A quantitative evaluation of vehicle emission regulations: Evidence from Japanese experience

Abstract

Japanese people in metropolitan areas suffered from severe air pollution problems in 1960's. Even in 1980's and 1990's they still faced air pollution problem from automobiles. Since then, the government has implemented various policy instruments and successfully improved the air quality. To date, however, it is not clear which policy instruments were effective in mitigating air pollution from automobiles The purpose of this paper is to empirically reveal whether these implements significantly help attaining cleaner air. With long term data from 1976 to 2005, we estimate the concentration functions where the dependent variables are emission concentration levels of Nitrogen Oxides (NOx) and Particulate Matters (PM). We find that all regulations and subsidies decreased the concentration levels of both pollutants. Among them, the traditional vehicle unit regulation was found to be more effective than the others. As for subsidies, it is also revealed that subsidies for the vehicle replacement were more cost-effective than those for pollutant removal equipments. Furthermore, the empirical result indicates that subsidy in one municipality air had spillover effects on the surrounding municipal areas in improving the pollutant concentrations.

1. Introduction

Japanese people in metropolitan areas suffered from severe air pollution problems in 1960's. Even in 1980's and 1990's they still faced air pollution problem from automobiles. Since then, the government has implemented various policy instruments Japan's first vehicle emission control was emission factor regulation in 1966, which was a type of vehicle unit regulation. Twenty years thereafter the government mainly focused on intensifying unit regulation, paying particular attention to reducing SO_2 emissions. Along with industry's voluntary effort, SO_2 levels significantly declined by the late 1980s. Reducing NO_x and PM[1] emissions had then become the major concern in the 1990s. Consequently, the Automobile NO_x Law (hereafter called "the NO_x law") was introduced in 1992, and PM was included in 1993 as part of the target air pollutants of unit regulation. Driving regulation has been implemented since 2000 at the municipal level (e.g., Tokyo in 2003). Further, vehicle type regulation was enacted in 2001 (and introduced in 2002) under the Automobile NO_x-PM Law (hereafter called "the NO_x-PM law"). In this way, Japanese government imposed severer regulations to satisfy emissions targets and introduced further additional measures if necessary.

As of 2008, the administrative emissions policy comprises of three parts: vehicle unit regulation, vehicle type regulation and driving regulation. These regulations appear to have been effective, as NO_x and PM concentration levels are decreasing over years. This is, however, only inferred from looking at the relationship between the regulations and the concentration levels over years. Although air quality has been monitored, individual regulations have not been evaluated from an ex-post perspective. We will thus examine the effectiveness of individual regulations by conducting an ex-post evaluation of past and current regulations, including vehicle unit regulation, vehicle type regulations both under the NO_x Law and the NO_x-PM Law, as well as driving regulation.

Besides these regulations, two types of subsidies have been offered at the municipal level since 2000 as part of emissions control. The subsidies are for promoting replacement of older high emission

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[1] In this study, PM represents PM_{10}, whch particulate diameter is less than 10 μm.

vehicles with new cleaner ones and for encouraging installation of PM removal equipment. Iwata's (2009) ex-ante analysis of driving regulation concludes that subsidies should be spent on low emission vehicles because the marginal abatement cost is higher for subsidizing PM removal equipment than subsidizing low emission vehicles. In this study, we will examine which type of subsidies is more effective in reducing air pollutants.

Because it is mainly metropolitan areas that are under the impact of vehicle air pollution, we focus on four metropolitan regions (Tokyo, Nagoya, Osaka, and Fukuoka) in Japan[2].

Using long term air quality data on NO_x and PM concentrations from 1976 to 2005, we examine the effectiveness of the two types of subsidies as well as the following regulations: vehicle unit regulation, driving regulation, and vehicle type regulation both under the NO_x law and the NO_x-PM law.

Although this is one of the first studies that conduct ex-post analysis of the effectiveness of vehicle emission regulations in Japan, several studies report cases overseas. In the United States, the federal government made it mandatory that counties provide their improvement plan for reducing O_3 levels if they do not satisfy the emissions target. Using O_3 data at air pollution monitoring stations in the United States from 1977 to 1987, Henderson (1996) examined whether this control had led to decreasing O_3 emissions. The analysis suggested that it brought a decrease in O_3 concentrations by 3 to 8 percent.

Auffhammer et al.(2009) also pay their attention on air pollutant concentrations in United states. They focus on 1900 Clean Air Act Amendments and examines whether that contributed to reduce PM_{10} levels with the monitoring data from 1990 to 2005. They conclude that that the amendment dropped the concentration level by 11 to 14 percent.

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[2] The prefectures under study are Tokyo, Chiba, Kanagawa, Saitama, Aichi, Osaka, Hyogo, and Fukuoka.

Vehicle air pollution is a serious concern in developing countries just as in developed countries. Using data from air pollution monitoring stations in Delhi, India from 1990 to 2005, Narain & Krupnick (2007) found that the conversion of commercial passenger vehicles (buses, three-wheelers, and taxis) to compressed natural gas has helped to reduce PM, CO, and SO_2 concentrations.

These studies use data from monitoring stations because they are the only place where data on air quality are available. Following these previous studies, this study uses data from air pollution monitoring stations.

Several studies as an ex-ante policy evaluation examined the effectiveness of the NO_x-PM law. Focusing their analysis on vehicle type regulation of the law, Arimura & Iwata (2008) found that the regulation brought positive net social benefit with legal vehicle inspection data. Iwata & Arimura (2009) suggested that net social benefit can increase significantly by optimizing vehicle type regulation. Iwata (2009) conducted an ex-ante assessment of driving regulation. Yokemoto & Hiruta (2004) and Yokemoto (2007) discuss how the vehicle type regulation and driving regulation can be improved.

This study attempts to make contribution to the literature in the following four aspects. First, it identifies the effectiveness of each regulation. While an increasing number of regulations and subsidies have been introduced, it is not clear which regulation helped to reduce what air pollutant to what extent.

Second, we conduct an ex-post evaluation of driving regulation. Driving regulation is different from vehicle type regulation in that the former may not have been observed strictly. Without observing vehicle type regulation, drivers cannot pass vehicle inspection. They can, however, continue driving their vehicles while violating driving regulation unless found from on-site inspections. For this reason, driving regulation may not have brought much improvement on air quality.

Third, the paper captures free riding by firms on subsidies for low emission vehicles. Some firms may have purchased low emission vehicles 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 emissions.

Fourth, the paper will explore the free riding and spillover effect of subsidies. A municipality's subsidy may have contributed to reduce emissions in the neighboring municipalities. Firms may not necessarily use their vehicles only within a single municipality. If they purchase low emission vehicles with a particular municipality's subsidy and continue driving across municipalities, the subsidy is effective to reduce emissions not only in the municipality that offered the subsidy but also the other municipalities in which the vehicles are being used. In such a case, free riding to a municipality's subsidy by other municipalities may be observable. On the other hand, air pollutants may "spillover" to neighboring municipalities by winds, and the spillover effect may exist even when a firm's vehicles stay within a single municipality.

The rest of the paper will be organized as follows. In the next section, we describe our estimation model. Section 3. explains dataset and Section 4. provides estimation results. Section 5. concludes the paper.

2. Estimation model

Because emissions targets for NO_x and PM have been set based on their concentration levels in the air (ppm or mg/m_3), 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[3]:

$$AC_{p,ijt} = X_{1,ijt}\beta_1 + X_{2,ijt}\beta_2 + X_{3,ijt}\beta_3 + \varepsilon_{ijt} \quad (1)$$

[3] Sigman (2002), Greenstone (2003), and Greenstone (2004) estimate concentration/emission function similar to the one in 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 $AC_{p,ijt}$ is the concentration levels of air pollutant *p* (NO_x or PM) at monitoring station *i* in municipality *j* at year *t*. X_1 is the vector of variables for vehicle emission regulation, X_2 is the vector of social structure, and X_3 is the vector of climate/weather condition. β_k (k = 1,2,3) are the parameters to be estimated and ε is an idiosyncratic error term. We examine the effectiveness of the regulations by estimating coefficients in equation (1) and looking particularly at the estimated coefficients of X_1. Further, by comparing the size of the coefficients, we identify to what extent the existing regulations have helped to reduce NO_x and/or PM emissions.

2.1. Vector of regulations

X_1, the vector of regulations, includes the following six variables (and eight for PM concentration function). The first variable is the one that captures the effectiveness of vehicle unit regulation, i.e., the upper limit value of emission factor imposed by the regulation. NO_x regulation began in 1973 and PM regulation in 1993. Therefore, the values used for NO_x and PM concentration functions are different. NO_x regulation has seventeen categories and PM regulation has seven categories according to the weight and engine type of vehicles. This study uses the average value of those categories. The standard values of NO_x and PM are set to 100, respectively. The standard value of NO_x 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 NO_x law dummy, i.e., the variable that captures the effectiveness of the law. This law is the forerunner of the NO_x-PM law. Introduced in 1992, it is the nation's first law that focused on vehicle type regulation. The law was revised in 2001 as its effectiveness was said to be insufficient (Sano, 2008). However, this point has not been examined empirically. In order to estimate the effectiveness of the law, we use the NO_x law dummy where an air pollution monitoring station takes one if it is located in the areas designated by the NO_x law between 1992 and 2002 (i.e., from the year the law was introduced until the year it was taken over by the NO_x-PM law) and takes zero otherwise.

The third is the NO_x-PM law dummy, i.e., the variable that captures the effectiveness of the law, in particular, its vehicle type regulation. This dummy takes one if a monitoring station is located in the area designated by the law after 2003 and takes zero otherwise. The coefficient of this variable captures the effectiveness of vehicle type regulation. It should be noted that the designated areas by this law are different from those by its forerunner, the NO_x law[4]. Because we use the data from 1976 to 2005, the effectiveness of the NO_x-PM law can be measured only for the period of three years, from 2003 to 2005.

The fourth is driving regulation dummy, the variable that captures the effectiveness of the driving regulation that started in the Tokyo metropolitan region in October 2003. This variable takes one if a monitoring station was built in the designated areas after 2004 and takes zero otherwise. Unlike the NO_x-PM law's vehicle type regulation, driving regulation is effective in all areas of a municipality (though some islands are exceptional). Thus, it is possible for a monitoring station to take different values for the NO_x-PM law dummy and for the driving regulation dummy. The monitoring station in Chichibu city, rural city in Saitama prefecture, for example, takes 1 for the driving regulation dummy but takes 0 for the NO_x-PM law dummy because the city was not part of the NO_x-PM law's designated areas in 2004.

While driving regulation 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, 2009). This leads to help reduce NO_x emissions in addition to PM emissions, as new vehicles are compliant with the newest stringent emissions standards. Thus, we use driving regulation variable for NO_x concentration function as well as PM concentration function.

[4] The designated areas by the NO_x-PM law are composed of the Nagoya region and the areas designated by the NO_x law.

The fifth is the amount of the subsidies for low emission vehicles, i.e., a variable that captures the cost effectiveness of the subsidies. Lately, many municipalities offer subsidies and encourage a switch to low emission vehicles[5]. Types and amount of subsidies differ by municipality and year. In 2007, for example, Kanagawa prefecture subsidized one-eighth of the cost for either switching to low emission vehicles or technical remodeling to firms in the prefecture that own freight weighing over 3.5 tons and/or special-use vehicles.

Apart from the prefecture level, some governance cities subsidize low emission vehicles on their own. Yokohama city and Kawasaki city in Kanagawa prefecture are cases in point. Thus, firms located in either of these cities receive subsidies both from the prefecture and the city. In this study, we assume that the amount of subsidies in a governance city consists of the sum total of subsidies from the city and the prefecture to which the city belongs[6]. 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 low emission vehicles 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 subsidies for low emission vehicles. Subsidies are offered both at the levels of prefecture and its government ordinance city. Firms' vehicles subsidized in a prefecture may be used outside of the prefecture and thus, a prefecture's subsidy may help improving air quality in its neighboring prefectures. To capture this spillover effect, we grouped the areas under study into four regions (Tokyo, Nagoya, Osaka and Fukuoka) and use the sum total of subsidies in the region to which each municipality belongs. For example, to capture the value of Tokyo city, we included all subsidies except Tokyo city in the Tokyo region, i.e., Saitama, Chiba and Kanagawa prefectures as well as their government ordinance cities.

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[5] Hyogo prefecture is the first municipality that offered this type of subsidy; it started in 1999.
[6] Because we use the data from 1976 to 2005, we do not include Sakai city that became a governance city in 2006.

The seventh variable captures the cost effectiveness of subsidies for PM removal equipment. The equipment is effective to reduce PM emissions and not NO_x. Hence, these subsidies are used only for PM concentration function. Just like subsidies for low emission vehicles, subsidies for the equipment are treated with the following conditions. First, the subsidies from prefectures and from governance cities are treated separately. Second, the total amount of subsidies from a governance city and the prefecture to which the city belongs comprises the value of governance cities' subsidies. The effectiveness of a 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 PM removal equipment. Just like subsidies for low emission vehicles, a municipality's subsidy may lead to improving 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 equipment variable.

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 and compares between/among the regulations.

2.2. Vector of social structure

NO_x and PM levels are influenced by economic activities around monitoring stations. To capture the size of economy, 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 NO_x and PM pollutions are caused by diesel trucks. City-level data are not available for the freight tonnage and we thus use prefecture-level data. 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.

Air quality is also affected by industry activities at factories and firms 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 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 air quality deteriorates as economic activities become active.

2.3. Vector of climate

Climate conditions are also included into the model as explanatory variables. As pointed in Henderson (1996) and Narain & Krupnick (2007), meteorological conditions significantly affect air quality. Wind and rain disperse air pollutants while reducing their 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 like wind speed, rainfalls, and temperatures are also likely to affect NO_x 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.

3. Data

This study uses data derived from air pollution monitoring stations in four metropolitan regions (Tokyo, Nagoya, Osaka, and Fukuoka) from 1976 and 2005. The data are unbalanced panel data because the number of stations changes every year as new stations open and existing stations either close down or withdraw. Based on "air pollution monitoring stations data" located at the National Institute for Environmental Studies (NIES) website, we extracted a total of 22,677 stations in the metropolitan areas between 1976 and 2005[7]. The dataset contains information such as the location of each station, environment around the station, as well as the types of air pollutants it monitors. Using this dataset, we developed industrial-area dummy and highway dummy. The average annual concentrations and one-hour maximum concentrations of NO_x and PM were obtained from "monthly

[7] The data is located at "Numerical database of environment," (http://www.nies.go.jp/igreen/index.html) in Japanese.

and annual levels of air quality" available at the NIES website. Not all stations under study monitor NO_x and PM emissions every year. Among the 22,677 stations, 21,800 stations had been monitoring NO_x emissions and 16,128 stations had been monitoring PM emissions during the period of study[8].

The database on NO_x/PM levels at monitoring stations were then merged with the following data. NO_x and PM values for vehicle unit regulation were created from the database of Osaka prefecture in 2006. Because upper limit of emission intensity under vehicle unit regulation 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. Table 1 shows descriptive statistics of our dataset.

Tables 2 and 3 show the annual gross amount of subsidies for low emission vehicles and for PM removal equipment, respectively. These are obtained from the prefectures to which the respective governance cities belong. These values are identical for stations within the same prefecture/city. As shown in the tables, most prefectures introduced the subsidies after 2001. This is plausibly because the NO_x-PM law was introduced that year, allowing for municipalities to initiate their own regulations.

Installation of PM removal equipment is mandatory under the driving regulation in the Tokyo metropolitan region. Thus, subsidies for the installation are available in all governance cities in the area except Kawasaki-city. In some prefectures (Aichi, Osaka and Hyogo), subsidies are available although the installation is not mandatory. Yet the total amount of the subsidies in these prefectures is much smaller than that of prefectures in the Tokyo metropolitan region. Neither of these subsidies is available in the regions where vehicle type regulation and driving regulation are not implemented: Fukuoka prefecture, Fukuoka city, and Kita Kyushu city.

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[8] Among the 16,128 stations, eight stations did not monitor one-hour maximum PM concentrations and thus there are 16,120 stations altogether.

We used vehicle/freight tonnage by prefecture that is available at "Land and Transportation Statistics Directory (published by the Ministry of Land, Infrastructure, Transport and Tourism) for the volume of traffic in the respective municipalities.

We derived climate/weather data from the weather station nearest to each monitoring station. These data are available in "Weather Statistics Information" published by Japan Meteorological Agency. There are some missing values in the data, especially in the 1970s.

4. Estimation results

We estimated the concentration function (1) by least-squares. Conducting the White test, we found that heteroskedasticity is present in the error term. We thus conducted Hausman test to examine which model – a fixed effects model or a random effects model – is suitable. 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.

4.1. NO_x concentration function

Table 4 presents the results of NO_x concentration function. The second and third columns show estimation results when the annual average concentration is used, and the fourth and fifth columns show results when the hourly maximum concentration is used. These results are also available for the cases using data from all stations under study (19,724 stations) as well as from vehicle emission monitoring stations only (4,813 stations). The sample size is slightly smaller than that in Table 3 because values for one year had been cut down by the AR1 fixed effects model. Variables for the regulations are highlighted in the table.

The coefficient of unit regulation is positive and significant at the 1 percent level both for the annual and maximum concentrations. This means that NO_x concentration levels decrease as NO_x unit regulation becomes severe (i.e., as the maximum allowable limit of NO_x emissions becomes lower). It was found that the average concentration decreases by 0.0003ppm and the maximum concentration by 0.0014ppm if the maximum allowable limit is reduced to 1 percent below 1972 levels[9]. The effectiveness of unit regulation holds for the case when the sample is limited to vehicle emission monitoring stations; furthermore, the level of decrease was found to be greater.

In all estimation results, the NO_x law dummy variable is negative and significant. This means that vehicle type regulation helped reducing NO_x emissions. The reduction was about 0.002 to 0.004ppm for the average concentration and about 0.014 to 0.022ppm for the maximum concentration. Although the effectiveness of the law was said to be restrictive (Sano, 2008), it was indeed effective.

Vehicle type regulation by the NO_x-PM law also reduced the average NO_x concentration by 0.002 to 0.004ppm and the maximum concentration by 0.032 to 0041ppm (statistically significant at the 1 percent level). The size of reduction is greater under the NO_x-PM law than the NO_x law for the maximum concentration, while it is the same for the average concentration. That is, the law revision was meaningful as far as the effect for reducing concentration levels is concerned.

The effectiveness of driving regulation was not statistically significant. Although some firms may have switched to low emission vehicles to comply with the regulation, that did not seem to have much contribution to improving the concentration levels (i.e., the change brought by the regulation was not statistically significant).

The coefficient of the subsidies for low emission vehicles (the stock value) is also negative and statistically significant. That is, the more subsidies the more NO_x concentration reduction. It thus appears that firms' free ride to the subsidies is either limited or not existent.

The spillover effect of a municipality's subsidy for low emission vehicles on other municipalities

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[9] As mentioned earlier, the regulation was not effective in 1972 and thus the value for the year was standardized to 100.

was significant at the 1 percent level. That is, NO_x concentration levels in a municipality improve even without subsidizing low emission vehicles if subsidies are offered in the surrounding municipalities.

This result suggests that an environmental subsidy using a municipality's own budget generates external economy effect. If a municipality offers a large amount of subsidy, the neighboring municipalities are likely to free ride[10]. The size of reduction brought by the free riding is, however, about a quarter of that achieved by a municipality that offers its own subsidy[11].

The coefficient of traffic volume, used as the vector of social structure, was positive and significant at the 1 percent level in all results. This means that air quality deteriorates as the volume of freight traffic increases. It was 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.

The fact that the average levels are higher in industrial areas whereas the maximum levels are the same as in other areas is consistent with intuition; it is not likely that massive industrial production takes place only at particular hours (which would lead to raise the hourly maximum levels).

The average temperature, i.e., the vector of climate/weather conditions, negatively influences the concentration levels. That is, NO_x levels rise as the temperature lowers. This is consistent with the results in Goyal (2002). It was also found that wind speed and rain fall negatively affect NO_x levels. However, some part of the result was opposite from our forcast.

4.2. PM concentration function

[10] 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.

[11] This is based on the estimation using data on all stations.

This section discusses the estimation results of PM concentration function. The sample size is 14,728 when values from all monitoring stations are used (columns 2 and 4) and 2,552 when values only from vehicle emission monitoring stations are used (columns 3 and 5). PM concentration function is different from NO_x concentration function in that there are eight variables for the category “vehicle emission regulations,” as subsidies for PM removal equipment and their spillover effect have been added.

Similar to that of NO_x concentration function, the coefficient of unit regulation is positive and statistically significant at the 1 percent level. That is, PM concentration decrease as the regulation becomes severe both at the average and maximum levels.

The average concentration decreases by 0.0001ppm/m_3 (and twice more reduction when only vehicle emission monitoring stations are considered) and the maximum concentration decreases by 0.0012ppm/m_3 (and 1.2 times more reduction when only vehicle emission monitoring stations are considered) if the regulation is reinforced to 1 percent above 1993 levels[12].

Both the coefficients of the NO_x law dummy and the NO_x-PM law dummy were found negative and statistically significant in all estimation models, meaning that these laws have contributed to reducing PM levels by 0.002 to 0.003mg/m_3 for the average concentration and approximately by 0.04 mg/m_3 for the maximum concentration. The results are slightly different from those of NO_x concentration function when their coefficients are compared at the absolute values. In all estimation results, the coefficient of the NO_x law is larger than that of the NO_x-PM law, suggesting that the reduction was larger before the law revision took place. This indicates that while the NO_x law was meant to reduce NO_x emissions exclusively, it actually reduced PM emissions as well.

The driving regulation dummy is negative and statistically significant at the 1 percent level for the average concentration. Their effect is 0.001 to 0.002mg/m_3, not as strong as that of the NO_x/NO_x-PM

[12] As mentioned earlier, the value for 1993 was standardized to 100 because the regulation was not effective then

laws. Nevertheless, it is still effective as a policy to reduce the average PM concentration levels. With regard to the maximum concentration, the coefficient is negative but not statistically significant.

The effectiveness of subsidies for low emission vehicles was found to be the same as that in NO_x concentration function, i.e., both the average and maximum PM levels decrease as the amount of subsidies increases. With regard to the average concentration levels, the effectiveness of the subsidies is higher for PM than for NO_x. This may be because PM unit regulation was reinforced rapidly in a shorter period of time compared to NO_x unit regulation.

The coefficient of subsidies for PM removal equipment is also negative and statistically significant at the 1 percent level. However, the value is lower than that of subsidies for vehicles and this is consistently observed across all estimation models. It is 11 times lower for the average concentration, and as large as 44 times lower for the maximum concentration. Thus, it is more cost effective to subsidize vehicles than the equipment. This is consistent with Iwata's (2009) simulation study[13]. Tables 2 and 3 show that the majority of municipalities in the Tokyo metropolitan region spend their subsidies more on the equipment than on vehicles, though the opposite is the case in other areas. It is more effective for the municipalities in the Tokyo region to shift their focus on subsidizing vehicles.

The spillover effect of subsidizing vehicles was statistically significant. For a municipality to reduce the average PM levels, spending a 100 million-yen subsidy has the same effect as having neighboring municipalities that spend a total of 310 million subsidies. As for the maximum PM levels, the ratio of these amounts (i.e., the amount of a municipality's own subsidy and the total amount of subsidies in the neighboring municipalities) is about the same. The result indicates the possibility of free riding among municipalities. The coefficient of the equipment's spillover effect is not statistically significant for the average concentration levels but it is positive and statistically

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[13] The 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, 2009).

significant for the maximum levels.

Moving to the variables for social structure, there was no clear link found between maximum PM levels and traffic volume. As for the coefficient of traffic volume, only the average concentration levels at vehicle emission monitoring stations were statistically significant. The effect of highways near monitoring stations was statistically significant. The coefficient of industrial-area dummy (i.e., the variables that capture the impact of factories) was not statistically significant in all estimation results.

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

4.3. The effectiveness of regulations after the 1990s

This section discusses how air quality was improved by the respective regulations, namely, vehicle type regulation, driving regulation and vehicle unit regulation. While Iwata (2009) estimated emissions exclusively from the vehicles under the driving regulation, this study uses observed values that include emissions from vehicles both under and not under regulations. It also differs from Iwata (2009) in that the effectiveness is estimated in terms of concentration levels. Hence, we cannot compare our results to those in Iwata (2009) in a straightforward manner. It should also be noted that our analysis here focuses on the areas in the Tokyo metropolitan region where all three regulations are effective.

Using the values in Tables 4 and 5, we estimated predicted values of concentration levels both for the cases where regulations exist and do not exist, while holding all other factors fixed. Figures 1 and 2 present NO_x and PM reductions by regulation, respectively, specifically, by showing the change of the means at monitoring stations.

For the purpose of comparing the effectiveness of the three regulations after the 1990s, the case where no unit regulation is effective means that the value of unit regulation in 1991 does not change afterward. In other words, as the baseline of our computation we conditioned on unit regulations before 1991.

The line, “without regulation”, in each figure shows the change of concentration levels when none of the three regulations exists. “+unit” is the case when only unit regulation exists. That is, the gap between “without regulations” and “+unit” indicates the reduction brought by unit regulation after 1992. Similarly, the gap between “+unit+type” and “+unit” is the reduction brought by vehicle type regulation, and the gap between “+unit+type” and “+unit+type+driving” is the reduction brought by the driving regulation carried out in municipalities in the Tokyo metropolitan region.

Even when no regulation was imposed, both NO_x and PM levels decreased gradually. This is because of the subsidies and also because traffic volume has decreased as the economy recessed in the 1990s. In the case when only unit regulation was effective, the levels decreased especially after 1997 as the regulation became severer. In the figure, the effectiveness of PM unit regulation is observable from 1997; though the regulation began in 1993, it became severer in 1997. The effectiveness of vehicle type regulation between 1992 and 2002 is attributed to the NO_x law, and that between 2003 and 2005 to the NO_x-PM law. NO_x reduction by driving regulation is very limited as shown in Table 4. The regulation was effective, however, for reducing PM emissions, though the impact is not so large.

Table 6 presents the annual average percentage of reduction by regulation. 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 “unit regulation” column show the percentages of reductions compared to the case where the regulation is not implemented. The percentages in the “vehicle type regulation by NO_x-PM” column show the reductions compared to the case where vehicle type regulation by the NO_x-PM law was not implemented while vehicle type regulation by the NO_x law and unit regulation were effective.

Unit regulation is quite effective for reducing NO_x and PM emissions. It was found that PM emissions reduced greatly in particular, apparently because PM unit regulation was reinforced rapidly in a short period of time. Although the regulation cannot improve the environmental performance of vehicles that are currently being used, the size of its effectiveness is as large as that of vehicle type regulation.

Although the NO_x law targeted NO_x emissions, it was found to be more effective to decrease PM than NO_x levels. Presumably, this is due to the combination of two reasons: 1) PM unit regulation has been reinforced rapidly since 1993 and thus PM emissions from new vehicles decreased more greatly than NO_x emissions, and 2) high emission vehicles were encouraged to be renewed under the law.

The change from the NO_x law to the NO_x-PM law seems to have contributed to improving air quality; vehicle type regulation was revised with the law revision, resulting in more reductions both in NO_x and PM concentrations.

With regard to driving regulation, NO_x reduction is less than 1 percent and thus their effectiveness is not as much. PM levels decreased approximately by 4 percent but the reduction is not as large as that by other regulations under study.

4.4. Comparison between ex-ante and ex-post evaluations on traffic regulation

According to Iwata’s (2009) ex-ante study, driving regulation reduced NO_x emissions by 28 percent more and PM emissions by 68 percent more than vehicle type regulation in the Tokyo metropolitan region between 2003 and 2005. Vehicle type regulation, on the other hand, reduced NO_x emissions by 13 percent and PM emissions by 28 percent (Iwata, 2009)[14]. That is, driving regulation was more effective than vehicle type regulation as far as these three years are considered.

However, this ex-post study indicates different results. As presented in the first line of Table 4, the coefficient of the NO_x-PM law dummy is -0.002. The coefficient of driving regulation is -0.0003 and statistically not significant. The effectiveness of driving regulation is 15 percent of vehicle type regulation. When maximum concentration levels are used (the third line of the table), it is only about 0.2 percent.

It was found that the effectiveness of driving regulation is smaller than that of vehicle type regulation in all of our estimation results. When the coefficient of PM concentration function (the first line of Table 5) is used, the effectiveness of driving regulation is 51 percent larger than that of vehicle type regulation. When maximum concentration levels are used (third line of the table), it is about 18 percent larger.

Because Iwata (2009) used emissions and this study used concentration levels, it is not easy to compare the results in these studies. However, if we assume that emissions and concentration levels are directly proportional, what other factors brought the difference? The critical difference between the two studies is the way they treat the vehicles that do not follow regulations. Iwata's ex-ante study assumes that all vehicles designated by vehicle type regulation and driving regulation obey the regulations. Our ex-post study on the other hand uses the observed values and thus the estimation takes into account the vehicles that did not observe the regulations.

The effectiveness of driving regulation greatly declined in our ex-post study apparently because a large number of vehicles did not observe the regulation. Because vehicle type regulation is a law that works in conjunction with the car registration system, it is impossible for drivers to keep using their vehicles against the regulation. With regard to driving regulation, in contrast, violation will not be

[14] In this simulation, the amount of reduction is the average value of reduction in 2004 and 2005 because vehicle type regulation starts to show its effectiveness after 2004.

penalized unless it is found during on-site inspections.

The number of vehicles that violate driving regulation does not appear to be so large, however. According to the on-site inspection report by Kawasaki city, for example, less than 1 percent of the vehicles violated the regulation in 2006 (38 cars out of 5,629 vehicles that underwent inspections)[15]. It may be the case that violating vehicles are used only at night time and thus have not been identified by on-site inspections that are usually conducted during day time. In that case, it is necessary to reconsider the monitoring method.

For a municipal ordinance like driving regulation, it is necessary to establish a system to insure the regulation is observed, just as the vehicle registration system guarantees the observance of vehicle type regulation. If such a system is not easy to be developed, the monitoring should be reconsidered and made more intensive and thorough. Social welfare will be improved by an effective regulation only when the regulation is well observed.

15. Conclusion

Using long term data on NO_x and PM concentration levels at air pollution monitoring stations from 1976, this study estimated the effectiveness of the past and current vehicle emission regulations. Our results indicated that all regulations are effective to decrease both NO_x and PM levels. It was also found that the revision from the NO_x law to the NO_x-PM law was effective for improving air quality.

The results suggested that subsidies should be spent on low emission vehicles rather than PM removal equipment. In the Tokyo metropolitan region, more subsidies are spent on the equipment perhaps because they have imposed an ordinance to make its installation mandatory. Subsidizing the equipment was found to be cost ineffective both in the ex-ante and ex-post evaluations. Thus, it is advised that the municipalities, particularly those in the Tokyo metropolitan region, shift their target

[15] This information is available only in Japanese in the website of the city’s Bureau of Environment (http://www.city.kawasaki.jp/30/30zidou/home/kensa/kensa.htm).

to subsidizing low emission vehicles.

Subsidies were found to have spillover effect and the effect on other municipalities is not negligible. The spillover effect of subsidies for the equipment is, however, in some part questionable. There is a possibility for a municipality to free ride to other municipalities' regulation(s). If the neighboring municipalities are keen to reduce emissions, it is not necessary for a municipality to keep intensifying its own regulation.

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 NO_x reductions by regulation (Left: average concentration, Right: maximum concentration)

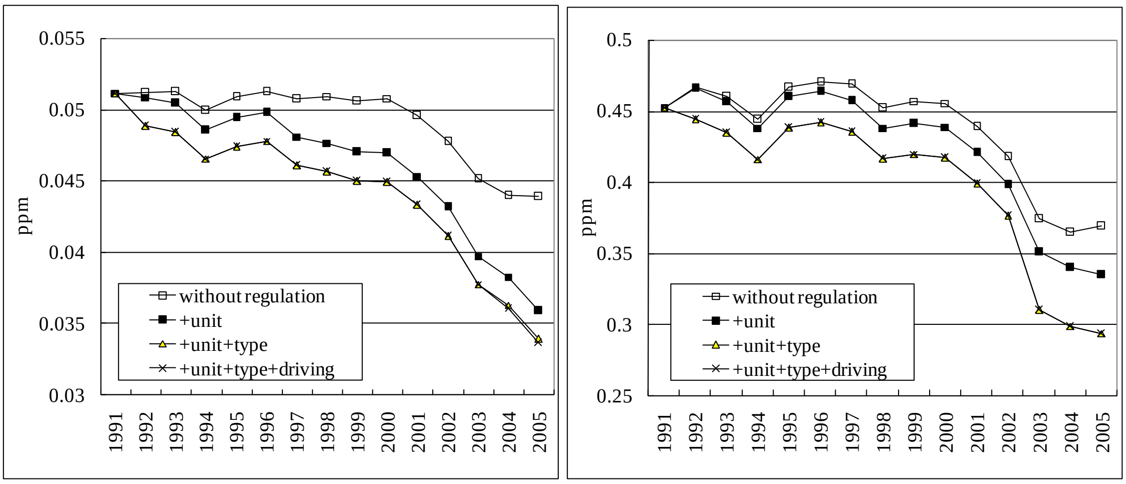

Figure 2 PM reductions by regulation (Left: average concentration, Right: maximum concentration)

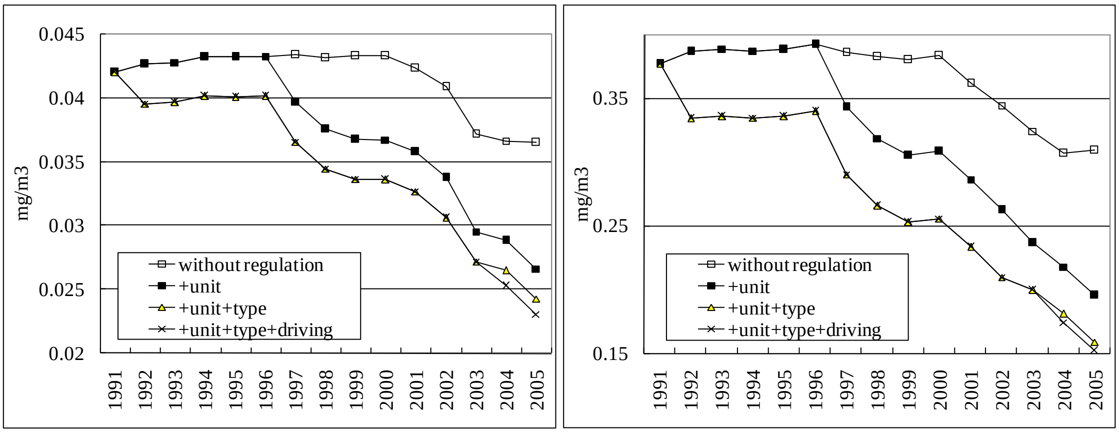

Table 1 Descriptive Statistics

Dependent variable	Nobs	Mean	S.D.	Mininum	Maximum
Annual Average Concentration Levels (NOx) (ppm)	21800	0.048	0.037	0.005	0.42
Hourly Maximum Concentration Levels (NOx) (ppm)	21800	0.431	0.213	0.05	2.24
Annual Average Concentration Levels (PM) (mg/m3)	16128	0.036	0.011	0.005	0.11
Hourly Maximum Concentration Levels (PM) (mg/m3)	16122	40.99	67.61	0	1211
Explanatory variable	Nobs	Mean	S.D.	Mininum	Maximum
Average Temperature (℃)	21628	15.42	1.09	4.2	19.4
Wind Speed (m)	21585	2.412	0.895	0.5	5.9
Rain Fall (mm)	22144	1432	352	0	2985
Industrial-Area Dummy	22677	0.065	0.246	0	1
Highway Dummy	22677	0.213	0.410	0	1
Freight Tonnage (1,000 tonnages)	22677	245062	60532	118239	376485
Subsidies (Low Emission Vehicles) (10,000 yen)	22677	4920	17918	0	125732
Subsidies (PM Removal Equipment) (10,000 yen)	22677	32500	146549	0	1082497
Spillover (Low Emission Vehicles) (10,000 yen)	22677	21072	76480	0	601394.3
Spillover (PM Removal Equipment) (10,000 yen)	22677	149795	626669	0	4964536
Unit Regulation (NOx)	22677	31.54	13.50	6.941	69.059
Unit Regulation (PM)	22677	78.39	31.79	5.857	100
NOx Law Dummy	22677	0.234	0.423	0	1
NOx-PM Law Dummy	22677	0.089	0.285	0	1
Traffic Regulation Dummy	22677	0.037	0.188	0	1

Table 2 Annual amount of subsidies for low emission vehicles by municipality (unit: 10,000 yen)

Year	Tokyo pref	Saitama pref	Kanagawa pref	Chiba pref	Aichi pref	Osaka pref
1999						
2000						
2001	47500			4529		
2002	47500	1470	2479	7386	4139	12400
2003	28000	11	875	5270	8749	12438
2004	7000	653	752	1832	23510	12418
2005	7000	1410	874	1285	25619	9695
Total	137000	3543	4979	20301	62017	46950
Year	**Hyogo pref**	**Saitama city**	**Kawasaki city**	**Yokohama city**	**Chiba city**	**Kobe city**
1999	2146					
2000	2465					
2001	2228				175	
2002	9810			1522	208	
2003	14627	173	109433	5541	89	1679
2004	16560		11935	5000	59	1845
2005	14585	1650	6502	14787	10	1372
Total	62421	1823	127870	26850	541	4896

Note: The following municipalities were not offering the subsidy at the time this study was conducted: Fukuoka prefecture, Nagoya city, Fukuoka city, and Kitakyushu city.

Table 3 Annual amount of subsidies for PM removal equipment by municipality (unit: 10,000 yen)

Year	Tokyo pref	Saitama pref	Kanagawa pref	Chiba pref	Aichi pref	Osaka pref
1999						
2000						
2001		3640		56948		3500
2002	303660	55860		148760		689
2003	591080	183264	757079	10717	4691	
2004	119000	22857	64365	4175	2586	
2005	71280	7736	29809	7403		
Total	1085020	273356	851253	228003	7278	4189
Year	**Hyogo pref**	**Saitama city**	**Kawasaki city**	**Yokohama city**	**Chiba city**	**Kobe city**
1999						
2000						
2001	2000					
2002	2000			19512		
2003	10000	9540		242124	4525	
2004	3321	1330		22390	138	
2005	5600	515		10578		
Total	22921	11385		294604	4663	

Note: The following municipalities were not offering the subsidy at the time this study was conducted: Fukuoka prefecture, Kawasaki city, Nagoya city, Osaka city, Kobe city, Fukuoka city, and Kitakyushu city.

Table 4 Estimation results of NO_x concentration function

	Annual Average NOx Concentration Levels						Hourly Maximum NOx Concentration Levels					
	All Stations			Emission Stations Only			All Stations			Emission Stations Only		
Variable	Coefficient	t-value		Coefficient	t-value		Coefficient	t-value		Coefficient	t-value	
Vehicle Emission Regulations												
Unit Regulation	0.0003	16.43	***	0.0009	13.57	***	0.0014	11.25	***	0.0041	12.42	***
NOx Law Dummy	-0.0020	-6.30	***	-0.0037	-4.00	***	-0.0218	-7.44	***	-0.0141	-1.97	**
NOx-PM Law Dummy	-0.0020	-4.52	***	-0.0036	-2.71	***	-0.0411	-8.62	***	-0.0318	-2.61	***
Traffic Regulation Dummy	-0.0003	-0.72		-0.0007	-0.61		-0.0001	-0.02		0.0061	0.52	
Subsidies (Low Emission Vehicles)	-0.0518	-7.00	***	-0.0469	-2.46	**	-0.6352	-9.56	***	-0.5937	-4.28	***
Spillover (Low Emission Vehicles)	-0.0129	-6.49	***	-0.0193	-3.16	***	-0.1483	-8.46	***	-0.1081	-2.56	***
Social Structure												
Industrial-Area Dummy	0.0053	2.61	***	0.0076	1.71	*	-0.0066	-0.40		0.0043	0.14	
Highway Dummy	0.0081	2.28	**	0.0049	0.84		0.1208	2.38	**	0.1008	1.61	
Freight Tonnage	0.0128	4.78	***	0.0254	2.92	***	0.4062	13.02	***	0.4175	5.13	***
Climate Conditions												
Average Temperature	-0.0004	-6.59	***	-0.0007	-3.07	***	-0.0055	-5.66	***	-0.0088	-3.23	***
Wind Speed	-0.0009	-3.00	***	-0.0036	-3.53	***	0.0038	1.28		0.0182	2.11	**
Rain Fall	0.3010	1.99	**	0.7241	1.55		-23.5848	-10.34	***	-27.1443	-4.84	***
Constant term	0.0431	96.36	***	0.0769	45.47	***	0.3913	22.95	***	0.4333	7.95	***
Nobs	19724			4813			19724			4813		
Rho	0.749			0.769			0.259			0.285		
R-Squared: within	0.067			0.112			0.140			0.195		
R-Squared: between	0.293			0.049			0.196			0.102		
R-Squared: overall	0.176			0.099			0.190			0.162		
F-value (P-value)	111.26	(0.00)		47.39	(0.00)		253.69	(0.00)		91.44	(0.00)	

Note: ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively. Units for rain fall, traffic volume, subsidy and spillover effect (low emission vehicles) were modified to 1 kilometer, 1,000,000,000 tonnes and 10,000,000,000 yen, respectively.

Table 5 Estimation results of PM concentration function

	Annual Average PM Concentration Levels						Hourly Maximum PM Concentration Levels					
	All Stations			Emission Stations Only			All Stations			Emission Stations Only		
Variable	Coefficient	t-value		Coefficient	t-value		Coefficient	t-value		Coefficient	t-value	
Vehicle Emission Regulations												
Unit Regulation	0.0001	31.51	***	0.0002	16.27	***	0.0012	24.60	***	0.0015	12.65	***
NOx Law Dummy	-0.0031	-12.73	***	-0.0028	-4.26	***	-0.0526	-14.53	***	-0.0442	-5.50	***
NOx-PM Law Dummy	-0.0023	-6.91	***	-0.0019	-2.17	**	-0.0368	-6.51	***	-0.0417	-3.36	***
Traffic Regulation Dummy	-0.0012	-3.63	***	-0.0020	-2.87	***	-0.0066	-1.02		-0.0089	-0.79	
Subsidies (Low Emission Vehicles)	-0.0333	-5.77	***	-0.0399	-3.35	***	-0.4356	-4.66	***	-0.4218	-2.61	***
Spillover (Low Emission Vehicles)	-0.0106	-2.88	***	-0.0138	-1.71	*	-0.4417	-7.12	***	-0.4105	-3.58	***
Subsidies (PM Removal Equipment)	-0.0029	-4.10	***	-0.0031	-2.08	**	-0.0100	-0.84		-0.0100	-0.50	
Sppillover (PM Removal Equipment)	-0.0001	-0.18		0.0000	-0.02		0.0343	4.98	***	0.0341	2.74	***
Social Structure												
Industrial-Area Dummy	0.0006	0.41		-0.0014	-0.54		-0.0029	-0.15		-0.0334	-1.03	
Highway Dummy	0.0143	4.97	***	0.0132	4.01	***	0.0590	0.97		0.0364	0.64	
Freight Tonnage	-0.0008	-0.32		0.0137	1.78	*	-0.0307	-0.68		-0.0932	-0.83	
Climate Conditions												
Average Temperature	-0.0001	-0.84		0.0002	1.09		-0.0073	-5.65	***	-0.0043	-1.27	
Wind Speed	-0.0003	-1.05		-0.0007	-0.98		-0.0169	-4.29	***	-0.0135	-1.35	
Rain Fall	-0.6356	-4.02	***	-0.4897	-1.14		-11.0351	-3.43	***	-0.8977	-0.12	
Constant term	0.0309	43.99	***	0.0214	10.40	***	0.4246	19.51	***	0.3594	5.41	***
Nobs	14728			2552			14728			2552		
Rho	0.493			0.534			0.207			0.191		
R-Squared: within	0.229			0.327			0.198			0.274		
R-Squared: between	0.132			0.103			0.038			0.198		
R-Squared: overall	0.278			0.346			0.193			0.305		
F-value (P-value)	219.85	(0.00)		79.93	(0.00)		243.48	(0.00)		61.99	(0.00)	

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 6 Reductions of annual average NO_x/PM levels by regulation

	unit regulation	vehicle type regulation by NOx law	vehicle type regulation by NOx-PM law	driving regulation
Annual average NOx concentration level	7.00%	4.20%	5.17%	0.80%
Hourly maximum NOx concentration level	3.49%	4.92%	12.04%	0.03%
Annual average PM concentration level	11.00%	7.92%	8.30%	4.75%
Hourly maximum PM concentration level	14.62%	15.66%	17.11%	3.89%

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.