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Using On-Board Diagnostic and Global Positioning System to Price Emissions from On-Road Heavy-Duty Vehicles

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Abstract: Economists have long urged governments to use Pigouvian taxes to efficiently reduce emissions. This has rarely happened, mostly because until now, technology has not existed to precisely measure in-use emissions by location and time. In recent years, increasingly sophisticated on-board diagnostic (OBD) devices have been required for cars and trucks to monitor engine operation and measure the in-use fuel consumption and emissions of vehicles. This paper proposes the use of Pigouvian pricing to reduce emissions from on-road heavy-duty vehicles (HDVs) by utilizing emission data from OBD devices and location data from global positioning system (GPS) devices. Thus, emissions can be measured and managed over time and space using geofencing. The authors address the feasibility of using OBD and GPS devices in this way, taking into account a monitoring system consisting of OBD and GPS, designated area, pricing scheme, and the relationship with other related policies. The authors conclude that emission data can be collected reliably using OBD technology, and that geofenced time-specific pricing policies are technically feasible. **DOI: 10.1061/JTEPBS.0000167.** *© 2018 American Society of Civil Engineers.*

Introduction

Heavy-duty vehicles (HDV) are a significant consumer of petroleum-based fuels and a growing contributor to carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions (Sharpe 2013). Historically, diesel engines have been the dominant power plant for HDV applications.

In California and many other places around the world, vehicle exhaust emissions from HDVs account for a major fraction of particulate matter (PM) and oxides of nitrogen (NOx), which are a significant contributor to poor air quality and both chronic and acute health effects (Sharpe 2013). Performance standards are the predominant approach to reducing emissions from trucks (and cars). California has gone further, requiring that older trucks be replaced or retrofitted with additional pollution control devices (California Air Resources Board 2015b). The US Environmental Protection Agency is exploring more stringent NOx standards for trucks, as is California, and California is exploring a range of options to further incentivize and perhaps require lower emitting trucks in areas with high pollution levels and in disadvantaged communities, including the use of zero emission technology. The imposition of much tighter emission standards for PM and especially NOx would be very expensive, since it would be applied to all trucks, including those that never operate in polluted regions. In this paper, the authors explore the potential for a more targeted approach that relies on pricing to achieve a more efficient reduction of emissions.

On-board diagnostics (OBD) is a computer-based system built into all 1996 and later light-duty vehicles and trucks less than 6,345 kg (14,000 lbs), required by the Clean Air Act Amendments of 1990. Recently, the California Air Resources Board has developed similar OBD requirements for HDVs over 14,000 lbs (California Air Resources Board 2015a). It provides the heavy-duty OBD regulation, section 1971.1 of title 13, California Code of Regulations, as filed with the Secretary of State on July 31, 2013. Except as specified in section (d)(7), "all 2010 and subsequent model-year heavy-duty engines shall be equipped with an OBD system that has been certified by the Executive Officer as meeting all applicable requirements of this regulation."

California's second generation of OBD systems (OBD II) monitors virtually every component that can affect vehicle emission performance to ensure that the vehicle remains as clean as possible over its entire life, and assists repair technicians in diagnosing and fixing problems with computerized engine controls (California Air Resources Board 2015a). The vehicle's driving parameters can be readily obtained from the electronic control unit (ECU) via OBD. It is possible for an onboard instrumentation to communicate with the ECU and collect all the sensor data from a vehicle, then use them as input values to fuel consumption and emissions models (Ortenzi and Costagliola 2010; Wu et al. 2013).

A Pigouvian tax is a tax applied to a market activity that generates negative externalities. The tax is aimed at correcting an inefficient market outcome, and does so by being set equal to the social cost of the negative externalities (Sandmo 2008). Based on this economic concept, the proposed Pigouvian pricing of emissions is designed to encourage reductions in fuel consumption and emissions from HDVs by levying fees on relatively high-emitting vehicles in designated areas, based on the OBD technology that is used for collecting fuel consumption and emission data. Market-based environmental pricing schemes are the most economically efficient way to reduce emissions. Also, they can be flexibly designed for different environmental purposes and changing situations.

The design approach is to combine the emission data of HDVs from OBD and the location data from global positioning system (GPS) and then calculate an emission charge by time and place based on a tariff structure.

The primary objective of this paper is to evaluate the technical feasibility of using OBD technology for measuring emissions from

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on-road HDVs including NO_X, hydrocarbons (HC), carbon monoxide (CO), and PM. The analysis will focus on the reliability of OBD technology to obtain fuel consumption and emission data. The authors will also explore implementation issues, such as the definition of the designated area, the pricing scheme, and the relationship with other policies.

Literature Review

Pigouvian tax has been widely discussed and applied since it was developed in 1920. The basic idea is to use the tax to shift the marginal private cost curve up by the amount of the tax. For example, if the tax is placed on the total quantity of emissions from a factory, manufacturers have an incentive to reduce emissions output to the socially optimum level. If the tax is placed on the percentage of emissions per unit of production, the factory has an incentive to upgrade to cleaner processes or technology (Pigou 2013).

In modern times, many researchers have discussed the application of Pigouvian taxes to serious environmental problems. Bovenberg and de Mooij (1994) argued that there is a first-best case scenario and a second-best case scenario. In the first-best case, the government does not need to get revenue from distortionary taxes such as income tax, and the Pigouvian tax is able to create a long-term social optimum. The second-best case, which is more likely to be observed in the real world, is that the status quo includes an income tax that distorts the labor supply. In such a case, Bovenberg and de Mooij considered that the best tax would come in below the level of the Pigouvian tax. Goulder et al. (1999) agreed that after the implementation of a tax, the net social welfare hinges on the preexisting tax rate. The Pigouvian tax is considered as a method commonly used by government, because it has relatively low transaction costs associated with implementation. However, it is usually implemented indirectly because until now, technology did not exist to precisely measure in-use emissions by location and time.

The OBD standards were developed to detect vehicle engine problems that can provoke an increase in exhaust emission levels beyond acceptable limits. Nowadays, OBD technology could realize the function of information transmission from ECU to an external device. Zhong et al. (2009b) designed an information conversion and output device to record vehicle driving parameters (such as engine speed and torque). In Europe, Ortenzi and Costagliola (2010) developed a method intended to estimate instantaneous vehicle emissions of CO_2, CO, HC, and NOx by inputting sensor data collected from OBD. Alessandrini et al. (2012) designed a similar methodology to estimate in real time the energy and environmental impact of spark ignition and diesel vehicles. In their research, an on-board instrumentation capable of communicating with the vehicle electronic system was developed to collect all sensor data available (such as rpm, vehicle speed, engine load, lambda sensor voltage, catalyst temperature, intake airflow, pressure, temperature, etc.). Those parameters were then used as input for power and consumption models. The results showed that the values calculated by the models were comparable with those measured; therefore, it may be concluded that using OBD technology is a feasible methodology for computing the consumption and emissions of vehicles during their real use.

The objective of this pricing policy using the Pigouvian pricing of emissions is to make users more aware of the costs that they impose upon one another. It is designed to use a price mechanism to encourage the reduction of fuel consumption and emissions in designated areas that suffer from the problems of high emissions and human exposure levels, and to encourage HDV users to use lower-emitting vehicles in those areas. This paper is intended to analyze the technical feasibility of Pigouvian pricing on emissions by using OBD technology to collect emission data for on-road HDVs and also to assess the potential design and the relationship with other related policies.

Policy Design

For the geofenced pricing policy, three elements critical to designing and implementing environmentally effective and economically efficient Pigouvian pricing programs are

- a monitoring system that collects emission data using OBD technology and collects location data using GPS,
- a designated area that defines the location where HDVs will be charged for emitting pollutants, and
- a pricing scheme that determines payment amounts for each pollutant.

Fig. 1 shows the policy design of the Pigouvian pricing of emissions. The core part of this policy is the monitoring system. It will be responsible for collecting fuel consumption and emission data from on-road HDVs. Also, by combining GPS and OBD data, it is feasible to draw an *emission map* that indicates the distribution of emissions from the HDVs. Thus, the emission map could be treated as a theoretical support for designating high-emission areas.

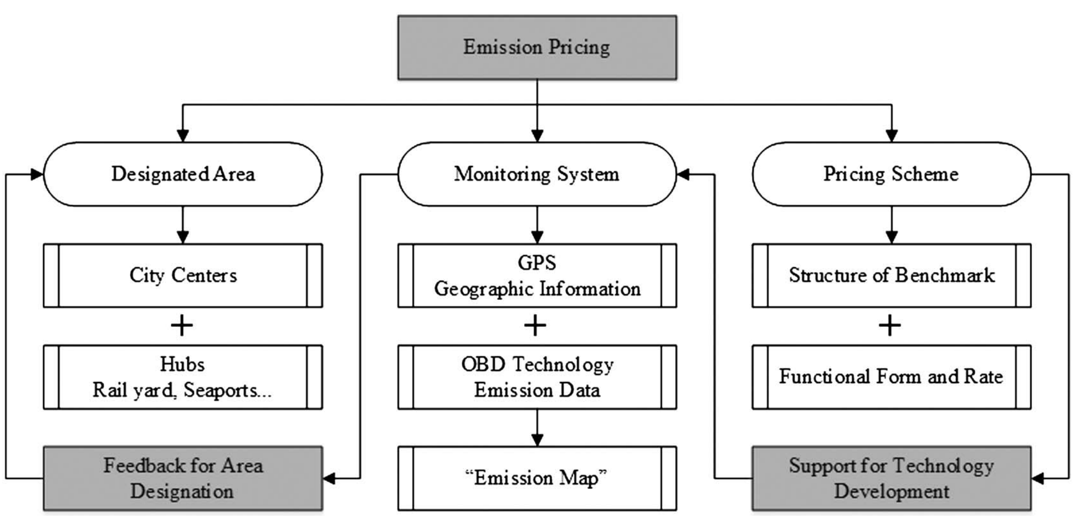

Fig. 1. Policy design of emission pricing.

Since the development of a monitoring system requires fiscal support, the design of the pricing scheme could potentially provide the revenue source. Therefore, different sections of the policy work together to achieve the goal of the reduction of fuel consumption and emissions.

Monitoring System

The monitoring system consists of OBD and GPS, which are responsible for collecting fuel consumption and emission data and geographic information. Since OBD is the core part of the emission pricing policy, it is important to consider its feasibility and accuracy. The reliability of OBD technology is analyzed below for both fuel consumption calculations and emission models.

Calculation of Fuel Consumption

In much existing research (Pinto and Oliver-Hoyo 2008; Gao and Checkel 2007; Gregg et al. 2008), the strong relationship between fuel consumption and CO_2 emissions have been proved. In this study, fuel consumption data is collected and charged for emission pricing in order to reduce the CO_2 emissions.

The process for calculating fuel consumption is to obtain the mass air flow (MAF) through driving parameters from ECU and then obtain the fuel flow. Fuel consumption is estimated from the fuel flow and vehicle speed. The detailed calculation process is documented in SAE (2007). The main steps are shown subsequently.

There are three methods available for calculating the MAF, through various parameters.

- If SAE.MAF (SAE is a standard published by the Society of Automobile Engineers, which provides industry references for measurements of engine power) from ECU is available, MAF can be calculated using Eq. (1):

$$\mathrm{MAF[g/s]} = ((256 \times A) + B)/100 \tag{1}$$

  where A, B = returned binary value of SAE.MAF from ECU.
- If SAE.LOAD_ABS (the absolute load value) is available, MAF can be calculated using Eq. (2):

$$\mathrm{MAF[g/s]} = air\_density \times displacement \times load\_abs \times engine\_speed/120 \tag{2}$$

  where *air_density* = density of air (g/L), generally taken to be 1.184 g/L; *displacement* = displacement of engine (L); *load_abs* = absolute load value (%); and *engine_speed* = speed of engine (rpm).
- If manifold absolute pressure (MAP) and intake air temperature (IAT) are available, MAF can be calculated using Eq. (3):

$$\mathrm{MAF}[g/s] = (\mathrm{MAP/IAT}) \times (M/R) \times (\mathrm{RPM}/60) \times (\mathrm{ED}/2) \times \mathrm{VE} \tag{3}$$

  where MAP = intake manifold absolute pressure (kPa); IAT = intake air temperature (K); M = air relative molecular mass (g/mol), generally taken to be 29 g/mol; R = molar gas constant = 8.3145 J/(K · mol); RPM = engine speed (rpm); ED = engine displacement (L); and VE = volumetric efficiency, generally taken to be 75%.

  Fuel flow can be calculated from MAF using Eqs. (4) and (5):

$$Fuel\_flow\mathrm{[L/h]} = \mathrm{MAF}/(\mathrm{AFR_{actual}} \times fuel\_density) \tag{4}$$

$$\mathrm{AFR_{actual}} = lambda \times \mathrm{AFR_{optimal}} \tag{5}$$

where $\mathrm{AFR_{actual}}$ = actual air-fuel ratio; $\mathrm{AFR_{optimal}}$ = optimal air-fuel ratio, generally taken to be 14.64 for gasoline; *lambda* = parameter from ECU provided by the universal exhausts gas oxygen sensor; and *fuel_density* = fuel density (g/mL).

If the fuel is diesel, it needs the load value calculated from ECU to modify Eq. (4) by multiplying the load value (SAE.LOAD_PCT, in %).

The calculation of instantaneous fuel consumption (IFC) is based on

$$\mathrm{IFC} = Fuel\_flow/\mathrm{SAE.VSS} \tag{6}$$

where SAE.VSS = vehicle speed from ECU (km/h).

The calculation of average fuel consumption (AFC) is based on

$$\mathrm{AFC} = Fuel_T/d_T \tag{7}$$

where $Fuel_T$ = total fuel consumption (g) in a certain period T; and d_T = total distance traveled (km) in a certain period T.

The entire calculation process is shown in Fig. 2.

A field test was conducted in Beijing, China in July 2012 (Wu et al. 2013). A 2007 Nissan Altima (Guangzhou, China), equipped with a GPS and a Snap-On Microscan OBD-II Scanner (Beijing, China), was used to collect two types of field data. The first type was driving parameters, collected through the ECU. It collected the vehicle's driving parameters, such as engine rpm, intake MAP, and IAT, and then calculated fuel consumption by the aforementioned method. Then, the ECU outputted the second-by-second fuel consumption rate data in μL/s. The second type of data was the GPS data. A Columbus V-900 Multifunction GPS Data Logger (Fuzhou, China) was used in the test. The raw data consist of time, geographic information, and instantaneous speed on a second-by-second basis. In this study, due to the limitations of the test equipment, the applicability of OBD was tested on a light duty vehicle (LDV). Because the OBD installed on the LDV during the test in China used the same protocols as that on the HDV, the test results were able to validate their feasibility (Zhong et al. 2009a). In the future, similar tests will be conducted on an on-road HDV.

To collect data from a wide variety of traffic conditions, the vehicle was tested in the predesigned routes in Beijing, China, which covered diverse vehicle-operating conditions and various road types. Each test lasted about 4 h including 2 peak hours and 2 non-peak hours for 2 days in July 2012. After the process of data quality control, a total of 23,208 records of valid second-by-second data were identified for this study. Each preprocessed record includes time, road name, travel speed, and the flow consumption rate calculated from the ECU.

The measurement data from the ECU was compared with the data from the vehicle-specific power (VSP) based model. Because of their simple calculation process, the algorithm and modeling based on the relationship between VSP and fuel consumption have recently become the main trend. It has been verified that VSP is a convenient single parameter which has direct physical interpretation of and strong statistical correlation with fuel consumption and emissions (Song and Yu 2012). The Motor Vehicle Emission Simulator (MOVES), which is the latest generation of USEPA's regulatory mobile source emissions model, also follows the VSP based model (USEPA 2012a). The detailed VSP based model is documented in previous work (Wu et al. 2013). The basic idea is to build the relationship between fuel consumption and VSP, since VSP is strongly correlated with fuel consumption. Then the relationship is used to estimate fuel consumption with easily obtained VSP data. A binning approach is applied to avoid the random errors that could appear from the second-by-second fuel consumption meter data, in which the VSP data are binned into 1 kW/t; then the average fuel consumption rate within each bin is calculated. In this study, field data via the OBD system and

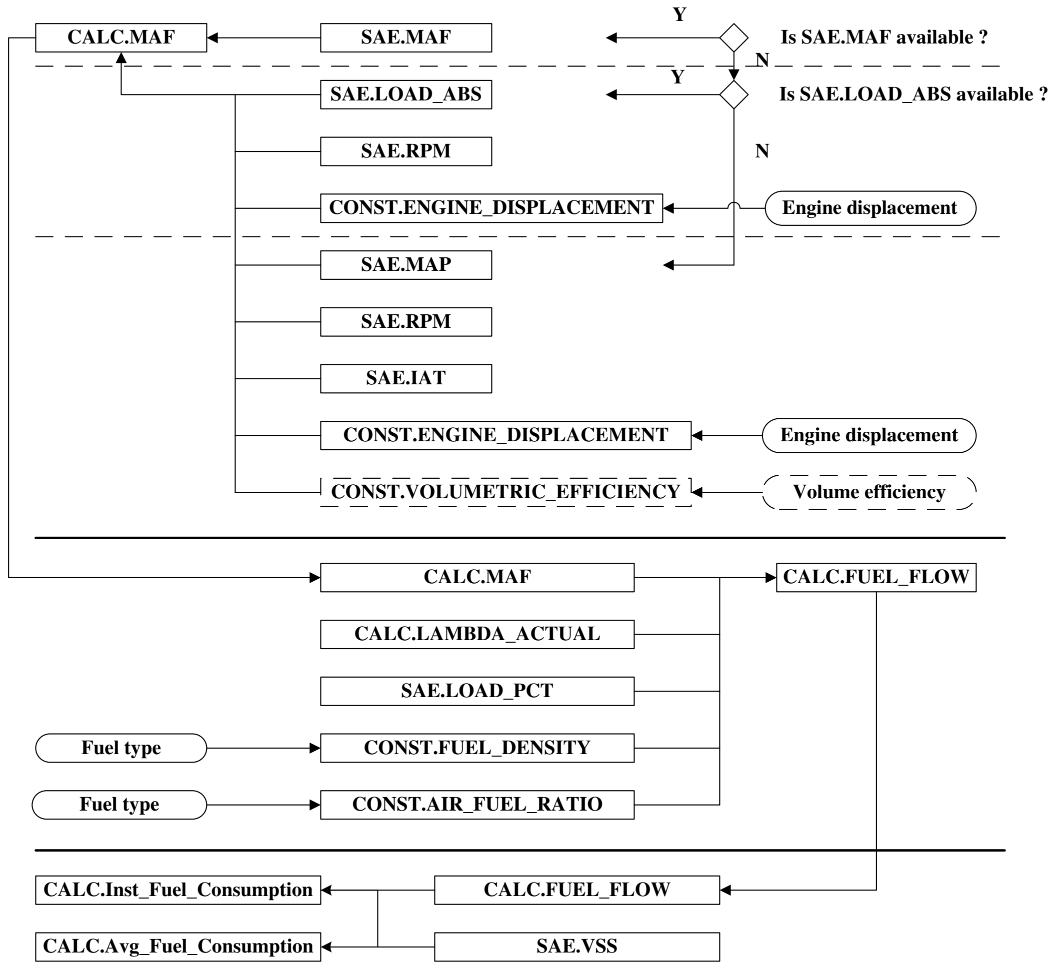

Fig. 2. Calculation process of fuel consumption by ECU (CALC. = calculate; CONST. = constant; PCT = percentage; Inst = instantaneous; and Avg = average).

GPS are used to build the relationship between fuel consumption and vehicle activities for developing the prediction model.

For the evaluation, a comparison of different aggregation levels (10, 30, 60, and 120 s) was conducted. The aggregation process is to bin the data together in a specific time interval (such as 10 s) and then calculate the average fuel rate in each interval. The results are shown in Fig. 3. With the increase of the aggregation level, the two data sets become closer, which means that the OBD technology may not be good at short-term calculations. However, for emission pricing, only a sum of the emissions in a long period are needed (the period must be longer than 120 s), so for fuel consumption, OBD technology can feasibly support emission pricing policy.

To evaluate the difference between two emission rates databases, many quantification analyses can be used. Wu et al. (2014) used normalized mean square error (NMSE) to evaluate the average relative discrete degree, which is also adopted in evaluating the comprehensive modal emission model (CMEM) model (Scora and Barth 2006), as shown in Eq. (8):

$$\text{NMSE} = \frac{1}{n}\sum_{i}^{n}\frac{(C_{o,i} - C_{p,i})^2}{\overline{C_o}\cdot\overline{C_p}} \tag{8}$$

where C_o = OBD based measured value; C_p = VSP based predicted value; $\overline{C_o}$ = mean of C_o; $\overline{C_p}$ = mean of C_p; and $i = 1, 2, 3 \ldots n$.

In an accurate model, the NMSE should be close to 0. Song (2008) proposed that NMSE <0.5 is the acceptable limit. The NMSE in the aggregation levels of 10, 30, 60, and 120 s were 0.966, 0.636, 0.463, and 0.361, respectively. These results show that, for emission pricing policy, OBD technology is eligible for collecting fuel consumption data, since it only needs to provide the sum of the fuel consumption in a long period.

Fig. 4 shows the results for the evaluation of total fuel consumption. The data came from four time periods in July 2012. The values from two methods are close, with relative errors of 6.12, 5.22, 1.14, and 4.53% in each time period. The similarity between peak and nonpeak hours is attributed to insufficient testing time and the total number of records.

It can be concluded that OBD technology is able to estimate fuel consumption over a long period fuel consumption accumulation.

Emission Models

USEPA's MOVES is a state-of-the-science emission modeling system. MOVES estimates mobile source emissions at the national, county, and project level for criteria air pollutants, greenhouse gases, and air toxics. Detailed emission data (i.e., base emission rate) of US vehicle models since the 1960s are stored in the database, which applies the relationship between vehicle operating modes and emissions (USEPA 2012a). In this study, the authors combined the parameters collected by OBD and GPS with the emission model in MOVES to estimate real-world HDV emissions.

In the MOVES database, emission rates for criteria air pollutants (including HC, CO, NOx, and PM) are stored in the "Emission

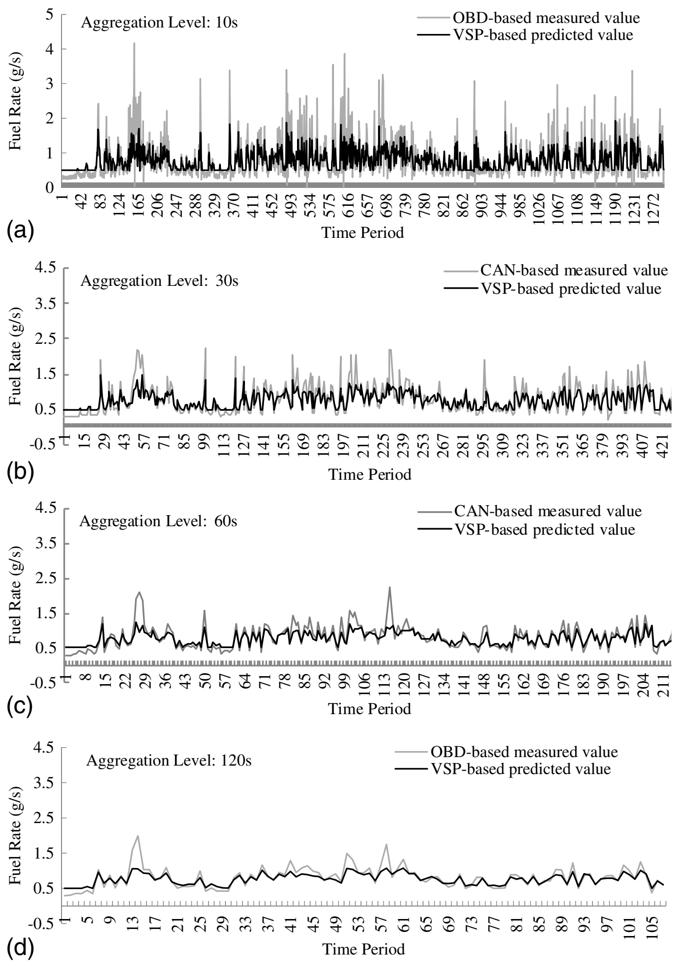

Fig. 3. Comparison of different aggregation levels for fuel consumption: (a) average fuel rate in the aggregation level of 10 s; (b) average fuel rate in the aggregation level of 30 s; (c) average fuel rate in the aggregation level of 60 s; and (d) average fuel rate in the aggregation level of 120 s.

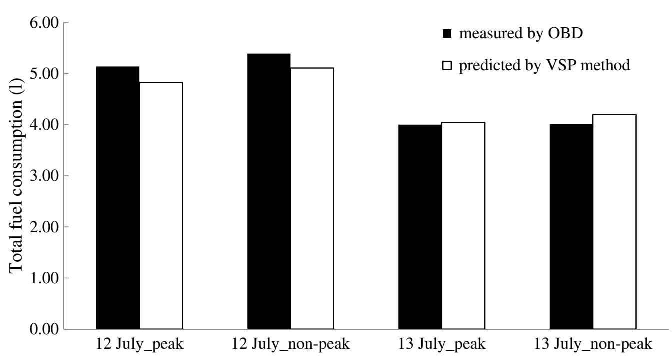

Fig. 4. Total fuel consumption in each time period.

RateByAge" table. The emission rates in this table are stored according to (1) MOVES regulatory class, (2) fuel type [diesel, gasoline, and compressed natural gas (CNG)], (3) model year group, (4) vehicle age, (5) emission process (e.g., running exhaust, start exhaust, crankcase emissions), and (6) vehicle operating mode. The detailed definitions of each parameter used to classify HDV emissions in MOVES are discussed in detail in a technical report (USEPA 2015a).

In this study, the monitoring system is responsible for providing the vehicle operating modes. For HDV and running exhaust, operating modes are defined in terms of power output (with the exception of the idle and braking modes). For HDV, this parameter is called "scaled-tractive power" (STP) in MOVES. There are two ways to obtain STP; one is by measuring directly from the ECU, and the other is by estimating from road load coefficients. For on-road tests, measuring power from the ECU is generally more accurate than estimating power from road load coefficients (USEPA 2015a), which is the advantage of applying OBD to obtain STP. Unlike a generic road load equation in which vehicle characteristics such as aerodynamic drag and rolling resistance are assumed, the ECU measures engine speed and torque directly. Also, wind speed and wind direction, which can have a significant effect on aerodynamic drag, are not typically measured in on-road tests, which causes errors in estimations by generic equation. Additionally, road load equations may not reflect the actual vehicle test weight, and the tests may not have accurate grade information for the entire route tested. Therefore, the monitoring system is able to accurately provide the required model parameters. By matching those parameters to the MOVES emission database, it is able to locate the base emission rates for the target on-road HDV.

After getting the base emission rates, MOVES includes the flexibility to adjust them to reflect the effects of temperature, humidity, and local inspection and maintenance (I/M) programs. The detailed adjustment rules are introduced in the MOVES technical report (USEPA 2015b). After taking into account the adjustment factors, the emission data of on-road HDV can be obtained for implementing pricing policy. Future studies will need to conduct field comparison tests to validate the accuracy of this MOVES based approach. Here, since MOVES is the regulatory emission modeling tool, it is reasonable to apply it to estimate emissions for policy purposes.

Hence, by matching the timestamp from GPS and the emission data, it is possible to collect the total emission data for each pollutant in the designated area. However, in the real world, it may be challenging to combine these two categories of data for millions of trucks. One possible solution is to develop a module imbedded into the OBD system by automobile manufacturers that would combine the two kinds of data and calculate the final amount of the fees for each truck.

Designated Area

Pigouvian pricing of emissions for on-road HDVs will charge a fee to enter or drive within a high-emission and high level of exposure area, such as hubs (seaports, rail yards, airports, etc.) and densely inhabited areas. The monitoring system is an effective way to determine the designated area. After launching the onboard instrumentation on HDVs, the monitoring system will record location and emission data. Based on this data, it is feasible to get an emission map of these vehicles, which shows the distribution of emissions on the map. This would make it convenient to determine the high emission areas. This method works on a micro level, which means it is able to define small areas like hubs. However, in the infant stages of this policy, the data sources may not be sufficient to generate an emission map. Other data sources could be applied in this stage. Air quality monitoring data provided by AirNow (USEPA 2016) is a feasible complementary data source for defining high emission areas.

The *nonattainment area* also can be treated as guidance in this process. A nonattainment area is an area considered to have air quality worse than the National Ambient Air Quality Standards as defined in the Clean Air Act Amendments of 1970 (Public Law 91-604, section 109). The shortcoming is that the basic unit of

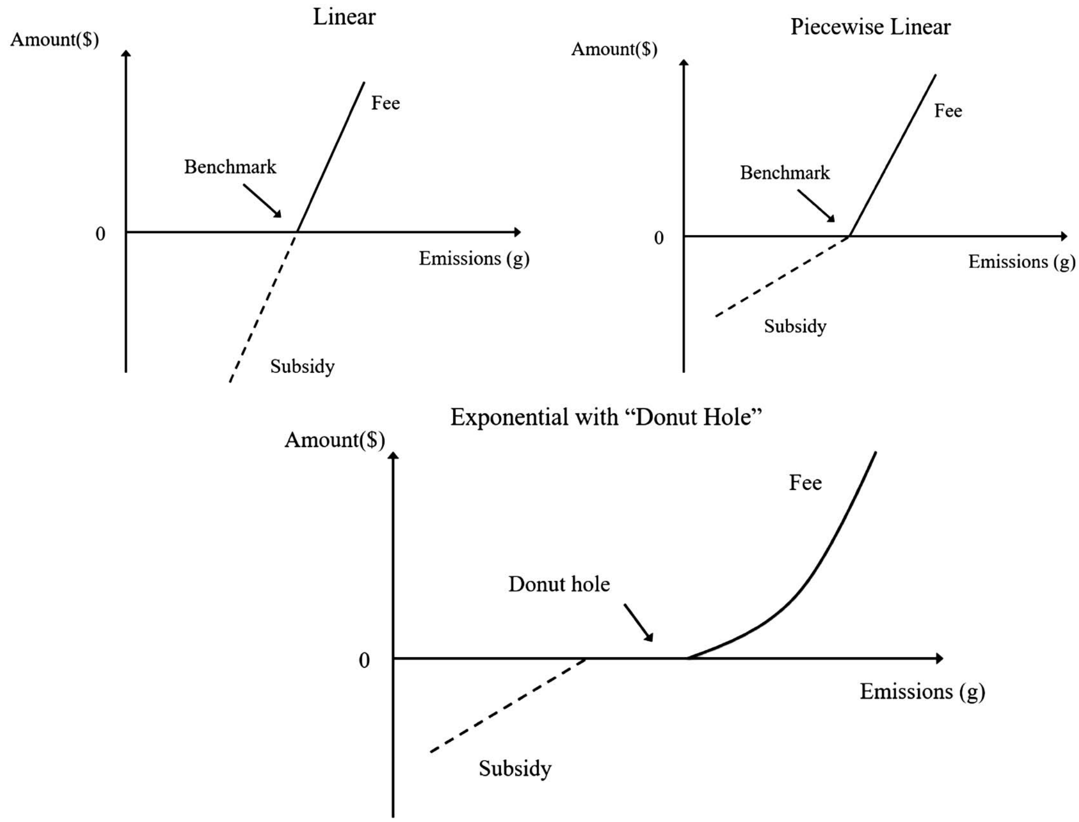

Fig. 5. Three functional forms of pricing scheme.

the nonattainment area is the county, which may be too large for implementing this policy.

Another consideration is the dispersion of air pollutants. The monitoring system only provides emission data on the road. However, based on air dispersion, it will have a greater detrimental impact on those locations near communities, especially on schools, hospitals, and residential areas. Further research is required to define the high emission and high exposure level area by air dispersion model.

Pricing Scheme

Based on the concept of emission pricing in this study, in the infant stage, only diesel HDVs will be charged fees. The goal of defining the pricing scheme is to encourage more low-emitting HDVs to enter the designated area in order to reduce the number of high-emitting HDVs. Hence, the rate structure will be designed to levy fees on relatively higher-emitting vehicles and provide subsidies to lower-emitting vehicles. In order to achieve this goal, the pricing scheme requires a benchmark, a functional form with rate parameters, and implementation strategies.

Structure of Benchmarks

A benchmark defines an acceptable emission amount. If emissions from HDVs exceed the benchmark, they will be charged fees. Otherwise, they will receive subsidies. A single benchmark is the simplest possible way to set up the pricing. The rate and benchmark will be designed separately for each pollutant. The total amount is given by a simple equation:

$$Amount = \sum_p rate_p \times (emission\_amount_p - benchmark_p) \quad (9)$$

where $rate_p$ is expressed in dollars per gram for pollutant p; and $emission\_amount_p$ and $benchmark_p$ are measured in grams. The final result is the sum of the amounts for all pollutants. For example, consider a policy with a rate of \$20/g and a benchmark of 300 g for NOx in a specific time period. A vehicle emitting 350 g emits more than the benchmark, and would be assessed a fee of $20 \times (350 - 300) = \$1000$. A vehicle emitting 250 g would be assessed a fee of $-\$1000$; i.e., it would receive a \$1000 subsidy.

A single benchmark representing an absolute standard for all vehicles is an easy way to implement this policy, but it may not be fair for large trucks.

Another method is to set up a footprint-based benchmark, which is assigned on the basis of a vehicle's size as measured by its footprint, defined as wheelbase × track width. This is a relatively fair way to establish benchmarks as a function of size, but it increases the complexity of the policy.

Functional Form and Rate

Functional form decides how fees and subsidies vary as a function of distance away from the benchmark. Options for functional forms include linear, piecewise linear, and exponential functions, which are shown in Fig. 5.

The simplest function is a linear one, which uses a single rate on both the fee side and the subsidy side. Piecewise linear functions use two different rates; rates are steeper on the fee side. This kind of design raises revenue by charging fees to high-emitting HDVs. The exponential form is designed with a donut hole, in which there is no emission pricing for a specific range. The advantage of this form is that it severely punishes those HDVs with extremely high emissions. The donut hole avoids an abrupt change near the benchmark.

Implementation Strategies

Another element potentially affecting the success of a Pigouvian pricing policy is the way that it is introduced. The policy could be implemented either abruptly or with prior notice given to

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manufacturers and HDV users. A delay between the announcement and implementation of the policy could give them time to adapt.

In the infant stage, the implementation of the policy may need strong fiscal support in order to develop the related technology and set up related new facilities. The costs will be focused on technology developed by vehicle manufacturers. Regarding the development of automobile technology, it will not cost much since the onboard instrumentation for obtaining fuel consumption and emission data is already available. The only requirement is to combine these data with GPS to determine the location of the emissions. Government funding could be used to support the development.

After this stage, the fees collected by emission pricing will be treated as the main revenue source. They will be used to support the development of technology by the manufacturers, to give bonuses to low-emitting vehicles, and be applied to other emission-reduction programs in local communities, such as adding more bus lines to encourage a mode shift. Therefore, the design of the pricing scheme requires an overall consideration to balance the benefits of all parties.

Relationship with Other Policies

There are three general ways to curtail criteria pollutants and/or GHGs from vehicles: (1) improving vehicle technology, (2) changing fuel feedstock or fuel characteristics, and (3) modifying vehicle operating patterns (Sharpe 2013). There are a number of different policy options that target emissions and fuel use from HDVs in each of these three areas.

Technology-Focused Policies

There are various ways that policy can encourage the adoption of new technologies in both new and in-use vehicles. In general, a policy targeting vehicle technologies typically impacts either one of two distinct sets of entities: (1) the technology producer, or (2) the technology consumer. The former encompasses vehicle and component developers, manufacturers, and suppliers, while the latter includes any company, organization, or individual that owns or operates a vehicle. One example of a manufacturer incentive is government funding for research, development, and demonstration. This type of financial support can aid in the development of products for both the new and in-use HDV markets. In addition to incentives, manufacturers in the HDV sector are generally subject to both environmental and safety regulations for their products. Examples of environmental regulations include engine emission standards (which often contain provisions for onboard diagnostics, durability, and warranty) and technology performance requirements.

Compared with Pigouvian pricing policy, technology-focused policies always need strong fiscal support from the government. The process of development is time-consuming. Sometimes, it may not achieve the expected goal.

Fuel-Focused Policies

A fuel's feedstock and characteristics have important impacts on both criteria pollutant and GHG emissions. The use of higher quality conventional fuels or certain alternative fuels with lower carbon content and/or embodied GHG emissions can be an effective strategy to control vehicle emissions. For reducing diesel sulfur levels, many countries and regions around the world, including California and the US, have implemented fuel quality regulations requiring the reduction of diesel sulfur content to near-zero levels in order to enable the adoption of the most effective emission control technologies. For reducing the embodied GHG content of fuel, there are two major low carbon fuel policies in the United States: (1) the USEPA's Renewable Fuel Standard (RFS) (USEPA 2012b), and (2) the California air resources board (ARB's) Low Carbon Fuel Standard (LCFS) (California Air Resources Board 2011).

Fuel-focused policies and emission pricing policies are complementary. Pricing policy could be treated as an incentive to fuel policies, encouraging HDV operators to use the latest fuels, which have the lower diesel sulfur levels and embodied GHG content. Also, fuel-focused policies could reduce emission fees for HDV users.

Vehicle Operation-Focused Policies

Along with technology and fuel improvements, changing vehicle operating patterns is the third broad area of strategy for decreasing fuel use and emissions. Within this area, there are two general types of changes to vehicle operating behavior that can lead to lower emissions and/or fuel consumption: (1) reducing the total amount of vehicle activity, and (2) operating vehicles in a more fuel-efficient manner.

Emission pricing policy belongs to this category. It encourages vehicle operators to reduce the total amount of vehicle activity in the designated area.

Conclusions

This study intends to analyze the technical feasibility of using OBD technology to price emissions from HDVs. The policy of combining Pigouvian pricing of emissions from HDVs with geofencing creates the potential to reduce emissions in a more targeted and thereby less costly manner. Three critical elements—a monitoring system, a designated area, and a pricing scheme—are discussed in this study. The main findings in this study can be summarized as follows:

1. While Pigouvian taxes are commonly used by government, they are usually not effectively targeted at the source because until now the technology to precisely measure in-use emissions in real time has not existed.
2. With the advancement of modern automobile technology, a vehicle's driving parameters can be readily obtained from ECU via OBD. Thus, it is possible to use onboard instrumentation to communicate with the ECU and collect all sensor data from a vehicle and then use the data as input values to the fuel consumption and emissions models. Based on some field tests, OBD technology has been proven to be reliable for collecting emission data.
3. Three critical elements of geofencing pricing policy are discussed in this study. For the monitoring system, by matching the timestamp from GPS and the emission data from OBD, it is possible to collect the total emission data for each pollutant in the designated area. For the designated area, an emission map is an effective way to define the high emission area. For the pricing scheme, a single benchmark with an exponential function is proposed in this study.
4. Pricing truck emissions in a geofenced area is potentially cost-effective. It can be used synergistically with vehicle performance standards, vehicle purchase incentives, and other policies to reduce the cost of pollution reduction not only for trucks, as demonstrated here, but also for cars.

The design of price-based geofencing policies, while technically feasible, requires further applied research on human exposure, costs of administration and compliance, and political acceptance.

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