_{mj}, and the interest rate i. First, owners of regulated vehicles do not sell their old vehicles in used car markets (this means that $Cs_{rmw}^{T_{rm}} = 0$). Second, all owners repurchase the same type of new vehicles ($rp_{mj} = 1$). Third, the interest rate is 7 percent rather than 3 percent.

5.4.1 First Case: $Cs_{rmw}^{T_{rm}} = 0$

Our estimation model assumes that there is no profit on the sale of older vehicles. In other words, owners are assumed to dispose of their older vehicles without selling them in used car markets when they repurchase new vehicles. Thus, in calculating compliance cost we use only equation (1), and the total cost is larger than previous results.

The optimization problems are solved with point, lower bound, and upper bound estimates of MEC. Results are shown on the top row of Table 10. The optimal retirement timing under the point estimate is 357.5 billion yen, an extensive increase in social net benefit. With both cases of the lower and upper bound estimates we can also recognize that the increases are large enough to justify the ex-ante regulatory analysis.

5.4.2 Second Case: $Cs_{rmw}^{T_{rm}} = 0$ and $rp_{mj} = 1$

In the second case, we consider that all owners choose to repurchase new vehicles as a compliance method. In addition, we assume that there is no profit on the sale of the older vehicles. This second case scenario generates the largest regulation cost.

The middle row of Table 10 exhibits the net benefits resulting from the optimization problems with the point, lower, and upper bound estimates. Again, the optimal policy can increase the social net benefits with any of the three estimates of MEC.

5.4.3 Third Case: i = 7 Percent

The choice of interest rate affects both the cost and benefit. Thus, to examine the effects of the interest rate choice in the third case, we change the interest rate from 3 percent to 7 percent. The results are shown in the bottom row of Table 10. We confirm that the net increase social welfare is great for the three MEC estimates.

From these sensitivity analyses we can confirm that the optimal retirement regulation can increase the social net benefit regardless of the choice of the assumptions. Hence, in taking all the results of simulations into account, we can robustly conclude that there is inefficiency under the current regulation. This finding leads to the importance of an ex-ante quantitative regulatory impact analysis, such as this study, to improve the social welfare.

5.5 Discussion

Some people may argue that our optimal retirement schedule is too drastic to be accepted by the public. In response to this potential criticism, we conducted a simple simulation with a small change from the current retirement schedule. That is, the regulator postpones the retirement of passenger vehicles from 2005 to 2006 and accelerates the retirement of trucks from 2006 to 2005. This exchange in retirement timing can increase the net benefit by 13 percent as shown in the fifth column in Table 9. This simple simulation reinforces the importance of ex-ante quantitative policy evaluations to improve the social welfare related to environmental regulations.

6. Conclusions

This paper empirically investigated the efficiency of the vehicle type regulation recently implemented in three Japanese metropolitan areas to mitigate air pollution problems. By solving an optimal problem of retirement timing, we find that the regulator can increase the social net benefit dramatically by changing the timing of the ban for each vehicle type. Our choice set of policy instruments is narrower than in the ideal world where economic instruments such as emissions taxes can maximize the social net benefit. On one hand, this restriction of alternative policy is disadvantageous since it does not realize the maximum social welfare, which economic instruments can achieve. On the other hand, this restriction is advantageous since it does not change administrative costs in the alternative regime compared with the current regulation. In other words, it assures the practicality and the feasibility of the alternative policy discussed in this study. Further, this analysis confirmed that a simple alternative policy can improve the net benefit dramatically. Even with a command-and-control approach there can be differences in cost effectiveness.

Our results imply that two important points argue for conducting an ex-ante policy evaluation before legislating new policy. First, it is important to show multiple feasible alternate plans to assure high efficiency. Though the regulator showed only one schedule of terminal years, in legislating the NO_x-PM Law we find that the social net benefit could increase by 104 percent if the regulator had chosen the most efficient schedule of terminal years from among the alternatives. This fact confirms the importance of comparing multiple policy proposals.

The second point concerns the importance of quantitative economic analysis in an ex-ante policy evaluation. The 2007 revision of the Japanese Government Policy Evaluations Act obligates the regulator to conduct an ex-ante policy evaluation of command-and-control policy.

There are, however, several ways to evaluate a policy. Our quantitative economic analysis shows that there can be a large variance in the efficiency among feasible policies. This result implies that efficiency is an important indicator in choosing the most preferable policy from among alternatives. We suggest that the regulator should carry out a quantitative economic analysis as an ex-ante policy.

In addition to air pollution problems, climate change has become an important factor in regulating the transportation sector. We have to address two issues in this regard. First, a life-cycle analysis of vehicles is important, as Spitzley et al. (2005) point out. The acceleration of vehicle retirement speeds up the replacement of older vehicles with new ones. The production of new vehicles in the earlier timing will increase CO_2 emissions in the short run. However, the impact of CO_2 emissions increase from this process will be negligible in the long run because the NO_x-PM Law requires the early retirement of old vehicles only once. Hence, we consider that the change of CO_2 emissions over the life cycle due to the early retirement is limited.

Second, the technological trade-off between NO_x and PM reduction and CO_2 reduction is worth discussion. Recently in Japan, CO_2 emissions intensity among some small-size trucks deteriorated due to the technological trade-off. The improvement of fuel economy for larger trucks, however, is larger than the deterioration effect. Therefore, the amount of CO_2 emissions may decrease overall. Needless to say, future ex-ante quantitative policy evaluations for air pollution regulation should include the impact on CO_2 emissions.

References

Alberini, A., W. Harrington, and V. McConnell. 1995. Determinants of Participation in Accelerated Vehicle Retirement Programs. *RAND Journal of Economics* 26: 93–112.

Alberini, A., W. Harrington, and V. McConnell. 1996. Estimating an Emissions Supply Function from Accelerated Vehicle Retirement Programs. *Review of Economics and Statistics* 78: 251–265.

Arimura, T. H., and K. Iwata. 2006. Inefficiency in Command-and-Control Approach toward Adoption of Low Emission Vehicles: Japanese Experience of Air Pollution from Diesel Trucks. Paper presented at the 3rd World Congress of Environmental and Resource Economists. July 2006, Kyoto, Japan. http://www.webmeets.com/files/papers/ERE/WC3/484/NOxPM_WC_submitted.pdf (accessed June 17, 2008).

Arimura, T. H., and K. Iwata. 2008. Economics Analysis on Motor-Vehicle Type Regulation: Policy Evaluation of NOx-PM Law. *Environmental Science* 21(2): 103–114 (in Japanese).

Dill, J. 2004. Estimating Emissions Reductions from Accelerated Vehicle Retirement Programs. *Transportation Research Part D* 9: 87–106.

Hibiki, A., and T. H. Arimura. 2002. *Introduction to Environmental Economics*. Tokyo, Japan: Chukoshinsho Publishing (in Japanese).

Koyama, S., and A. Kishimoto. 2001. External Costs of Road Transport in Japan. *Transport Policy Studies' Review* 4(2): 19–30 (in Japanese).

Kuroda, M., K. Shinpo, K. Nomura, and N. Kobayashi. 1997. *KEIO database: Measurement of Output, Labor and Capital Inputs*. *Keio Economic Observatory Monograph Series* 8. Tokyo, Japan (in Japanese).

Lumbreras, J., M. Valdés, R. Borge, and M. E. Rodríguez. 2008. Assessment of Vehicle Emissions Projections in Madrid (Spain) from 2004 to 2012 Considering Several Control Strategies. *Transportation Research Part A* 42: 646–658.

Ministry of Internal Affairs and Communication (MIC). 2006. *2006 Evaluation of Air Pollution Policy in the Metropolitan Area* (in Japanese).

National Environmental Technology Centre (NETCEN). 2002. *Estimates of the Marginal External Costs of Air Pollution in Europe*. http://ec.europa.eu/environment/enveco/air/pdf/betaec02a.pdf (accessed June 17, 2008).

Nomura, T. 2002. A Study on Duration of Standard Trucks at Facilities: Effects on Emission Control. In *Study on Control of CO2 Emission from Transport Sector,* edited by Y. Kanemeto. Tokyo, Japan: *The Japan Research Center for Transport Policy,* 26–51 (in Japanese).

Oka, T., Y. Fujii, M. Ishikawa, Y. Matsuo, and S. Susami. 2007. Maximum Abatement Costs for Calculating Cost-Effectiveness of Green Activities with Multiple Environmental Effects. Edited by G. Huppes and M. Ishikawa. *Quantified Eco-Efficiency (Eco-Efficiency in Industry and Science),* 41–78.

Spitzley, D. E., D. E. Grande, G. A. Keoleian, and H. C. Kim. 2005. Life Cycle Optimization of Ownership Costs and Emissions Reduction in U.S. Vehicle Retirement Decisions. *Transportation Research Part D* 10: 161–175.

Suri-Keikau Inc. 2005. *Vehicle Emission Intensities and Total Emission Estimation Survey 2004: Commission Research Report to the Ministry of the Environment.* Tokyo, Japan (in Japanese).

Viscusi, W. K., and J. E. Aldy. 2003. The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World. *The Journal of Risk and Uncertainty* 27(1): 5–76.

Data Sources

Automobile Inspection and Registration Association. 1990–2004. *Survey on Vehicle Ownership in Japan*.

Automobile Inspection and Registration Association. 2003. *Survey of Automobile Possession*.

Japan Automobile Dealers Association. 2000. *Annual Report on New Vehicle Registration.* Vol. 23.

Japan Automobile Manufacturers Association. 2005a. *Standard Truck Market Survey 2004*.

Japan Automobile Manufacturers Association. 2005b. *Small Truck Market Survey 2004*.

Japan Trucking Association. 2004. *Japanese Truck Freight Transportation 2004*.

Ministry of Land, Infrastructure, Transport and Tourism. 2001. *Monthly Statistical Report on Motor Vehicle Transportation 2001 March*.

Tables and Figures

Table 1. Terminal Years under the Current Vehicle Type Regulation

First Registration Year	Vehicle Type	Standard	Small	Standard	Small	Standard	Small	Standard	Small	Standard	Small
		Truck		Bus		Special Use Vehicle		Passenger Car			
	inspection	every two year						every one year		every two year	
2002		2012	2011	2015	2013	2013	2013	2012	2012	2012	2012
2001		2011	2010	2014	2012	2012	2012	2011	2011	2011	2011
2000		2010	2009	2013	2011	2011	2011	2010	2010	2010	2010
1999		2009	2008	2012	2010	2010	2010	2009	2009	2009	2009
1998		2008	2007	2011	2009	2009	2009	2008	2008	2008	2008
1997		2007	2006	2010	2008	2008	2008	2007	2007	2007	2007
1996		2006	2006	2009	2007	2007	2007	2006	2006	2006	2006
1995		2006	2006	2008	2006	2006	2006	2006	2006	2005	2005
1994		2006	2005	2007	2006	2006	2006	2006	2006	2005	2005
1993		2005	2005	2006	2006	2006	2006	2005	2005	2005	2005
1992		2005	2005	2006	2005	2005	2005	2005	2005	2005	2005
1991		2005	2005	2006	2005	2005	2005	2005	2005	2005	2005
1990		2005	2004	2005	2005	2005	2005	2005	2005	2005	2005
1989		2004	2004	2005	2005	2005	2005	2004	2004	2005	2005
1988 or before		2004	2004	2005	2004	2004	2004	2004	2004	2005	2005

Table 2. Number of Regulated Vehicles

Vehicle Type	Standard	Small	Standard	Small	Standard	Small	Standard	Small	Standard	Small	Total
	Truck		Bus		Special Use Vehicle		Passenger Car				
inspection	every two year						every one year		every two year		
	581,192	893,415	27,638	19,001	268,384	31,634	3,249	3,691	358,973	407,772	2,594,949

Table 3. Life Remaining without the Regulation: $L_m(u)$ (Years)

Vehicle Age (u)	Vehicle Type	Standard	Small	Standard	Small	Standard	Small	Standard	Small	Standard	Small
		Truck		Bus		Special Use Vehicle		Passenger Car			
	inspection	every two year						every one year		every two year	
0		15.21	11.85	15.21	11.85	15.21	11.85	14.08	11.67	14.08	11.67
1		14.30	10.87	14.30	10.87	14.30	10.87	13.14	10.69	13.14	10.69
2		13.45	9.96	13.45	9.96	13.45	9.96	12.19	9.73	12.19	9.73
3		12.52	9.05	12.52	9.05	12.52	9.05	11.29	8.82	11.29	8.82
4		11.63	8.26	11.63	8.26	11.63	8.26	10.50	8.04	10.50	8.04
5		10.74	7.59	10.74	7.59	10.74	7.59	9.52	7.11	9.52	7.11
6		9.94	7.16	9.94	7.16	9.94	7.16	8.77	6.45	8.77	6.45
7		9.12	6.64	9.12	6.64	9.12	6.64	7.86	5.61	7.86	5.61
8		8.38	6.21	8.38	6.21	8.38	6.21	7.22	5.07	7.22	5.07
9		7.70	5.93	7.70	5.93	7.70	5.93	6.42	4.36	6.42	4.36
10		7.13	5.57	7.13	5.57	7.13	5.57	5.94	4.10	5.94	4.10
11		6.61	5.25	6.61	5.25	6.61	5.25	5.25	3.55	5.25	3.55
12		6.12	4.97	6.12	4.97	6.12	4.97	5.05	3.59	5.05	3.59
13		5.69	4.72	5.69	4.72	5.69	4.72	4.63	3.17	4.63	3.17
14		5.28	4.47	5.28	4.47	5.28	4.47	4.66	3.40	4.66	3.40
15		4.84	4.21	4.84	4.21	4.84	4.21	4.24	3.07	4.24	3.07
16		4.35	3.90	4.35	3.90	4.35	3.90	4.16	3.27	4.16	3.27
17		3.83	3.54	3.83	3.54	3.83	3.54	3.75	2.98	3.75	2.98
18		3.25	3.09	3.25	3.09	3.25	3.09	3.38	2.85	3.38	2.85
19		2.61	2.54	2.61	2.54	2.61	2.54	2.69	2.41	2.69	2.41
20		1.87	1.84	1.87	1.84	1.87	1.84	1.89	1.79	1.89	1.79
21		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4. Reduced Years under the Current Regulation: $Y_{rm}(T_{rm}, L_m)$

First Registration Year	Vehicle Type	Standard	Small	Standard	Small	Standard	Small	Standard	Small	Standard	Small
		Truck		Bus		Special Use Vehicle		Passenger Car			
	inspection	every two year						every one year		every two year	
2002		7.13	5.93	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
2001		7.13	5.93	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
2000		7.13	5.93	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
1999		7.13	5.93	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
1998		7.13	5.93	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
1997		7.13	5.93	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
1996		7.13	5.57	5.69	5.25	6.61	5.25	5.94	4.10	5.94	4.10
1995		6.61	5.25	5.69	5.25	6.61	5.25	5.25	3.55	5.94	4.10
1994		6.12	5.25	5.69	4.97	6.12	4.97	5.05	3.59	5.25	3.55
1993		6.12	4.97	5.69	4.72	5.69	4.72	5.05	3.59	5.05	3.59
1992		5.69	4.72	5.28	4.72	5.69	4.72	4.63	3.17	4.63	3.17
1991		5.28	4.47	4.84	4.47	5.28	4.47	4.66	3.40	4.66	3.40
1990		4.84	4.47	4.84	4.21	4.84	4.21	4.24	3.07	4.24	3.07
1989		4.84	4.21	4.35	3.90	4.35	3.90	4.24	3.07	4.16	3.27
1988		4.35	3.90	3.83	3.90	4.35	3.90	4.16	3.27	3.75	2.98
1987		3.83	3.54	3.25	3.54	3.83	3.54	3.75	2.98	3.38	2.85
1986		3.25	3.09	3.25	3.09	3.25	3.09	3.38	2.85	2.69	2.41
1985		2.61	2.54	2.61	2.54	2.61	2.54	2.69	2.41	1.89	1.79
1984		1.87	1.84	1.87	1.84	1.87	1.84	1.89	1.79	1.00	1.00

Table 5. Marginal Externality Costs of NO_x and PM (ten thousand yen/ton)

	NOx	PM
Cited from	NETCEN (2002)	Koyama and Kishimoto (2001)
Upper Bound	French	Upper Value
Point Estimate	Middle	Middle
Lower Bound	Average of EU-15	Lower Value
Upper Bound	76.9	3192.6
Point Estimate	58.1	2276.3
Lower Bound	39.4	1360.0

Table 6. Terminal Years in the Optimizing Model (Point Estimate): T_{rm}

First Registration Year	Vehicle Type	Standar	Small	Standar	Small	Standar	Small	Standar	Small	Standar	Small
		Truck		Bus		Special Use		Passenger Car			
	inspection	every two year						every one year		every two year	
2002		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
2001		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
2000		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1999		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1998		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1997		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1996		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1995		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1994		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1993		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1992		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1991		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1990		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1989		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1988		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1987		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1986		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1985		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1984		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex

Ex = exempt.

Table 7. Optimal Terminal Years with the Lower Bound Estimate of MEC: T_{rm}

First Registration Year	Vehicle Type	Standar	Small	Standar	Small	Standar	Small	Standar	Small	Standar	Small
		Truck		Bus		Special Use		Passenger Car			
	inspection	every two year						every one year		every two year	
2002		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
2001		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
2000		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1999		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1998		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1997		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1996		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1995		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1994		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1993		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1992		2004	Ex	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1991		2004	Ex	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1990		2004	Ex	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1989		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1988		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1987		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1986		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1985		2004	Ex	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1984		2004	Ex	2004	2004	2004	2004	Ex	Ex	Ex	Ex

Ex = exempt.

Table 8. Optimal Terminal Years with the Upper Bound Estimate of MEC: T_{rm}

First Registration Year	Vehicle Type	Standar	Small	Standar	Small	Standar	Small	Standar	Small	Standar	Small
		Truck		Bus		Special Use		Passenger Car			
	inspection	every two year						every one year		every two year	
2002		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
2001		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
2000		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1999		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1998		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1997		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1996		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1995		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1994		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1993		2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
1992		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1991		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1990		2004	2004	2004	2004	2004	2004	Ex	2004	Ex	2004
1989		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1988		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1987		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1986		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1985		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex
1984		2004	2004	2004	2004	2004	2004	Ex	Ex	Ex	Ex

Ex = exempt.

Table 9. Increase in the Social Net Benefit from the Current Regulation (one hundred million yen)

Policy Scenario	Optimization			Simple Model
MEC Estimates	Point Estimate	Lower Bound	Upper Bound	
	7,073	5,266	8,959	910

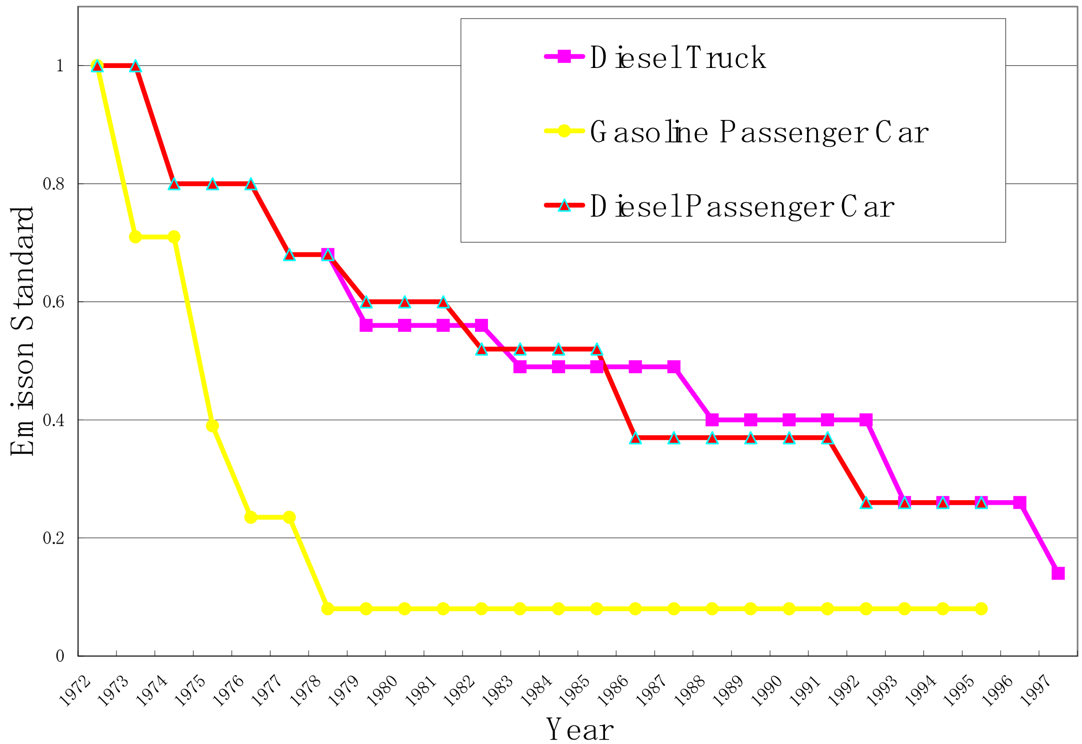
Note: The net benefit of the current regulation is 6,812 with the point estimate of the marginal externality cost. All are in discounted present value in 2004.

Table 10. Robustness Check of Estimation Results: Increase in the Social Net Benefit from the Current Regulation (one hundred million yen)

Policy Scenario		Optimization			Simple Model
MEC Estimates		Point Estimate	Lower Bound	Upper Bound	
Change of Assumption	Profit on Sale	3,575	3,006	4,908	859
	Profit on Sale and Repurchasing	3,396	6,284	3,361	447
	Interest Rate	5,967	7,710	6,657	587

Note: On the column of "Profit on Sale," "Profit on Sale and Repurchasing," and "Interest Rate" the net benefits of the current regulation are 3,241, –1,421, and –3,552, respectively, with the point estimate of the marginal externality cost. All are in discounted present value in 2004.

Figure 1. Changes in Emissions Vehicle Standards



Note: The emissions standard is normalized by the emissions level in 1973 when there was no emissions standard regulation. Source: Hibiki and Arimura (2002).

Figure 2. Timing of Replacement

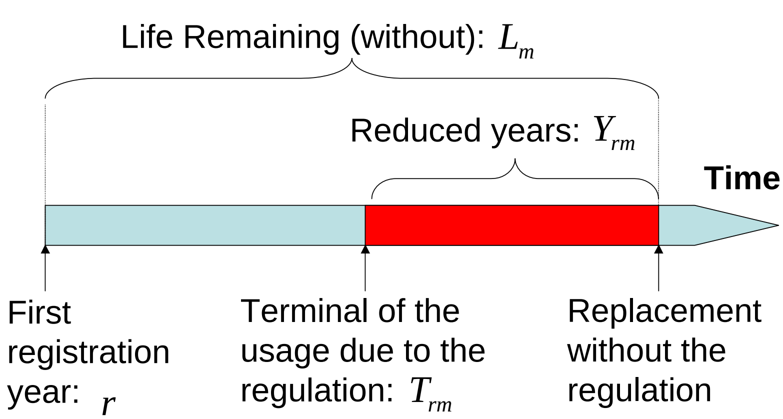


Figure 3. Structure of Optimization Problem

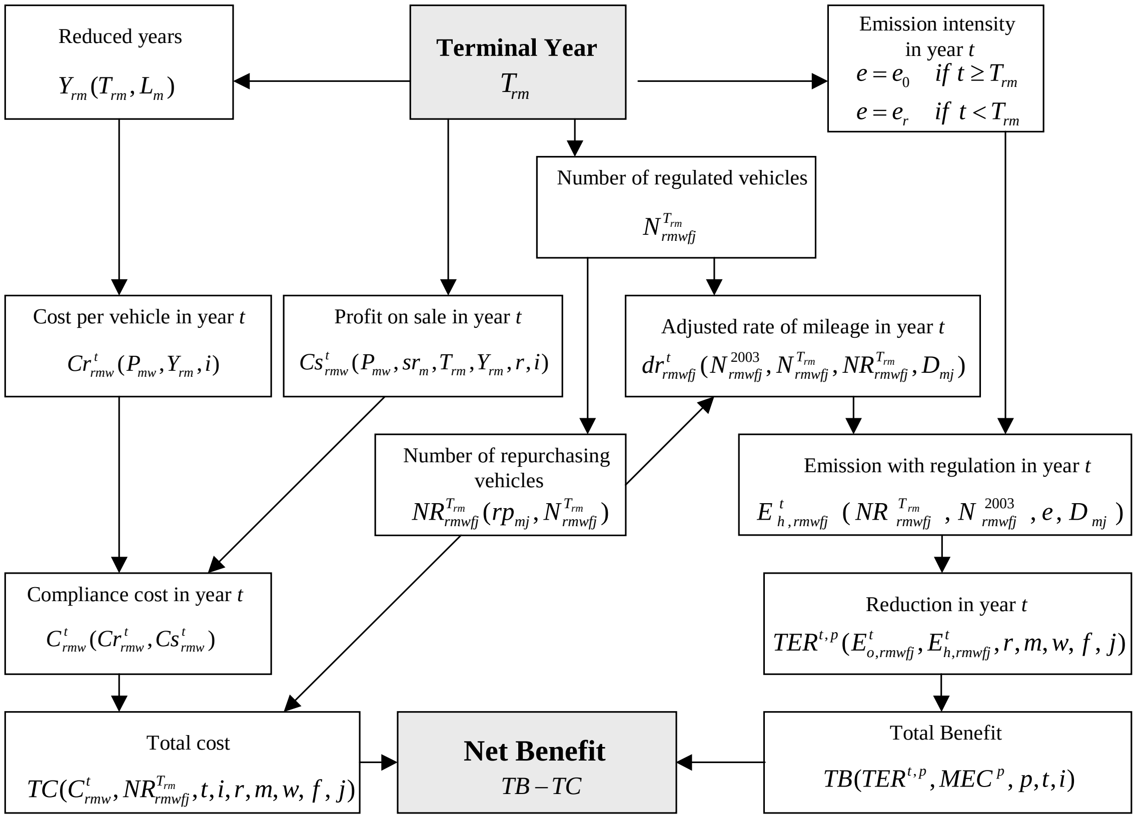


Figure 4: Transition of NO_x Emissions (ton)

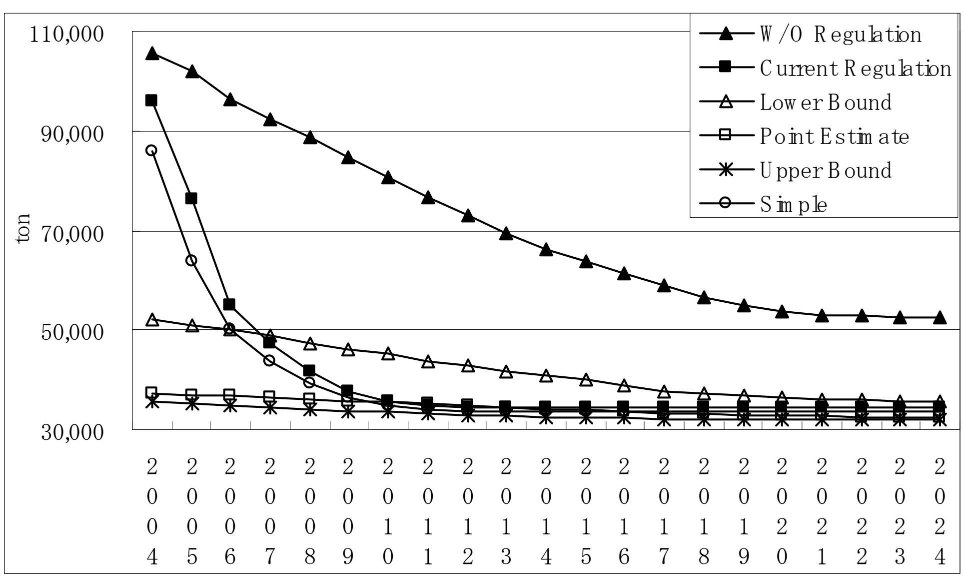
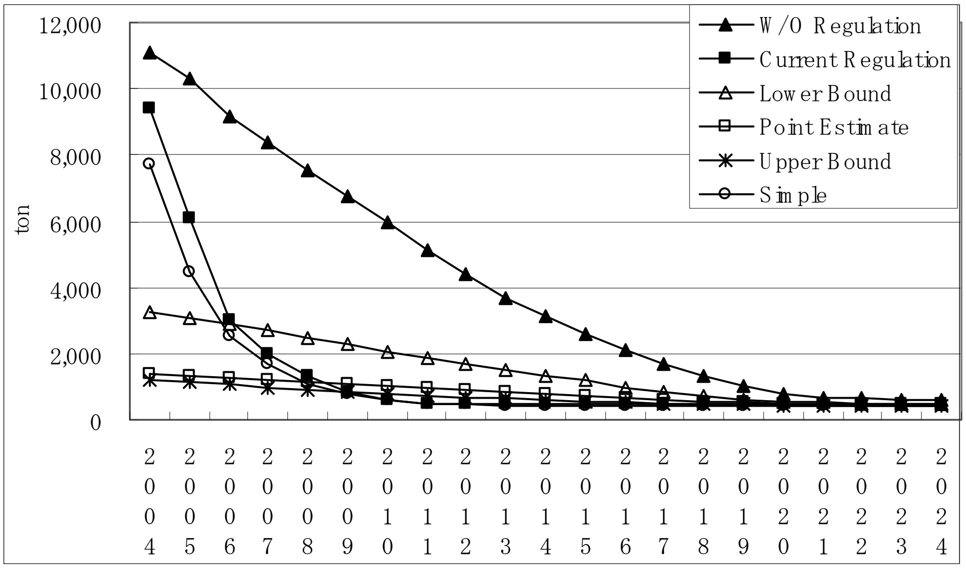


Figure 5: Transition of PM Emissions (ton)



Appendix

The computation of the average life remaining L_m was done as follows.

First, the number of registered vehicles $N_m(k)$ with vehicle age k was obtained from *Survey on Vehicle Ownership in Japan* for standard trucks, small trucks, standard passenger cars, and small passenger cars. The disposal rate $d_m(k)$ is computed by using following equation:

$$d_m(k) = \left(N_m(k) - N_m(k+1)\right) / N_m(k)$$

From this disposal rate, the survival rate $s_m(k)$ is calculated as

$$\begin{aligned} s_m(k) &= s_m(k-1)[1 - d_m(k-1)] \quad && if \quad k \geq 1 \\ s_m(0) &= 1 && if \quad k = 0 \end{aligned}$$

Following Oka et al. (2007), we assume that no vehicles are used after 21 years. Using the survival rate, the average life remaining $L_m(u)$ for a vehicle aged T is calculated by

$$L_m(u) = \frac{\sum_{k=u}^{21} s_m(k)}{s_m(u)}$$