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The effectiveness of vehicle emission control policies: Evidence from Japanese experience

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The effectiveness of vehicle emission control policies: Evidence from Japanese experience

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Abstract

Governments in developed countries have implemented various regulations to manage air pollutants from automobiles, such as emission standards and subsidies for low emission vehicles. Japan is a unique example of a country that has overcome the severe air pollution of nitrogen oxides (NOx) and particulate matter (PM) through the mandatory retirement of old, high emission vehicles in metropolitan areas. To date, however, it is not clear which policy instruments have been effective in mitigating the air pollution from automobiles. The purpose of this paper is to empirically examine the effectiveness of policy instruments in attaining cleaner air in Japanese metropolitan areas. Using data from 1990 to 2005, we estimate the concentration functions of NOx and PM using a spatial econometric model. We find that most regulations and subsidies decreased the concentration levels of both pollutants. Traditional emission standards were found to be more effective than other policy instruments. Vehicle replacement subsidies were more cost-effective than those for PM-removal equipment. Furthermore, the empirical results indicate that the effect of subsidies for vehicle replacement on one municipality's air had spillover effects by improving the pollutant concentrations in the surrounding municipal areas.

Keywords

Air pollution, Automobile, Regulation, Subsidies and Spillover

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1. Introduction

Air pollution presents health risks, such as cardiovascular and respiratory diseases and lung cancer. The World Health Organization (WHO) reports that urban outdoor air pollution killed 1,152,000 people globally in 2004.[2] This human suffering occurred not only in developing countries but also in developed countries, such as in Europe, where the estimated death toll from urban air pollution in 2004 was 225,000. Numerous governments are facing the urgent need to implement effective countermeasures against this externality.

The two major sources of air pollution are stationary sources, such as factories, and mobile sources, such as automobiles. Governments in developed countries have implemented various regulations to control emissions from stationary sources and have dramatically reduced these emissions. However, it has been more difficult to control emissions from mobile sources, for two reasons. First, mobile sources are more numerous than stationary sources. Second, due to the mobility of these sources, it is difficult for regulators to identify and control air pollution from vehicles at the appropriate level of marginal external cost.

A traditional approach to this problem is the introduction of emission standards (ESs). Although ESs seem to be effective, they face several problems. First, even with a stringent ES, the increasing number of vehicles makes it difficult to achieve the ambient standard in metropolitan areas. Second, ESs apply to new vehicles only, which comprise only a small portion of all vehicles. Consequently, ESs have limited impacts on the ambient air quality, at least in the short term.

Since 1990, the Japanese government has taken a unique approach to overcoming this problem. Although the Japanese government has continuously intensified ESs since their introduction in 1966, the concentrations of nitrogen oxide (NOx) and particulate matter (PM)[3] in metropolitan areas remained high in the 1990s. The government introduced a mandatory replacement of old, high emission vehicles with new, cleaner vehicles in designated metropolitan areas. The first replacement policy (RP) was introduced in 1992 to manage NOx. This policy was amended in 2001 to reduce PM emissions as well as NOx. Although there have been several voluntary programs to promote the retirement of old vehicles, mandatory retirement is a unique

[2] Refer to the WHO database, http://www.who.int/healthinfo/global_burden_disease/en/index.html.
[3] In this study, PM indicates PM_{10}, which has a particulate diameter less than 10 μm.

policy. Therefore, this replacement policy is worthy of empirical analysis.

In addition to regulations by the national government, local governments in Japanese metropolitan areas introduced a technical regulation in 2003, when local governments began requiring the installation of PM removal equipment (DPFM) if vehicles did not satisfy a certain emission standard. Furthermore, local governments have offered two types of subsidies since 2000 in an attempt to control emissions. The first type promotes the replacement of older, high emission vehicles with new, cleaner vehicles, and the second type of subsidy encourages the installation of PM removal equipment.

As of 2008, the Japanese emissions policy comprises five parts: an ES, an amended replacement policy (ARP), DPFM and two types of subsidies. These regulations and subsidies appear to be effective because the NOx and PM concentrations at the monitoring stations have been decreasing (see Figures 1 and 2). However, this effectiveness is inferred from the relationship between the regulations/subsidies and the concentration levels over the years. Rigorous empirical analysis is necessary to clarify the impacts of various policy instruments on air quality.

Several studies have examined the effectiveness of Japanese regulations for vehicle emission control as an ex-ante policy evaluation. Using a theoretical model, Iwata and Arimura (2009) found that the amended replacement policy (ARP) could provide a positive net social benefit, and they suggested that this benefit could be significantly increased through the design of optimal policies. Iwata (2011) conducted an ex-ante cost-benefit assessment of DPFM with a theoretical framework and concluded that DPFM was a valid policy for attaining cleaner air. These studies showed that ARP and DPFM theoretically improved social welfare. Iwata (2011) also suggested that subsidies should be spent on low emission vehicles (LEVs) because the marginal abatement cost is higher to subsidize PM removal equipment than to subsidize LEVs. These studies, however, are ex-ante theoretical analyses, which cannot guarantee that the policy improved air quality.

Although the air quality has been monitored, the effectiveness of individual regulations and subsidies has not been evaluated from an ex-post perspective. Using ambient air quality data on NOx and PM concentrations from 1990 to 2005, this paper examines the effectiveness of individual regulations and subsidies by conducting an ex-post evaluation of past and current regulations.

Specifically, we examine the effectiveness of ES, RP, ARP, DPFM and two types of subsidies. Because metropolitan areas are primarily affected by vehicle air pollution, we focus on the four largest metropolitan areas in Japan (Tokyo, Nagoya, Osaka, and Fukuoka) (see Figure 3).

Although this paper is one of the first studies to conduct an ex-post analysis of the effectiveness of vehicle emission policies in Japan, several studies have reported similar cases in other countries. In the United States, the federal government requires counties to provide improvement plans for reducing ozone (O_3) levels if they do not satisfy emissions targets. Using O_3 data at air pollution monitoring stations in the United States from 1977 to 1987, Henderson (1996) suggested that these controls decreased O_3 concentrations by 3 to 8 percent.

Auffhammer et al. (2009) also examined the impact of regulation on air pollutant concentrations in the United States. They focused on the 1990 Clean Air Act Amendments and used monitoring data from 1990 to 2005 to examine whether these amendments contributed to the reduction of PM_{10} levels. These authors concluded that that the amendments reduced concentrations by 11 to 14 percent.

Using data from air pollution monitoring stations in Delhi, India from 1990 to 2005, Narain and Krupnick (2007) found that the conversion of commercial passenger vehicles (buses, three-wheelers, and taxis) to compressed natural gas helped to reduce PM, CO, and SO_2 concentrations. These studies used data from monitoring stations managed by governments. Following these studies, the current study also uses data from governmental air pollution monitoring stations.

This study attempts to contribute to the literature in the following four ways. First, this is the first study to examine the effectiveness of the mandatory replacement of old vehicles. Although voluntary programs to replace old vehicles have been implemented in several US states, such as California (Dill, 2004) and Delaware (Alberini et al., 1996), research on the mandatory replacement program has yet to be scrutinized. In addition, an ex-ante study (Iwata & Arimura, 2009) showed that the cost of this replacement policy is significant. Thus, the effectiveness of RP is worthy of research.

Second, this study identifies the effectiveness of each emission control policy. Although an increasing number of regulations and subsidies have been introduced, it is not clear which policies have helped to reduce specific air pollutant and to what extent these policies have been effective. The Japanese experience can provide useful implications for policymakers in both developed and emerging countries. For example, Korea introduced a regulation requiring the installation of pollutant elimination equipment in in-use vehicles in the Seoul metropolitan area, which is similar to the Japanese DPFM.[4] Many cities in these countries and states are experiencing severe air pollution and have high population densities similar to Japanese metropolitan cities.

Third, this study adopts a spatial econometric approach to evaluate the air pollution regulations of mobile sources. The concentrations of pollutants at neighboring monitoring points can be correlated if they are geographically close because the omitted variables are often spatially correlated. Because it is difficult to control all omitted variable problems, we adopt an econometric approach to the spatial correlation issue, in contrast to previous studies (Henderson, 1996; Auffhammer et al., 2009; Narain & Krupnick, 2007).

Finally, this paper explores the spillover effect of subsidies. One municipality's subsidy may contribute to the reduction of emissions in neighboring municipalities. Furthermore, firms may not necessarily use their vehicles only within a single municipality. If firms purchase LEVs with a particular municipality's subsidy and drive across municipalities, the subsidy will effectively reduce emissions not only in the municipalities with the subsidy but also in the municipalities where the vehicles are used. However, air pollutants may spread to neighboring municipalities by wind, and the spillover effect may exist even when a firm's vehicles remain within a single municipality.

The rest of the paper is organized as follows. In the next section, we explain the details of the Japanese vehicle emission control policies. Our estimation model is described in Section 3. Section 4 explains the dataset, and Section 5 provides the estimation results. Section 6 concludes the paper.

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[4] This regulation is based on the Special Act on Seoul Metropolitan Air Quality Improvement.

2. Overview of the Japanese NOx and PM Regulations

2.1. Emission Standards (ES)

The first air pollution regulation on the vehicle was emission standards (ES) introduced in 1966. The ES sets the upper limit value of emission intensity and applies to new cars only. The type of this regulation is implemented by many countries such as United States, Canada, Mexico, EU, China, India and so on. Unless automakers comply with the standard, they cannot sell their vehicles in Japan. At first, target pollutant was only Carbon Oxide. And then the ES on NOx was announced in 1972 (enforced in 1973) and gradually has become stringent overtime. For example, the standard for the standard diesel truck in 1973 was 5.28g/km, and 0.33g/km in 2005. The standard on PM was introduced much later in 1993. The standard on PM on diesel standard truck was 0.033g/km. Later, it was revised to 0.002g/km for the 2005 vehicles. The transition of tightening of these emission intensitys is shown in Figure 4. This standard covers all regions of Japan.

2.2. Replacement Policy (RP)

Due to the ES on vehicle, the air quality improved dramatically since 1970s. The annual average NOx concentration level in Japan dropped from 0.073 ppm in 1972 to 0.039 ppm in 1990. The level in the two largest metropolitan areas (Tokyo and Osaka) in 1990, however, was still high, 0.059 ppm (see Figure 1).

One limitation of the ES is that it applies to new vehicles only. Vehicles in use were not affected by ES. Facing the high NOx concentration in the areas, the national government introduced Automobile NOx Law in 1992. Unlike ES, this law covers only the two largest metropolitan areas, which the national government designated as non-attainment area. The law regulates vehicles in use in the non-attainment areas and is unique in the sense that it sets the terminal years of the vehicle usages in the non-attainment areas. Thus, it enforces replacement of the old-dirty vehicles with new ones. The main objective was to reduce NOx concentration from diesel trucks. The terminal years depends on vehicle type such as trucks, buses and passenger vehicles.

2.3. Amended Replacement Policy (ARP)

Despite the introduction of RP, the NOx concentration in the Tokyo and Osaka metropolitan areas was still higher than the other areas (see Figure 1). The PM concentration was even worse. In response to this situation, the Automobile NOx Law was amended in 2001 into Automobile NOx-PM Law to improve the ambient air quality of both NOx and PM more effectively. This time, Nagoya metropolitan area, the third largest metropolitan area in Japan, was also added as non-attainment area. The amended law expanded target vehicles more than before by tightening the criteria of regulation. We refer this amended regulation as "ARP".

2.4. Diesel Particulate Filter Mandate (DPFM)

Apart from the national government regulation such as ES and RP, in 2003 municipalities in the Tokyo metropolitan area independently implemented another regulation, diesel particulate filter mandate (DPFM), in order to reduce PM concentration. Specifically, they mandated the installation of diesel particulate filter (DPF) to dirty diesel trucks in use unless they satisfy the 1999 emission intensity under ES. DPF is a kind of PM emission control technology (Lopez et al., 2009). The official equipments approved by municipalities can remove PM emission by between 30 and 70 percent (8Capital Pref City Aozora Network, 2007). Trucks without DPFs are prohibited to operate in Tokyo metropolitan area unless they comply with the 1999 standard.

2.5. DPF and LEV Subsidies

Some municipalities in non-attainment areas provided two types of subsidies to reduce emission from vehicles since late 1990's. One is a subsidy for promoting the DPF installation (DPF subsidy). Another is for purchase of LEVs such as natural gas and hybrid vehicles (LEV subsidy). The amounts of subsidies are different from each municipality. For example, municipalities in Tokyo area spent 27.5 billion yen for DPF installation from 2002 to 2005. On the contrary, same subsidy in Osaka area was only 0.27 billion yen. There was no subsidy in Fukuoka metropolitan area that is the fourth biggest metropolitan area (see Table 1). Fukuoka metropolitan area is assigned as attainment area, unlike the top three metropolitan areas. This Fukuoka area is applies as a control group because only ES is introduced in this area..

3. Econometric Model

NOx and PM concentration levels (ppm or mg/m^3) have been measured as ambient air quality. Thus, vehicle emission regulations are expected to reduce their levels. Their concentration levels also depend on other factors including socio-economic and climate/weather conditions. Following Henderson (1996), we thus specify the concentration function as follows[5]:

$$AC_{p,ijt} = \mathbf{X}_{1,p,ijt}\boldsymbol{\beta}_{1,p} + \mathbf{X}_{2,ijt}\boldsymbol{\beta}_{2,p} + \mathbf{X}_{3,ijt}\boldsymbol{\beta}_{3,p} + \varepsilon_{p,ijt} \tag{1}$$

where $AC_{p,ijt}$ is the concentration levels of air pollutant *p* (NOx or PM) at monitoring station *i* in municipality *j* at year *t*. $\mathbf{X}_1$ is the vector of variables for vehicle emission control policies, $\mathbf{X}_2$ is the vector of social structure, and $\boldsymbol{X}_3$ is the vector of climate/weather condition. The parameters $\boldsymbol{\beta}_k$ (k = 1,2,3) are to be estimated and ε is an error term. We examine the effectiveness of the regulations by estimating coefficients in equation (1) for each pollutant and looking particularly at the estimated coefficients of $\mathbf{X}_1$. Further, by comparing the size of the coefficients, we identify to what extent the existing regulations have helped to reduce NOx and/or PM concentrations.

Considering unobserved station specific effects, we employ two specifications for the error term; fixed effects and spatial random effects (Leggett & Bockstael, 2000). Additionally, we assume autocorrelation between current error term and last year's error term as we use panel dataset. The error terms for fixed effect model and spatial random effect model are thus described as following equation (2) and (3), respectively.

$$\varepsilon_{p,ijt} = \lambda\varepsilon_{p,ijt-1} + \eta_{p,i} + \nu_{p,ijt} \tag{2}$$

$$\varepsilon_{p,ijt} = \rho\sum_{l} W_{il}\varepsilon_{p,ljt} + \lambda\varepsilon_{p,ijt-1} + \eta_{p,i} + \nu_{p,ijt} \quad ,i \neq l \tag{3}$$

5 Sigman (2002), Greenstone (2003), and Greenstone (2004) estimate concentration/emission function similar to this study. Our concentration function uses flow concentration at a certain point in time with the assumption that the concentration levels at a monitoring station in the previous year do not influence the levels in the next year.

where λ and ρ are parameters in the both specifications. W is a spatial weighting matrix for distances between any two stations.

3.1. Vector of Emission Control Policies

The vector of policies, $\mathbf{X}_1$, includes the following six variables (and eight for PM concentration function). The first variable is to capture the effectiveness of ES, i.e., the upper limit value of emission intensity imposed by the regulation. NOx regulation began in 1973 and PM regulation in 1993. Therefore, the values used for NOx and PM concentration functions are different. NOx regulation has seventeen categories and PM regulation has seven categories based on the weight and vehicle type. This study uses the average value of those categories. The standard values of NOx and PM are set to 100, respectively. The standard value of NOx is that in 1972, i.e., the year before the regulation started. The standard value of PM is that in 1993, that is, the year when the regulation started. PM values before 1993 are also set to 100 because information on PM emissions before 1993 is not available.

The second is the RP dummy, i.e., a variable that captures the effectiveness of the Automobile NOx law. This law is the forerunner of the ARP under Automobile NOx-PM law. RP introduced in 1992 is the nation’s first regulation that focused on vehicles in use. The law was amended in 2001 as its effectiveness was said to be insufficient (Sano, 2008). In order to estimate the effectiveness of the RP, we use the RP dummy where an air pollution monitoring station takes one if it is located in the Tokyo and Osaka metropolitan areas designated as non-attainment area by the RP between 1992 and 2002 (i.e., from the year the regulation was introduced until the year it was taken over by the NOx-PM law) and takes zero otherwise.

The third is the ARP dummy, i.e., a variable that captures the effectiveness of the Automobile NOx-PM Law. This dummy takes one if a monitoring station is located in the Tokyo, Osaka and Nagoya metropolitan areas, which were designated as non-attainment area by the law after 2003 and takes zero otherwise. Although the law was amended in 2001, the ARP had teeth since 2003. It should be noted that the designated areas by this law are different from those by its forerunner, the Automobile NOx Law. Because we use the data from 1990 to 2005, the effectiveness of the ARP can be measured only for the period of three years, from 2003 to 2005.

The fourth is the DPFM dummy. This variable captures the effectiveness of the DPFM that started in the Tokyo metropolitan area in October 2003. This variable takes one if a monitoring station was built in the designated areas after 2004 and takes zero otherwise. While DPFM makes it mandatory to install PM removal equipment, some firms observe the regulation by replacing their vehicles to new ones instead of installing the equipment (Iwata, 2011). This may lead to help reduce NOx concentration in addition to PM concentration, as the two pollutant emission intensities of new vehicles are better than those of old ones because of the ES. Thus, we use DPFM dummy variable for NOx concentration function as well as PM concentration function.

The fifth is the amount of the LEV subsidies, i.e., a variable that captures the cost effectiveness of the subsidies. Lately, many municipalities offer subsidies and encourage a switch to LEVs. Amount of LEV subsidies differ by municipality and year (see Table 1). In 2007, for example, Kanagawa prefecture in Tokyo metropolitan area subsidized one-eighth of the cost for either switching to LEVs to firms in the prefecture that own freight weighing over 3.5 tons. Because a subsidy affects air quality not only of the year when the subsidy is offered but also in the subsequent years (i.e., subsidized firms that purchased LEVs will continue using the vehicles in the later years), we consider the subsidy as flow and revised the stock based on the assumption that the depreciation rate is 3 percent.

The sixth variable captures the spillover effect of LEV subsidies. Vehicles in a municipality may be used outside of the municipality and thus, a municipality's subsidy may help improving ambient air quality in its neighboring municipalities. To capture this spillover effect, we grouped the areas under study into four metropolitan areas (Tokyo, Nagoya, Osaka and Fukuoka) and use the sum total of subsidies in the region to which each municipality belongs. For example, there are 8 municipalities in Tokyo metropolitan area. We set all subsidies except Tokyo municipality in the Tokyo metropolitan area as the value for spillover effect of Tokyo municipality.

The seventh variable captures the cost effectiveness of DPF subsidies. The equipment is effective to reduce PM emissions and not NOx. Hence, DPF subsidies are used only for PM concentration function. Just like LEV subsidies, the effectiveness of DPF subsidy lasts after the year in which it was offered and thus, its stock value was revised in accordance with the 3 percent depreciation rate.

The eighth variable captures the spillover effect of DPF subsidy. Just like LEV subsidies, a municipality's DPF subsidy may lead to improving ambient air quality not only in that municipality but also in the surrounding municipalities. Thus, we applied the same procedure to this variable as that for the LEV subsidy.

All eight variables are expected to contribute to reducing air pollutants; that is, their coefficients are likely to be negative. This study looks at the size of the coefficients to compare the effectiveness between/among the regulations.

3.2. Vector of Social Structure

NOx and PM concentration levels are influenced by economic activities around monitoring stations as well. To capture the size of economic activity, we use the following three variables. As a variable for traffic volume around stations, we use the freight tonnage in the municipality to which each station belongs. We use freight tonnage because most NOx and PM pollutions are caused by diesel trucks. To understand traffic activities around stations in more details, we use highway dummy. "Highways" in this study refer to the "major regional roads" as defined in the census of transportation as well as the roads larger than them. The highway dummy takes one if a station is near a highway and takes zero otherwise.

Ambient air quality is also affected by industry activities at factories and thus, we use a dummy for industrial areas to capture productive activities near stations. This dummy takes one if a station is located either at "semi-industrial area," "industrial area," or "industrial exclusive area" as defined in The Japanese City Planning Law. The dummy takes zero otherwise.

All these variables capture economic activities. The coefficients of these variables are expected to be positive, as ambient air quality deteriorates as economic activities become active.

3.3. Vector of Climate

Climate conditions are also included into the model as explanatory variables. As pointed by Henderson (1996) and Narain & Krupnick (2007), meteorological conditions significantly affect ambient air quality. Wind and rain disperse air pollutants while reducing their concentration levels. In winter if warm air interacts with cold air, dispersion of pollutants occurs even when winds are weak around stations (Goyal, 2002). Therefore, factors such as wind speed, rainfalls, or temperatures are also likely to affect NOx and PM levels. We thus use three variables to capture climate conditions: the average annual temperature, the average annual wind speed, and the average annual rainfall.

4. Data

This study uses data derived from air pollution monitoring stations in four metropolitan areas (Tokyo, Nagoya, Osaka, and Fukuoka) from 1976 and 2005. Based on "Air Pollution Monitoring Stations Data" published by the Japanese Ministry of the Environment (JEPA), there are 1,003 and 944 monitoring stations for NOx and PM in the four metropolitan areas between 1976 and 2005, respectively.[6] The numbers of stations, however, change every year as new stations open and existing stations either close down or withdraw. To ensure computational feasibility for spatial estimation described in next section, we extract balanced data from the unbalanced one. In addition, to control for effects of non-transportation policies on air pollution from industrial sectors, we only use the data of load side monitoring station.

The period of extracted balanced panel data is from 1990 to 2005 as the data provides largest numbers of observations for PM which is 1,184 observations (87 stations for each year). Many PM monitoring stations were constructed since late 1980s. For example, when we use balanced panel data from 1982 to 2005, the number of PM monitoring stations for each year is only

[6] The data is located at the National Institute for Environmental Studies (NIES) website, http://www.nies.go.jp/igreen/index.html. The institution is established under the Japanese Ministry of the Environment.

15. On the contrary, the number of NOx monitoring stations did not change so much over years. The numbers of NOx monitoring stations for each year are 111 and 147 with 1982-2005 and 1990-2005 balanced panel data, respectively. Hence, to obtain large observations on PM, we use data from 1990 to 2005.

The data contains information including the location of each station, environment around the station, as well as the types of air pollutants it monitors. Using this data of the location, we develop industrial-area dummy and highway dummy.

The annual average concentrations and hourly maximum concentrations of NOx (unit: ppm) and PM (unit: mg/m^3) for each monitoring station are obtained from "Monthly and Annual Levels of Air Quality" published by the JEPA, and then we merge the station data and pollution data.

The database on NOx and PM concentration levels at monitoring stations is then merged with the following data. NOx and PM values for ES are created from Osaka Prefecture (2006). Because the upper limit of emission intensity under ES is identical across all regions in Japan, the variable changes only by year. As mentioned earlier, we have standardized the value to 100 for the years before the regulation was introduced, which means that if the regulation becomes more strict, the value becomes smaller than 100.

The annual gross amount of LEV and DPF subsidies are obtained from the municipalities. These values are identical for stations within the same municipality. As shown in Table 1, most municipalities introduced the subsidies after 2001 because the Automobile NOx-PM Law was introduced that year. Installation of DPF is mandatory under the DPFM in the Tokyo metropolitan area. Thus, the total amount of DPF subsidies in the area is larger than that in the other areas where the installation is not mandatory. Neither of these subsidies is available in Fukuoka area where RP, ARP and DPFM are not implemented.

In regard with the other data for control variables, we use vehicle/freight tonnage by municipality available at "Land and Transportation Statistics Directory" published by the Japanese Ministry of Land, Infrastructure, Transport and Tourism. We obtain climate/weather data from the weather station nearest to each monitoring station. These climate data are available in "Weather Statistics Information" published by Japan Meteorological Agency. Table 2 shows descriptive statistics of our data.

5. Estimation Results

We estimate the concentration function (1) with two specifications on the error terms; fixed effects and spatial random effects. First, considering monitoring station's unobserved specific fixed effect, we conducted Hausman test to examine which model is suitable – a fixed effects model or a random effects model –. The former one was found to be more suitable. When we conducted Serial test (Wooldridge, 2002), a serial correlation was observed. Thus, treating the effect at individual stations as fixed effect, we estimated AR1 fixed effects model.

Next, we consider spatiality, that is, the location of monitoring stations. If pollutant concentration level at a station is high, the level at other neighboring station is also likely to be high because socio-economic or geological characteristics between the two stations may not be different from each other. To consider this spatial autocorrelation between any two stations in same metropolitan area, we employ feasible generalized least squares with AR1 disturbance. We set spatial weighing matrix for each area, that is, we assume that error term in a monitoring station in a metropolitan area is correlated with that in same areas' station according to distance between the two stations. Weighting matrix for each area is assumed to be an inverse function of squared distance between two stations in same area, and value in the matrix is zero when distance between two stations is more than 10km.[7]

5.1. NOx Concentration Function

Table 3 exhibits estimation results by fixed effect model, column (1) and (2), and spatial random effect model, column (3) and (4), respectively.[8] Over viewing the estimation results of fixed and spatial random effect models, we do not find remarkable difference.

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[7] Though we use other functional forms for the weighting matrix, estimation results are not different.

[8] These results are also available for the cases using annual average and hourly maximum concentration levels as dependent variable.

The coefficient of ES in all estimation results is positive and significant at the 1 percent level both for the annual average and hourly maximum concentrations. This means that NOx concentration levels decrease as the maximum allowable limit of emission intensity for NOx under ES becomes severe. It is found that the average concentration decreases by 0.0003~0.0004 ppm and the maximum concentration by 0.0017~0.0024 ppm if the limit is reduced to 1 percent below 1972 levels.

In all the estimation results, the RP dummy variable is negative and significant. This means that RP helps reducing NOx concentration levels. The reduction is about 0.0020 ppm for the average concentration and 0.0111 to 0.0208 ppm for the maximum concentration. Although the effectiveness of the law was said to be restrictive (Sano, 2008), it was indeed effective.

ARP by the Automobile NOx-PM Law also reduces the average NOx concentration by 0.0022 to 0.0028 ppm and the maximum concentration by 0.0418 to 0.0432 ppm (statistically significant at the 1 percent level). All the estimation results show that the size of reduction is greater under the ARP than the RP for the average and maximum concentrations That is, the law amendment was effective in reducing concentration levels.

The effectiveness of DPFM is statistically significant only in the spatial random effect model at 10 percent. Hence, we can roughly conclude that DPFM improved NOx concentration level in Tokyo metropolitan area. The absolute values of the coefficient are smaller than those of RP and ARP. Although some firms may have switched to LEVs to comply with the regulation, DPFM did not seem to have much contribution in improving the concentration levels (i.e., the change brought by the regulation is not statistically significant), compared with the other regulations.

The coefficient of the LEV subsidies is also negative and statistically significant. That is, the more subsidies are given, the more NOx concentration reduced. Some firms may have purchased LEVs with the subsidies simply because they were planning to renew their vehicles anyway. In that case the subsidies do not have actual effect to reduce concentration levels. The results, however, show that the kind of free ride behavior is limited.

The spillover effects of a municipality’s LEV subsidy on other municipalities are significant in all the estimation results. That is, NOx concentration levels in a municipality improve even without subsidizing LEVs if LEV subsidies are offered in the surrounding municipalities. This result suggests that an environmental subsidy using a municipality's own budget generates positive external economy effect. The size of reduction brought by the spillover is about a third of that achieved by a municipality that offers its own subsidy.[9] Therefore, the spillover effect of the subsidy is neither small nor negligible.

The coefficient of traffic volume, used as the vector of social structure, is positive and significant at the 1 percent level (insignificant in fixed effect model). This means that ambient air quality deteriorates as the volume of freight traffic increases. It is also found that the average concentration levels are significantly high in industrial areas and both the average and maximum concentration levels are significantly high in the areas near highways. In fixed effect model, these dummy variables are dropped because the values do not vary over years.

The average concentration levels are higher in industrial areas whereas the maximum levels are the same as in other areas. The reason is because massive industrial production may not take place only at particular hours (which would lead to raise the hourly maximum concentration levels).

The average temperature, i.e., the vector of climate/weather conditions, negatively influences the concentration levels. That is, NOx concentration levels rise as the temperature lowers. This is consistent with the results in Goyal (2002). It is also found that wind speed and rain fall significantly affect NOx concentration levels.

5.2. PM concentration function

This section discusses the estimation results of the PM concentration function described in Table 4. The sample size is 8,384. The PM concentration function is different from the NOx concentration function in that there are eight variables for the category "emission control policies"; DFP subsidies and spillover effect have been added.

Similar to that of the NOx concentration function, the coefficient of ES is positive and

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[9] On spillover effect and free-riding, see Sigman (2002) that explores the context of the European Union and examines the spillover effect of pollution in international rivers as well as countries' free-riding.

statistically significant at the 1 percent level in all estimation results. That is, PM concentration decrease as the regulation becomes stringent both at the average and maximum concentration levels. The average concentration decreases by 0.0001 mg/m^3 and the maximum concentration decreases by 0.0010 mg/m^3 if the regulation is reinforced to 1 percent above 1993 levels.

Both the coefficients of the RP dummy and the ARP dummy are found negative and statistically significant in all estimation models, meaning that these renewal policies have contributed to reducing PM levels by 0.0019 to 0.0031 mg/m^3 for the average concentration and by 0.0120 to 0.0224 mg/m^3 for the maximum concentration. The results are slightly different from those of the NOx concentration function when their coefficients are compared at the absolute values. In estimation results for the annual average concentration function, the coefficient of the RP is greater than that of the ARP, suggesting that the reduction was larger before the regulation amendment took place. This indicates that while the RP under the Automobile NOx Law was meant to reduce NOx emissions exclusively, it actually reduced PM emissions as well.

The coefficient of DPFM dummy is negative and statistically significant in one estimation result only. Hence, the DPFM is not robustly effective in reducing PM concentration level, unlike the ES and RP. The reduction brought from DPFM is not as strong as those of the RP and ARP Therefore, it is concluded that the municipal DPFM helped reducing neither NOx nor PM concentrations well.

The effectiveness of LEV subsidies is not found to be significantly negative except the result shown in column (1) by fixed effect estimation. The negative coefficient of DPF subsidies is significant by fixed effect model, but not by spatial random effect model. Hence, we cannot conclude that these subsidies brought reduction of PM concentration. Though the both coefficients of DFP and LEV subsidies are significantly negative in column (1), the value of DPF subsidies is eight times lower than that of LEV subsidies. Thus, it may be more cost effective to subsidize LEVs than DPFs. This is consistent with Iwata's (2011) simulation study.[10] Tables 1 shows that the municipalities in the Tokyo metropolitan area spent their subsidies more on the equipment than on

[10] The designated equipment can reduce PM emissions by 30 to 70 percent. However, switching to low emission vehicles is more cost effective than installing the equipment, because PM emissions from vehicles had been reduced significantly after the implementation of PM unit regulation in 1993 (Iwata, 2011).

vehicles, though the opposite is the case in other areas. It may be more effective for the municipalities in the Tokyo metropolitan area to shift their focus on subsidizing cleaner vehicles.

The spillover effects of LEV subsidies are statistically significant in most estimation results. The spillover effects of DPF subsidies are insignificant or significantly positive. That is, unlike the NOx concentration function, neither subsidies have robust spillover effects in mitigating PM concentration in other municipalities.

Unlike the NOx concentration function, obvious differences between estimation results for subsidies from fixed and spatial random effect model are found. If we take spatial correlation among monitoring stations into account, the significant effects of the subsidies and their spillovers in improving ambient air quality do not tend to be observed. This fact shows that spatiality plays an important role in considering the PM concentration function.

Moving to the variables for social structure, we can find link between PM concentration levels and traffic volume. Also, the effect of highways near monitoring stations is statistically significant. The coefficient of industrial-area dummy is not statistically significant.

Although some are not statistically significant, most coefficients of meteorological conditions are negative. That is, PM concentration levels decrease as the average temperature becomes higher, the wind speed becomes faster, or rainfall increases. This is consistent with the results in the past studies.

5.3. The Effectiveness of Policies After the 1990s

This section discusses how ambient air quality was improved by the each policy, namely, ES, RP, ARP, DPFM, DPF and LEV subsidies. Our analysis here focuses on the areas in the Tokyo metropolitan area where all policies are effective. Using the values from the spatial random effect estimation results in Tables 3 and 4, we estimated predicted values of concentration levels both for the cases where vehicle emission control policies exist and do not exist, while holding all other factors fixed. Figures 5 to 8 present NOx and PM concentration reductions from each policy, respectively, specifically, by showing the change of the means at monitoring stations.

For the purpose of comparing the effectiveness of the policies, we set 1991 as an initial year in simulation because the RP started in 1992. The value of ES in 1991 is assumed to unchange afterward. In other words, as the baseline of our computation we conditioned on the upper limits under ES before 1991.

The line, “Without policy”, in each figure, shows the change of concentration levels when none of the policies exists. “With ES” is the case when only ES exists. That is, the gap between “Without policy” and “With ES” indicates the concentration reduction brought by ES after 1992. Similarly, the gap between “With ES, RP & ARP” and “With ES” is the concentration reduction brought by RP and ARP, and the gap between “With ES, RP & ARP” and “With ES, RP, ARP & DPFM” is the concentration reduction brought by the DPFM carried out in municipalities in the Tokyo metropolitan region. The gap between “With ES, RP, ARP & DPFM” and “With all policies” means the concentration reduction brought by the two types of subsidies.

Even when no policy is imposed, both NOx and PM concentration levels change because traffic volume and weather/climate condition have changed. The amount of traffic volume in Japan dramatically dropped because of great recession in 1994, therefore the NOx and PM concentration levels in 1994 decrease even without policy.

In the case when only ES is effective, the PM concentration levels decrease especially after 1997 as the regulation became more stringent (see Figure 4). The effectiveness of RP between 1992 and 2002 is attributed to the Automobile NOx Law, and that of ARP between 2003 and 2005 to the Automobile NOx PM Law. NOx and PM concentration reductions by DPFM are limited as shown in figures, compared to other policies.

Table 5 presents the annual average percentage of concentration reduction by each type of regulation. The contribution of subsidies is excluded because variables representing regulations in the table are binary. The baseline is when the respective regulation is absent (though we conditioned on regulations that were implemented prior to the studied period). That is, for example, the percentages in the column “ES” show the percentages of concentration reductions compared to the case where the ES regulation is not implemented. The percentages in the column “ARP” show the concentration reductions compared to the case where ARP is not implemented while RP and ES are effective.

ES is quite effective for reducing NOx and PM concentration levels. It is found that PM concentrations reduced greatly in particular, apparently because upper allowable limit of PM emission intensity under ES was reinforced rapidly in a short period of time (see Figure 4). Although the regulation cannot improve the environmental performance of vehicles that are currently being used, the size of its effectiveness is as large as those of RP and ARP.

Although the RP targeted NOx concentrations, it is found to be also effective to decrease PM concentration levels. Presumably, this is due to the combination of two reasons: 1) ES for PM concentrations has been reinforced rapidly since 1993 and thus PM concentrations from new vehicles decreased more greatly than NOx concentrations, and 2) high emission vehicles were encouraged to be renewed under the RP. The change from the RP to the ARP seems to have contributed to improving ambient air quality; this replacement policy is more effective with the law amendment, resulting in more reductions both in NOx and PM concentrations. With regard to DPFM, NOx and PM concentration reduction percents are small and thus their effectiveness is limited.

6. Conclusion

Using data from 1990 to 2005 on NOx and PM concentration levels at air pollution monitoring station, this study examines the effectiveness of the Japanese past and current vehicle emission control policies. Our results indicated that most policies are effective to decrease both NOx and PM concentration levels. Thus, it is concluded that Japanese authority succeeded in attaining cleaner air by emission control policies.

In all the estimation results, the improvement on ambient air quality by ES is great, and the RP and ARP are also effective to attain cleaner air. However, it is not clear if the DPFM had effects on decreasing emission concentration levels. LEV subsidies reduce NOx concentration level, whereas LEV and DPF subsidies do not robustly decreased PM concentration level.

From these findings, we can derive the following three policy implications. First, it is suggested that the emission intensity regulation like the ES is most important among available emission control policies. The reasons are following two; 1) robust improvement of emission concentrations are found only by the ES and RP. 2) replacement policy from old vehicles into new ones such as RP does not work as an emission control policy unless emission intensity of new vehicles is better than that of old ones. When an authority implements ES type regulation, it gives/enforces automakers an incentive/duty to produce cleaner vehicles. Therefore, in order to obtain further social welfare by mitigating air pollution from automobiles, emission intensity regulation for new vehicles should be firstly introduced in a country where any emission control policies have not been implemented yet.

Second, subsidies should be spent on LEVs rather than PM removal equipment because the later subsidy does not significantly robustly improve PM concentration level. In the Tokyo metropolitan area, more subsidies are spent on the equipment perhaps because they have imposed an ordinance to make its installation mandatory. Subsidizing the equipment is found to be cost ineffective both in the ex-ante (Iwata, 2011) and ex-post (this study) evaluations. Thus, it is advised that the municipalities, particularly those in the Tokyo metropolitan area, shift their target to subsidizing LEVs. In addition, if policymakers intend to subsidize LEVs, emission intensity regulation is necessary. This is because replacement by the subsidy is not environmentally friendly if environmental performance of new vehicles is equal to that of old ones.

Third, authority should consider presence of the spillover effect in subsidizing LEVs. The LEV subsidies are found to have spillover effect for improving NOx concentration on other neighboring municipalities, and the effect is not negligible. If neighboring municipalities are keen to reduce emissions, it is not necessary for a municipality to keep intensifying its own regulation. To avoid appearance of free-riding on environmental aggressive municipalities, co-operation or negotiation among municipalities is needed.

Due to data restriction, this study estimated the effectiveness of vehicle emission regulations exclusively. As part of the ex-post analysis, it is important to estimate the cost of the regulations. This issue is left for future studies.

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Tables & Figures

Figure 1. Transition of NOx Concentration Levels (unit: ppm)

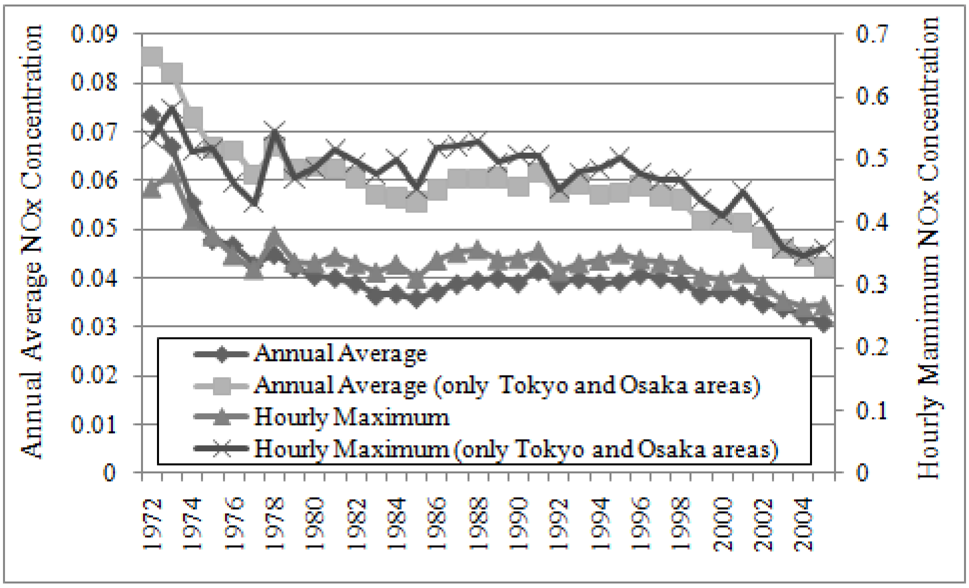


Figure 2. Transition of PM Concentration Levels (unit: mg/m^3)

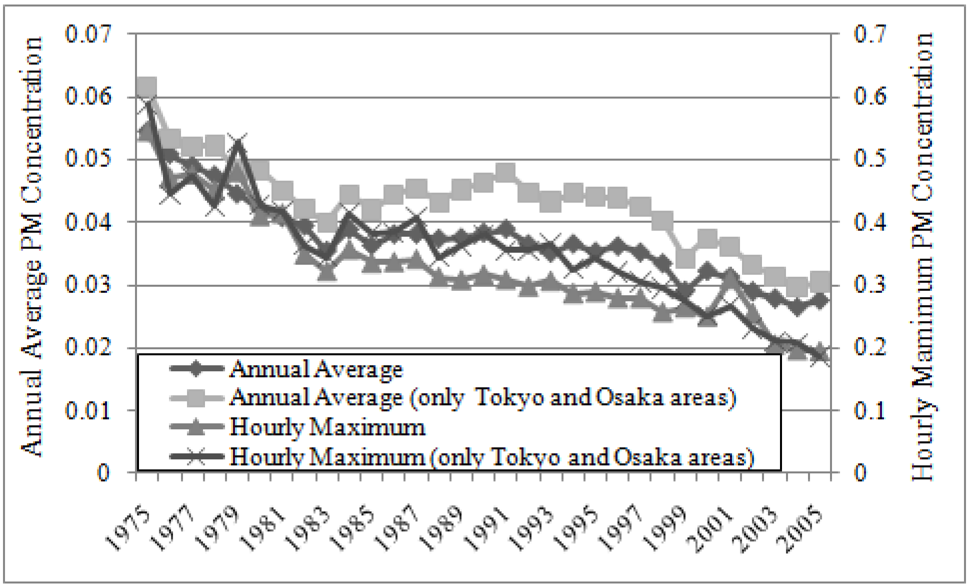


Figure 3. Biggest four metropolitan area in Japan

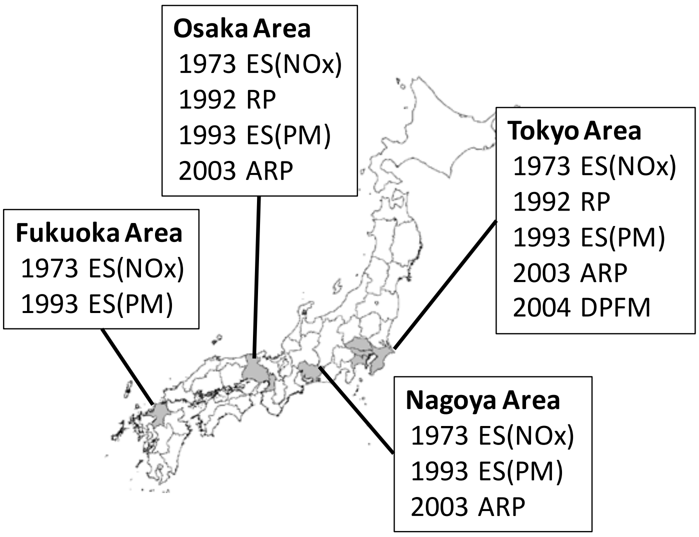
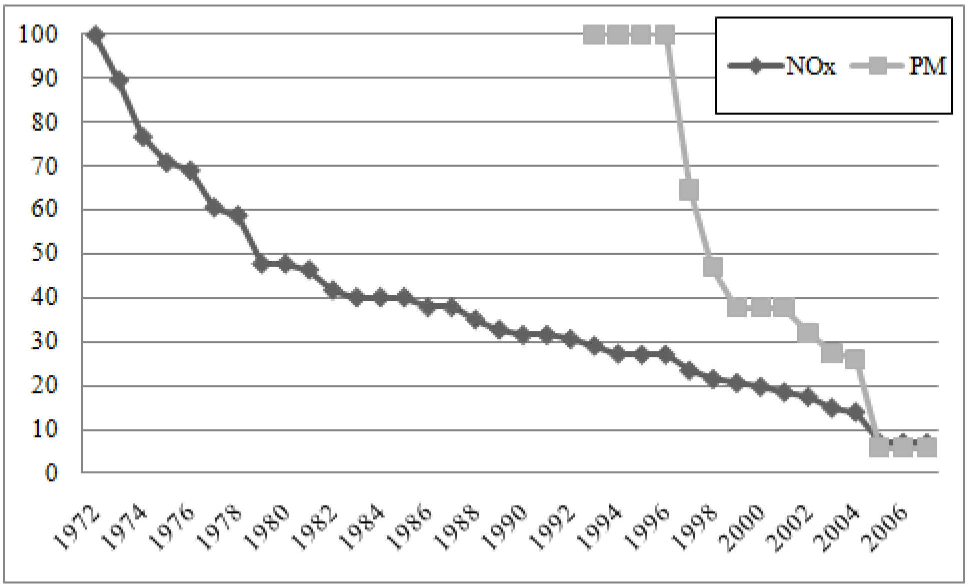


Figure 4. Transition of tightening of NOx and PM Emission intensitys



Note: The values are average because emission intensitys are set by vehicle type. The standard values are set to 100. The standard value of NOx and PM is in 1972 and 1993, respectively.

Figure 5 Annual average NOx reductions by policy (Unit: ppm)

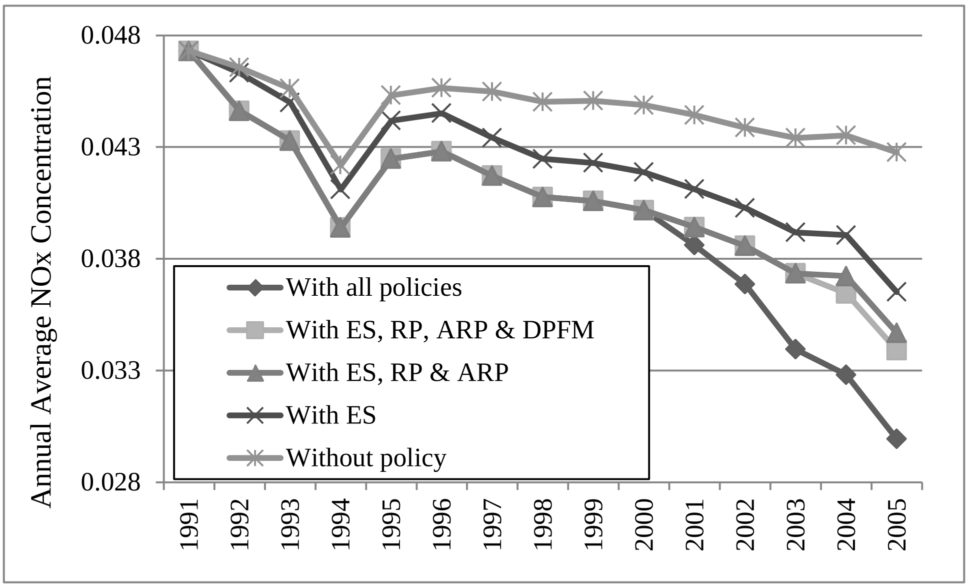


Figure 6 Hourly maximum NOx reductions by policy (Unit: ppm)

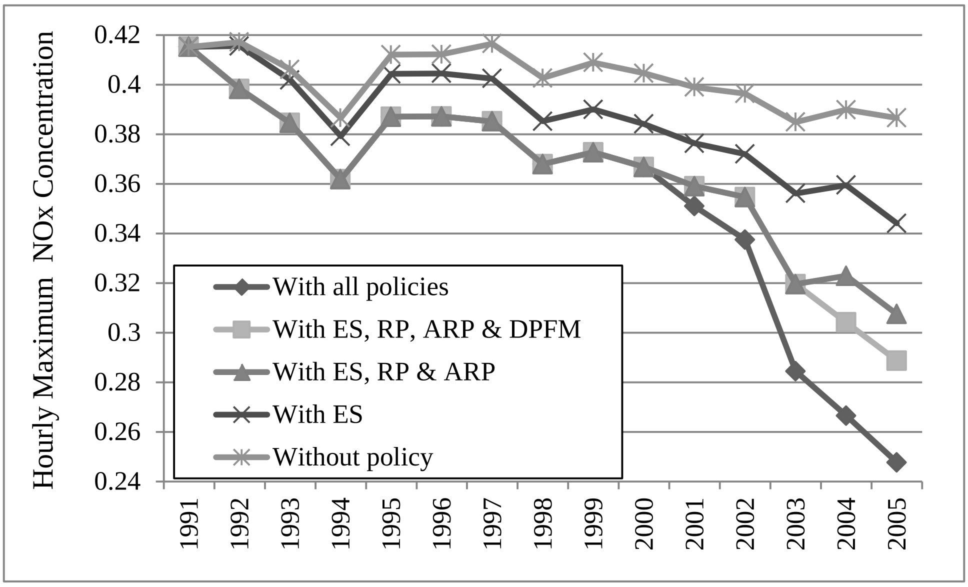


Figure 7. Annual average PM reductions by policy (Unit: mg/m^3)

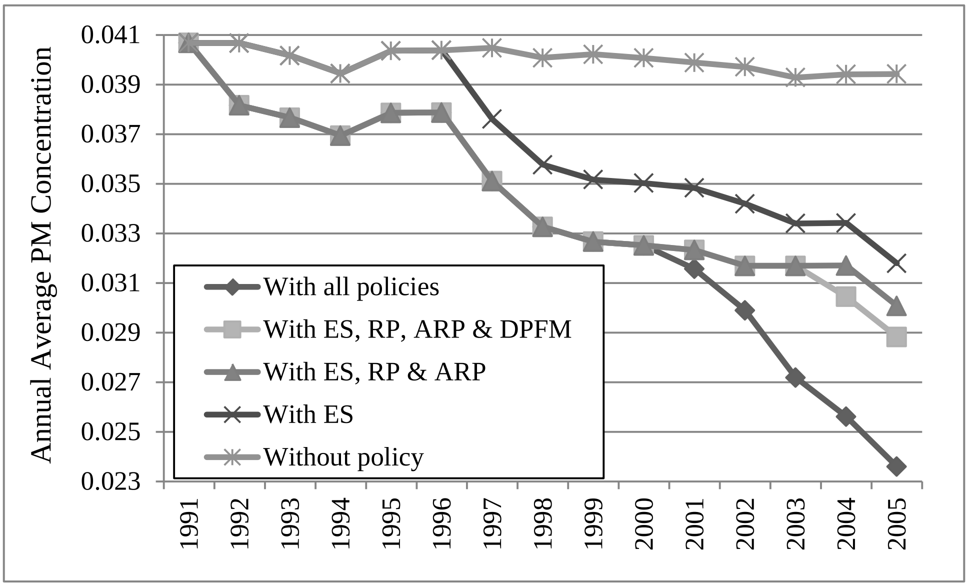


Figure 8. Annual average PM reductions by policy (Unit: mg/m^3)

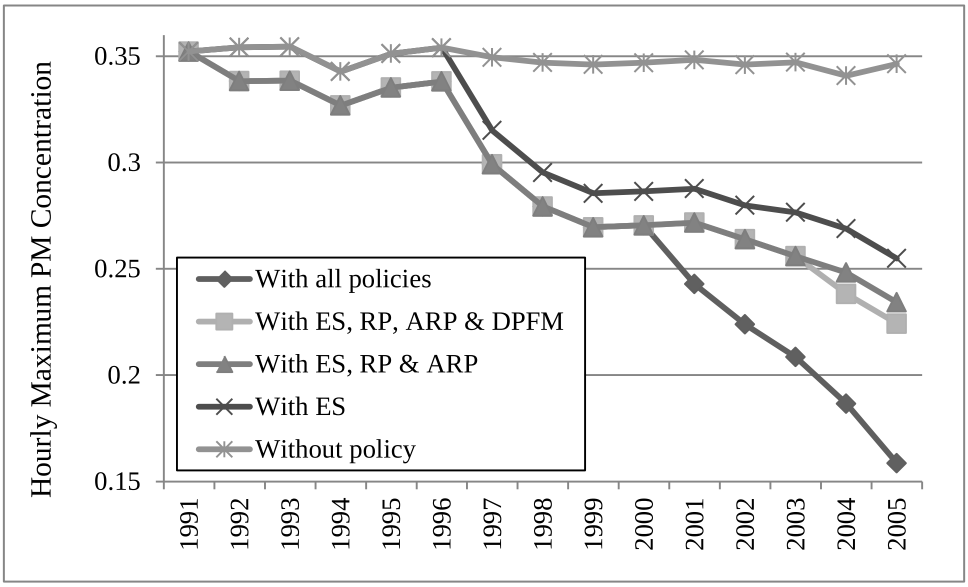


Table 1 Annual amount of subsidies by metropolitan area (unit: 10,000 yen)

Year	Tokyo Area	Osaka Area	Nagoya Area	Fukuoka Area
Subsidy for Low Emission Vehicle				
1999	0	2146	0	0
2000	0	2465	0	0
2001	52205	2228	0	0
2002	60564	22210	4139	0
2003	149391	28743	8749	0
2004	27230	30822	23510	0
2005	33518	25652	25619	0
Total	322907	114266	62017	0
Subsidy for DPF instration				
1999	0	0	0	0
2000	0	0	0	0
2001	60588	5500	0	0
2002	527792	2689	0	0
2003	1798329	10000	4691	0
2004	234255	3321	2586	0
2005	127320	5600	0	0
Total	2748284	27109	7278	0

Note: Tokyo, Osaka, Nagoya and Fukuoka metropolitan areas are consist of 8, 4, 2 and 3 municipalities, respectively.

Table 2 Descriptive Statistics

Pollutant	NOx		PM	
Number of Observations	9696		8384	
	Mean	S.D.	Mean	S.D.
Concentration level				
Annual Average NOx Concentration (ppm)	0.046	0.032		
Hourly Maximum NOx Concentration (ppm)	0.414	0.190		
Annual Average PM Concentration (mg/m3)			0.035	0.011
Hourly Maximum PM Concentration (mg/m3)			0.285	0.115
Emission Control Policies				
ES (NOx)	22.56	6.91		
ES (PM)			63.49	34.12
RP	0.421	0.494	0.420	0.494
ARP	0.150	0.357	0.151	0.358
DPFM	0.061	0.240	0.065	0.246
LEV subsidy (10,000 yen)	8175	22120	7951	21542
LEV spillover (10,000 yen)	44278	107097	46035	109718
DPF subsidy (10,000 yen)			52693	178272
DPF spillover (10,000 yen)			325341	968666
Social Structure				
Industrial-Area Dummy	0.071	0.258	0.073	0.259
Highway Dummy	0.221	0.415	0.128	0.334
Freight Tonnage (1,000 tonnages)	246417	54651	246706	55062
Climate Conditions				
Average Temperature (℃)	15.722	0.985	15.701	0.981
Wind Speed (m)	2.419	0.912	2.409	0.930
Rain Fall (mm)	1440	351	1440	347

Table 3 Estimation results of NOx concentration function

	(1)			(2)			(3)			(4)		
Model	Fixed Effect						Spatial Random Effect					
Dependent Variables	Annual Average			Hourly Maximum			Annual Average			Hourly Maximum		
	Coef.	t-value		Coef.	t-value		Coef.	t-value		Coef.	t-value	
Emission Control Policies												
ES	0.0004	15.65	***	0.0024	10.30	***	0.0003	8.30	***	0.0017	3.56	***
RP	-0.0020	-5.64	***	-0.0111	-2.55	**	-0.0020	-5.67	***	-0.0208	-2.68	***
ARP	-0.0028	-6.63	***	-0.0418	-8.20	***	-0.0022	-4.60	***	-0.0432	-4.63	***
DPFM	0.0005	1.35		0.0067	1.26		-0.0008	-1.77	*	-0.0188	-1.76	*
LEV subsidy	-0.0314	-4.45	***	-0.3787	-5.82	***	-0.0252	-2.96	***	-0.2060	-1.76	*
LEV spillover	-0.0123	-6.73	***	-0.1423	-8.03	***	-0.0076	-3.52	***	-0.0853	-2.51	**
Social Structure												
Industrial-Area Dummy							0.0085	7.90	***	-0.0020	-0.19	
Highway Dummy							0.0578	80.52	***	0.1663	21.13	***
Freight Tonnage	0.0060	1.45		0.0631	1.17		0.0596	17.61	***	0.5297	6.38	***
Climate Conditions												
Average Temperature	-0.0008	-7.56	***	-0.0086	-5.41	***	-0.0001	-0.49		0.0014	0.56	
Wind Speed	-0.0014	-3.78	***	0.0010	0.22		0.0011	4.39	***	0.0154	3.31	***
Rain Fall	1.0548	5.36	***	-6.4623	-2.14	***	0.4682	2.18	**	-13.7270	-2.53	**
Constant term	0.0517	65.02	***	0.5053	18.44	***	0.0096	4.32	***	0.1581	3.02	***

Note: ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively. Unit for rain fall was modified to 1 kilometer, for traffic volume to one billion tonnes, and for subsidies and spillover effect (both low emission vehicles and PM removal equipment) to ten billion yen.

Table 4 Estimation results of PM concentration function

	(1)			(2)			(3)			(4)		
Model	Fixed Effect						Spatial Random Effect					
Dependent Variables	Annual Average			Hourly Maximum			Annual Average			Hourly Maximum		
	Coef.	t-value		Coef.	t-value		Coef.	t-value		Coef.	t-value	
Emission Control Policies												
ES	0.0001	26.79	***	0.0010	20.21	***	0.0001	12.63	***	0.0010	13.92	***
RP	-0.0031	-9.18	***	-0.0120	-2.43	**	-0.0027	-6.43	***	-0.0174	-3.29	***
ARP	-0.0028	-7.23	***	-0.0169	-3.03	***	-0.0019	-3.42	***	-0.0224	-3.14	***
DPFM	-0.0006	-1.56		-0.0053	-0.88		-0.0013	-2.35	**	-0.0100	-1.17	
LEV subsidy	-0.0195	-2.80	***	0.0451	0.48		-0.0127	-1.27		0.0136	0.11	
LEV spillover	-0.0145	-3.65	***	-0.4186	-7.33	***	-0.0080	-1.32		-0.4355	-5.32	***
DPF subsidy	-0.0024	-2.76	***	-0.0272	-2.20	**	-0.0010	-0.71		-0.0261	-1.48	
DPF spillover	0.0002	0.44		0.0333	5.31	***	-0.0001	-0.18		0.0377	4.19	***
Social Structure												
Industrial-Area Dummy							0.0004	0.54		-0.0019	-0.26	
Highway Dummy							0.0105	19.64	***	0.0277	4.81	***
Freight Tonnage	-0.0034	-0.85		0.1373	2.24	**	0.0208	5.22	***	0.1062	1.94	*
Climate Conditions												
Average Temperature	-0.0004	-3.34	***	-0.0079	-4.12	***	0.0001	0.85		-0.0052	-2.62	***
Wind Speed	-0.0008	-2.25	**	-0.0066	-1.35		-0.0003	-1.14		0.0012	0.41	
Rain Fall	-0.0911	-0.45		-3.0120	-0.85		-0.4639	-1.77	*	-1.9184	-0.43	
Constant term	0.0398	29.59	***	0.3499	10.45	***	0.0248	9.47	***	0.3013	8.16	***

Note: ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively. Unit for rain fall was modified to 1 kilometer, for traffic volume to one billion tonnes, and for subsidies and spillover effect (both low emission vehicles and PM removal equipment) to ten billion yen.

Table 5 Reductions of annual average NO_x/PM levels by regulation

	ES	RP	ARP	DPFM
Annual average NOx concentration level	5.92%	3.97%	4.80%	2.16%
Hourly maximum NOx concentration level	4.47%	4.42%	10.35%	5.96%
Annual average PM concentration level	13.23%	6.69%	5.21%	4.07%
Hourly maximum PM concentration level	18.23%	5.05%	7.74%	4.16%

Note: The numbers are the percentages of reductions compared to the case where the respective regulations are absent. In each case, we conditioned on regulations that were imposed prior to the respective regulations.

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