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Marketable Credits for Light-Duty Vehicle Emission Control in California

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INTRODUCTION

Recent data indicate that many U.S. areas still fail to meet national ambient air quality standards (NAAQS) for one or more criteria pollutants. In 1990, ninety-six U.S. metropolitan areas violated the federal ambient ozone standard, and forty-one areas violated the standard for carbon monoxide (CO), affecting over 100 million people (U.S. EPA, 1990a). The federal Clean Air Act (CAA) Amendments of 1990 established more stringent control measures to further reduce air pollutants (U.S. EPA, 1990b) in an effort to attain air quality standards.

Motor vehicles emit the following criteria pollutants: hydrocarbon (HC), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matters (PM). Since the beginning of vehicle emission regulation in the late 1960s, extensive efforts have been made to reduce vehicle emissions. Consequently, it is estimated that HC and CO emissions from the transportation sector have been reduced by over 40% during the last twenty years (U.S. EPA, 1990c). However, nationwide, motor vehicles still generate 33% of the total volatile organic gas (VOC), 67% of the CO, 41% of the NO_x, 4% of the SO_x, and 20% of the PM emissions (EPA, 1990c). To attain NAAQS in U.S. urban areas, motor vehicle emissions, as well emissions from stationary sources, must be reduced further. Accordingly, the 1990 CAA enacts more stringent vehicle emission standards, requires clean-burning transportation fuels (alternative fuels and/or reformulated gasoline) to reduce per-mile vehicle emissions, and promotes transportation control measures to reduce VMT (vehicle miles traveled).

Motor vehicle emissions are currently regulated on a per-mile basis. For the purpose of emission regulation, motor vehicles are classified into passenger cars, light-duty trucks (LDTs), and heavy-duty trucks (HDTs). Per-mile emission standards are established for individual vehicle classes. Vehicles within each class must meet the same emission standards. Vehicle manufacturers are responsible for complying with vehicle emission standards. Under the current vehicle emission regulation system, each and every vehicle within a vehicle class must meet the uniform emission standards, regardless of differences in vehicle emission performance and emission control cost among vehicles. Vehicle manufacturers are allowed very little flexibility in meeting uniform emission standards.

Consequently, the current vehicle emission regulation system results in several problems. First, the current system causes unnecessarily high control costs for meeting overall motor vehicle emission reduction goals. Second, the current regulation system may delay vehicle emission reductions, because manufacturers do not have any incentive to actively invest in the research and development of vehicle emission control technologies. Third, within the current regulation system, it is technically difficult to incorporate alternative-fueled vehicles (AFVs) for the purpose of emission reductions. To ensure emission reductions from AFVs under the current regulation system, both emission standards and sales requirements of different types of AFVs are needed. The sales requirement of AFVs means further governmental intervention into manufacturers' sales strategies, as well as into their production strategy (through the current emission regulations).

As increasingly stringent vehicle emission standards are adopted in the future, these problems will become more severe. As an alternative to current regulation, we propose to use a marketable permit

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system for light-duty vehicle emission control. Such a system would provide manufacturers with flexibility and incentives to meet emission requirements. In this paper, we have designed a marketable permit system applicable to vehicle emission control and we have estimated the cost savings of vehicle emission control through the marketable permit system, relative to the current vehicle emission regulation system. [This paper is a summary of the Ph.D. dissertation of Quanlu Wang. Details of literature review, data collection, data analysis, and simulation results are presented in the dissertation. For a copy of the dissertation, contact Institute of Transportation Studies, University of California, Davis, CA 95616).

DESIGN OF THE MARKETABLE PERMIT SYSTEM

Under a marketable permit system, an environmental authority creates a limited number of emission permits and distributes them among sources. Each permit is an allowance for a given amount of emissions. Permits can be traded among sources. The total number of permits, or the emission allowance per permit, can be adjusted to achieve predetermined emission reduction goals. In a permit trading market, a market-clearing price per permit will emerge to indicate the opportunity cost of emission control. Such a system can also be designed with emission reduction credits. In this system emission permits are determined relative to vehicle emission standards. Sources (firms) that more than meet the standard earn emission reduction credits (ERCs) that can be traded with other firms. Firms that do not meet the standard would buy ERCs. In this way, total emission control costs from all sources are reduced.

We propose to use a marketable permit system for light-duty vehicle emission control. The marketable permit system includes three components: emission averaging among the vehicle engine families within a manufacturer, emission trading among manufacturers, and emission banking over time. These components are described below.

Emission Averaging

Under the marketable permit system, corporate average emission standards for light-duty vehicles would be established. Manufacturers would be required to meet the average emission standards in a way similar to the current CAFE regulations. An individual vehicle would not be subject to uniform emission standards. A manufacturer's fleet average emissions would be calculated from certified emission limits of its engine families weighted by the projected annual sales of its engine families. Average emission standards would be established for HC, CO, and NO_x separately. Manufacturers would be required to meet the standards for each of these three pollutants. Averaging across different pollutants would not be permitted because this could intensify adverse health effects of one pollutant or another. Average emission standards would be established for passenger cars and light-duty trucks, and averaging between them would be allowed due to their similar usage (i.e., they have similar annual VMT [Davis et al., 1991]).

Under the current uniform emission standards, vehicle emission certification levels are much below the uniform emission standards. The large difference between certified emission rates and emission standards (the margin of safety to meet emission standards) ensures that in-use vehicles meet emission standards during their useful lifetime (currently five years or 50,000 miles). Under average emission

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standards, the safety margin may decrease due to manufacturers' intention of using differences in emissions among their engine families for meeting average standards. If same emission standards were applied to the uniform standard system and to the marketable permit system, the permit system would result in increase in actual vehicle emissions, mainly due to the decrease in the safety margin by the permit system. In order to keep actual emissions the same under both the marketable permit system and the current uniform standard system, average standards should be stricter than the standards that would be established under the uniform standard regulation.

To enforce the marketable permit system, vehicles would be tested for emission certification in the same way that vehicles are currently tested for emission compliance. Manufacturers would determine the emission levels of each engine family and would submit the emission test results of engine families for emission certification. Compliance with emission requirements would involve two steps: vehicle models within an engine family would have to comply with the family emission levels, and a manufacturer would have to comply with the average emission standards.

The corporate sales-weighted average emissions can be calculated as follows:

$$CAER_i = \frac{\sum_{j=1}^{n} E_{i,j} \times Sales_j}{\sum_{j=1}^{n} Sales_j}$$

where

$CAER_i$ = corporate average emission rates for pollutant i (grams per mile [gpm])
$E_{i,j}$ = emissions of pollutant i for engine family j (gpm)
$Sales_j$ = sales volume of engine family j (equal to sales of all models contained in the engine family)
i = 1, 2, and 3 to represent HC, CO, and NO_x
j = engine family, and
n = total number of engine families within a manufacturer.

Emission Trading Among Manufacturers

Emission averaging gives vehicle manufacturers the opportunity to reallocate emission control efforts among their engine families. The emission trading component of a marketable permit system would make it possible to reallocate emission control efforts among engine families across manufacturers, resulting in greater flexibility in meeting emission standards at the automotive industry level. Emission trading would occur in the permit system as follows: If a manufacturer's fleet emissions were less than average emission standards, the manufacturer would earn emission reduction credits (ERCs) which would be the currency for emission trading and emission banking. The ERCs earned in a model year would be the difference between the average emission standards and the manufacturer's fleet emissions multiplied by its total vehicle sales in the model year. The earned ERCs could be sold to other manufacturers or banked for future use. ERCs of a manufacturer for a particular pollutant would be computed as

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$$ERC_i = (CAES_i - CAER_i) \times Sales$$

where

ERC_i = emission reduction credit of pollutant i (gpm-vehicle)
$CAES_i$ = corporate average emission standard of pollutant i (gpm)
$CAER_i$ = corporate average emission rate of pollutant i (calculated as the above formula, gpm)
Sales = total annual vehicle sales (sum of sales of all engine families) by a manufacturer

To effect the trade of ERCs between manufacturers, a formal emission trading market would be established to conduct transactions. Since there are about thirty-four manufacturers in the U.S. light-duty vehicle market, the trading market would not be complex. A private agency could emerge to broker the purchase or sale of ERCs. EPA or CARB would still need to certify the ERCs earned by manufacturers, and at the end of a model year, manufacturers would be required to submit the information on the ERC transactions for emission compliance to EPA or CARB.

Emission Banking

The ERCs earned from one model-year vehicles can be banked to offset emissions of another model-year vehicles. Emission banking gives manufacturers flexibility in meeting overall emission reduction goals over a period of time.

Emission banking can be forward or backward. Forward banking works like a deposit in a financial bank. The ERCs earned from earlier model-year vehicles can be used for offsetting the emissions of later model-year vehicles. To use emission banking to comply with emission standards, manufacturers must have adequate ERCs in emission banks. Forward banking encourages the deployment of emission control technologies earlier than a non-banking trading system.

Backward banking works like a loan in a financial bank. Manufacturers are allowed to use the ERCs from future model-year vehicles to offset the emissions of current or past model-year vehicles. To use backward banking to comply with emission standards, manufacturers must show their ability to earn ERCs in the future. Backward banking may delay deployment of emission control technologies, resulting in a delay in emission reductions over a period of time. The enforcement of backward banking is problematic when a manufacturer cannot later repay its earlier ERC withdrawal. For these reasons, we do not include backward banking in our proposed marketable permit system.

Manufacturers may accumulate ERCs over a longer period of time, which could distort future vehicle emission regulations and could delay the development and deployment of future emission control technologies. Manufacturers could create a monopoly power in the emission trading market by holding a large amount of ERCs. To discourage the possession of large amounts of ERCs, a discount rate will be applied to ERCs. Discounting ERCs over time also represents an actual emission reduction benefit because a manufacturer must reduce more than one unit of emissions now to offset one unit of emissions for the future.

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There are several marketable permit systems that are currently in effect to control air emissions from stationary sources and mobile sources. These are: EPA's stationary source emission trading program; the acid rain program adopted in the 1990 Clean Air Act Amendments; EPA's emission trading program for PM and NOx emissions from heavy-duty engines; and California Air Resources Board's low-emission vehicle program. For a detailed review of these and some other programs, see Wang (1992).

SIMULATION MODEL AND DATA COLLECTION

Simulation Model

The current vehicle emission regulation system requires that each and every vehicle produces emissions less than or equal to the uniform emission standards which are applied to a vehicle class (i.e., passenger cars, LDTs, or HDTs). In contrast, the emission trading system which is designed in the form of marketable emission permits requires that the average emission rates of all vehicles from the automotive industry be below or equal to the emission standards. Therefore, an individual vehicle is not subject to uniform emission standards.

An optimization model has been built to simulate manufacturers' production behavior under the current system and under the emission trading system so that the emission control cost savings of the trading system can be estimated. The optimization model is designed to minimize the total emission control costs of all vehicles subject to emission requirement constraints. These emission requirement constraints in the optimization model are different between the current regulation system and the trading system. Under the current system, the emission constraint is that every engine family must meet light-duty vehicle emission standards. However, under the emission trading system, the emission constraint is that the average emissions of all engine families meet emission standards.

The optimization model generates the total emission control costs for the light-duty vehicle fleet to meet emission standards. The cost difference between the current system and the trading system represents the cost savings of the emission trading system.

The specifications of the optimization model for the emission trading system is presented mathematically below. The model contains an objective function and a set of constraint functions. The objective function is to minimize the total emission control cost of all light-duty vehicles. The constraint functions reflect emission requirements.

$$\text{Minimize} \quad TC = \sum_i \sum_j CF_{i,j}(HC_{i,j}, CO_{i,j}, NOx_{i,j}) * Sale_{i,j}$$
$$HC_{i,j}, CO_{i,j}, NOx_{i,j}, Sale_{i,j}$$

subject to

$$(1) \quad \sum \sum Sale_{i,j} = \sum \sum CSale_{i,j}$$
$$(2) \quad \sum \sum HC_{i,j} * Sale_{i,j} \leq \sum \sum CHC_{i,j} * CSale_{i,j}$$
$$(3) \quad \sum \sum CO_{i,j} * Sale_{i,j} \leq \sum \sum CCO_{i,j} * CSale_{i,j}$$
$$(4) \quad \sum \sum NOx_{i,j} * Sale_{i,j} \leq \sum \sum CNOx_{i,j} * CSale_{i,j}$$

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where
i = vehicle size classes (i.e, small, medium, and large)
j = manufacturers
TC = total cost of vehicle emission control
$CF_{i,j}(HC_{i,j}, CO_{i,j}, NOx_{i,j})$ = emission control cost function of vehicle class i for manufacturer j
$Sale_{i,j}$ = sales of vehicle class i by manufacturer j under emission trading
$CSale_{i,j}$ = current sales of vehicle i by manufacturer j
$HC_{i,j}$ = HC emissions of vehicle i by manufacturer j under emission trading
$CO_{i,j}$ = CO emissions of vehicle i by manufacturer j under emission trading
$NOx_{i,j}$ = NO_x emissions of vehicle i by manufacturer j under emission trading
$CHC_{i,j}$ = current HC emissions of vehicle i by manufacturer j
$CCO_{i,j}$ = current CO emissions of vehicle i by manufacturer j
$CNOx_{i,j}$ = current NO_x emissions of vehicle i by manufacturer j

The total cost in the objective function is computed by multiplying the emission control cost function (cost per vehicle at given levels of HC, CO, and NO_x) by vehicle sales. The objective function shows that total control cost can be reduced by changing the emissions of HC, CO, and NO_x, by changing vehicle sales, or both.

There are four constraint functions in the optimization model. The first function is a sales constraint which limits the total number of vehicle sales under the trading system to the level under the current system. In other words, we assume that total vehicle sales will remain the same both under the current emission regulation system and under the trading system. However, sales of individual engine families may be changed. Total vehicle sales depends on both vehicle demand and vehicle supply. Although a change in total vehicle sales may occur due to changes in emission regulation systems, the change is likely to be small due to demand considerations.

The remaining three constraints are for the levels of HC, CO, and NO_x emissions. We designed the emission trading system to emit the same total amount of emissions as the total amount calculated from current emission certification rates under the current control system. The current emission certification rates are much lower than emission standards, resulting in a large safety margin. If the emission levels under the trading system were set at emission standard levels, the emission safety margin would be forgone, and the actual emissions under the trading system would increase over those of the current system. By constraining emission levels at the current certification level, we assign the same amount of emissions for both the current system and the emission trading system.

Estimate of Emission Control Cost Functions

To mathematically simulate manufacturers' production behavior of meeting vehicle emission requirements, and therefore to estimate the cost savings of the permit system, vehicle emission control cost as a function of emissions of three pollutants (i.e., HC, CO, and NO_x) must be estimated.

Since the marketable permit system designed here is based on individual engine families, a cost function for each of the engine families among all manufacturers is needed to fully estimate the emission control cost savings of the marketable permit system. Mainly due to data availability from CARB, vehicle

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emission control cost functions are established using the data on emissions and emission control costs of the light-duty vehicles sold in California. Thus, our simulation of the marketable permit system targets California light-duty vehicles.

Currently, there are about three hundred engine families produced for California's light-duty vehicle market. It would be impossible for us to estimate three hundred individual cost functions due to lack of data. Instead, we grouped vehicles into three vehicle groups: small (4-cylinder vehicles), medium (5- and 6-cylinder vehicles), and large (8- and 12-cylinder vehicles). We have established cost functions for the three vehicle groups of each manufacturer. However, by establishing a cost function for a group of engine families, the simulation of the permit system must be based on vehicle groups rather than on engine families, even though in practice, the permit system would be conducted on the basis of engine families. The size of the trading basis in the simulation, therefore, decreases from the number of engine families to the number of vehicle groups. The decrease in the size of the trading basis will underestimate the cost savings of a marketable permit system because a smaller trading basis means less trading flexibility.

Various functional forms have been tested for vehicle emission control cost functions. Here, we present one set of cost functions—log cost functions. This set of cost functions takes the following form:

$$\ln(TC) = BO + B1*Ln(HCCO) + B2*\ln(NO_x) + B3*\ln(MPG)$$

where:

TC = total emission control cost ($/vehicle)
HCCO = HC emissions (gpm) multiplied by CO emissions (gpm)
NO_x = NO_x emissions (gpm)
MPG = fuel economy
BO, B1, B2, and B3 are constants.

Data Collection

In order to statistically estimate the cost function, we need data on emissions and emission control costs for individual vehicles. We describe data sources here.

Emission Data. We use the emission rates of individual vehicle models tested for emission certification. We have selected twelve manufacturers: Audi, BMW, Chrysler, Ford, GM, Honda, Mazda, Mercedes-benz, Mitsubishi, Toyota, Volvo, and Volkswengen. We have a total of 387 vehicle samples to establish 29 individual cost functions (twelve manufactures and three vehicle classes could result in total of 36 vehicle groups. However, some manufactures do not produce one or two vehicle classes).

Vehicle Emission Control Costs. Our approach to estimate vehicle emission control costs is to identify emission control systems for individual vehicle models, to estimate manufacturing costs of these control systems through manufacturer's suggested retail prices for emission replacement parts, to consider dealer markup and manufacturer markup factors, and to add the cost of the individual systems together to calculate the total emission control costs.

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The information on the emission control systems installed on individual engine families is from the manufacturers' application forms for emission certification. We obtained manufacturer's suggested retail prices for the emission control systems from vehicle dealers. To calculate manufacturing cost of an emission control system from the retail price, we use a dealer markup factor of 40% and a manufacturer markup factor of 20% to discount retail price to manufacturing cost. We also included assembly costs of installing the parts into a vehicle.

Estimated Twenty-Nine Individual Cost Functions

Due to lack of sufficient data, we could not estimate the twenty-nine individual cost functions, separately. Instead, we estimated an aggregate cost function for the twelve manufacturers together. We adjust the aggregate cost function to an individual vehicle group by using the ratio of the average control cost of the vehicle group to the average cost of all vehicle groups. Through this "average approach" (in the sense that average costs are used to disaggregate cost functions), all parameters of the cost function are changed proportionally by the cost ratio. The approach implicitly assumes that the difference in emission control costs among vehicle groups is due to the difference in every parameter of the cost function. The twenty-nine cost functions estimated through this approach are presented in Table 1.

SIMULATION RESULTS: EMISSION CONTROL COST SAVINGS OF THE MARKETABLE PERMIT SYSTEM

Using the established optimization model, we have estimated the emission control cost savings of the marketable permit system in California, relative to the current vehicle emission regulation system. We have developed a GAMS (General Algebraic Modeling System) program for the optimization model to simulate the emission trading system. Appendix A presents an example of the optimization model in GAMS program. We have estimated cost savings under different trading situations through GAMS program. Two trading situations are presented below.

Emission Trading vs. Vehicle Sales Changes. We have simulated two methods that manufacturers can use to meet emission requirements under a permit system. The first method allows changes in the emission levels of different vehicle groups, and the second method allows changes in vehicle sales as well as in emission levels for different vehicle groups.

In reality, although the total number of vehicles sold could remain unchanged under the permit system and under the current emission regulation system, emission trading could result in changes in vehicle sales mix. However, without any other constraints, the optimization model may indicate that some vehicle groups will predominate vehicle sales and that other vehicle groups will be eliminated. This is not likely to occur in reality. To eliminate such unrealistic results, We have applied a sales change constraint to the optimization model. Our sales constraint is that total vehicle sales remain unchanged and that the vehicle sales of an individual group is allowed to change only 20% from the current vehicle sales for the group before trading.

Table 1. Coefficients of Twenty-Nine Individual Cost Functions[a]

Vehicle Group	B0	B1	B2	B3
Audi.small	8.7581	-0.1265	-0.2486	-0.7871
Audi.medium	9.1642	-0.1324	-0.2601	-0.8236
Audi.large	9.6517	-0.1395	-0.2739	-0.8674
BMW.small	8.9011	-0.1286	-0.2526	-0.8
BMW.medium	9.0523	-0.1308	-0.2569	-0.8136
BMW.large	9.9709	-0.1441	-0.283	-0.8961
Chrysler.small	7.3601	-0.1063	-0.2089	-0.6615
Chrysler.medium	7.7777	-0.1124	-0.2207	-0.699
Chrysler.large	8.2992	-0.1199	-0.2355	-0.7459
Ford.small	7.7026	-0.1113	-0.2186	-0.6923
Ford.medium	7.9639	-0.1151	-0.226	-0.7157
Ford.large	8.5007	-0.1228	-0.2413	-0.764
GM.small	7.4752	-0.108	-0.2121	-0.6718
GM.medium	8.0133	-0.1158	-0.2274	-0.7202
GM.large	8.2177	-0.1187	-0.2332	-0.7386
Honda.small	8.5241	-0.1232	-0.2419	-0.7661
Honda.medium	8.5882	-0.1241	-0.2437	-0.7719
Mazda.small	8.9115	-0.1288	-0.2529	-0.8009
Mazda.medium	9.1747	-0.1326	-0.2604	-0.8246
Mercedes.medium	9.7962	-0.1415	-0.278	-0.8804
Mercedes.large	10.0633	-0.1454	-0.2856	-0.9044
Mitsubishi.small	8.5303	-0.1232	-0.2421	-0.7667
Mitsubishi.medium	8.7787	-0.1268	-0.2491	-0.789
Toyota.small	8.598	-0.1242	-0.244	-0.7727
Toyota.medium	8.8563	-0.128	-0.2513	-0.796
Toyota.large	9.1357	-0.132	-0.2593	-0.8211
Volvo.small	8.9488	-0.1293	-0.254	-0.8043
Volvo.medium	8.8734	-0.1282	-0.2518	-0.7975
VW.small	8.7724	-0.1267	-0.249	-0.7884

[a] The cost function for each vehicle group is: $\ln(TC) = B0 + B1 \cdot \ln(HCCO) + B2 \cdot \ln(NO_x) + B3 \cdot \ln(MPG)$. TC is vehicle emission control cost in $/vehicle, HCCO is HC emissions (gpm) multiplied by CO (gpm), NO_x is in gpm, and MPG is vehicle fuel economy.

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Tightening of Vehicle Emission Standards. Vehicle emission standards will be tightened in the future. To test the effect of tightened emission standards on the cost savings of the trading system, we have established a scenario with tightened emission standards. The scenario assumes a 70% reduction in the HC emission standard and 50% reduction in the CO and NO_x emission standards. The reduction in the HC emission standard represents the HC emission standard of CARB's transitional low-emission vehicles. The reduction of the CO emission standard represents the CO standard of CARB's ultra-low emission vehicles, and the reduction in NO_x standard represents the NO_x standard of CARB's low-emission vehicles.

Cost Savings of the Marketable Permit System. The estimated cost savings of the permit system are presented in Table 2. The simulation results indicate that the marketable permit system can save $181-$412 million in California, or 13.3-30.4% of the current vehicle emission control costs. These cost savings translate into $103-$235 per vehicle.

Table 2. Emission Control Cost Savings of the Marketable Permit System in California

Trading Case	Cost Savings (million $)	Cost Savings (%)
Emission Trading with Current Standards[a]	181	13.3
Emission Trading with Tightened Standards[b]	290	21.4
Emission Trading and Vehicle Sales Changes with Current Standards[c]	259	19.0
Emission Trading and Vehicle Sales Changes with Tightened Standards[d]	412	30.4

[a] Under this case, emissions of vehicle groups are allowed to change, while vehicle sales of an individual group is fixed at the current level of the group. Total emissions after emission trading are set to be equal to the total emissions under the current emission standards.

[b] Under this case, emissions of vehicle groups are allowed to change, while vehicle sales of an individual group is fixed at the current level of the group. Total emissions after emission trading are set to be equal to the total emissions when emission standard of HC is assumed to reduce by 70%, CO by 50%, and NO, by 50%.

[c] Under this case, emissions of vehicle groups are allowed to change, and vehicle sales of an individual group is allowed to change by 20% of the current sales level of the group (while total vehicle sales of all groups is fixed at the current level). Total emissions after emission trading are set to be equal to the total emissions under the current emission standards

[d] Under this case, emissions of vehicle groups are allowed to change, and vehicle sales of an individual group is allowed to change by 20% of the current sales level of the group (while total vehicle sales of all groups is fixed at the current level). Total emissions after emission trading are set to be equal to the total emissions when emission standard of HC is assumed to reduce by 70%, CO by 50%, and NO, by 50%.

DISCUSSIONS

Our simulation model may underestimate the cost savings of the marketable permit system by a non-trivial amount, mainly because we have based our simulation on 29 vehicle groups rather than all engine families of the twelve manufacturers. Among these manufacturers, there are about 200 engine families. If the simulation was based on the 200 engine families, the cost savings of the permit system would be greater. To demonstrate the impact of changing trading basis on cost savings, we have estimated the cost savings of the permit system based on 15 vehicle groups (three vehicle classes, and three

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domestic manufacturers, European manufacturers together, and Japanese manufacturers together). Our simulation showed that the change from the 15-groups trading basis to the 29-group basis increased cost savings by $90-$145 million. Change from the 29-group trading basis to the 200-engine-family trading basis would increase cost savings substantially. Since the marketable permit system is proposed to based on engine families, actual cost savings of the permit system will be much greater than our estimated cost savings.

Alternative-fuel vehicles (methanol, compressed natural gas, electric, and other vehicles) in general produce less emissions than conventional gasoline vehicles. Manufacturers will certainly produce alternative-fuel vehicles to meet their emission requirements, if it is cost-effective to do so. Emission reduction credits earned by alternative-fuel vehicles, together with their CAFE (corporate average fuel economy) credits, may give manufacturers enough incentives to produce alternative-fuel vehicles. The inclusion of alternative-fuel vehicles in the marketable permit system will certainly increase emission trading flexibility, resulting in greater cost savings of the permit system.

We are conducting a project to incorporate alternative-fuel vehicles into the marketable permit system. Through the on-going project, we will estimate the cost savings of the marketable permit system when both gasoline vehicles and alternative-fuel vehicles are included. We will estimate the dollar value of emission reduction credits earned by alternative-fuel vehicles. Combining the dollar value of emission reduction credits and CAFE credits earned by alternative-fuel vehicles, we will analyze if the cost savings from emission credits and CAFE credits of alternative-fuel vehicles will be large enough to offset the additional cost of producing alternative-fuel vehicles.

CONCLUSIONS

The use of a marketable permit system for light-duty vehicle emission control has been proposed and evaluated. Through the designed marketable permit system, vehicle manufacturers would be allowed to average emissions across individual vehicle engine families, trade emission reduction credits among manufacturers, and bank the credits for future use.

The ultimate benefit of using such a marketable permit system would be its emission control cost savings, relative to the current regulatory system. A simulation model has been established to simulate vehicle manufacturer production behavior under a marketable permit system. The cost savings of the marketable permit system for light-duty vehicle emission control has been estimated through the simulation model. In California, it has been estimated that the permit system could save $180-$400 million per year, or 13-30% of the control cost under the current vehicle emission regulation system. The cost savings translate to $103-$235 per vehicle.

APPENDIX A:

<u>GAMS Program for the Optimization Model: Emission Trading with the Current Vehicle Emission Standards</u>

$TITLE   Vehicle Emission Trading with Current Emission Standards

SET
I cylinder   /Small, Medium, Large /
J maker   /Audi, BMW, Chry, Ford, GM, Honda, Mazda, Merc, Mitsu, Toyo, Volvo, VW/
M terms   /CONST, HCCO, NOx, MPG /;

PARAMETERS
CV(I,J)   Number of Vehicles Sold in Thousands
CHC(I,J)   Current HC Emissions
CCO(I,J)   Current CO Emissions
CNOx(I,J)   Current NO$_x$ Emissions
MPG(I,J)   Current MPG
C(I,J,M)   Cost Function Coefficients;

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* Sales by Vehicle Class and by Manufacturer in California   *
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TABLE CV(I,J)   (in thousands)

	Audi	BMW	Chry	Ford	GM	Honda	Mazda	Merc	Mitsu	Toyo	Volvo	VW
Small	3.78	0.4	32.76	98.45	110.7	158.94	86.8	0	57.81	140.63	23.92	25.78
Medium	2.7	20.34	79.21	253.87	219.87	13.56	9.13	76.71	24.48	64.66	3.09	0
Large	0.48	1.0	2.72	103.00	126.23	0	0	3.2	0	7.32	0	0

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* Emission Certification Rates (grams/mile): by Vehicle Class  *
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TABLE CHC(I,J)   Current HC Emissions

	Audi	BMW	Chry	Ford	GM	Honda	Mazda	Merc	Mitsu	Toyo	Volvo	VW
Small	0.268	0.22	0.197	0.16	0.222	0.181	0.161	N/A	0.221	0.156	0.242	0.222
Medium	0.228	0.218	0.305	0.172	0.193	0.183	0.237	0.162	0.243	0.182	0.317	N/A
Large	0.23	0.32	0.308	0.194	0.244	N/A	N/A	0.23	N/A	0.203	N/A	N/A

TABLE CCO(I,J)   Current CO Emissions

	Audi	BMW	Chry	Ford	GM	Honda	Mazda	Merc	Mitsu	Toyo	Volvo	VW
Small	2.15	0.96	3.46	1.99	3.33	2.18	1.96	N/A	1.85	1.37	2.02	2.37
Medium	2.01	1.45	2.33	2.65	2.59	1.17	2.29	1.50	1.80	1.69	2.47	N/A
Large	1.50	2.35	4.43	1.09	2.32	N/A	N/A	1.73	N/A	0.70	N/A	N/A

TABLE CNOX(I,J)   Current NOx Emissions

	Audi	BMW	Chry	Ford	GM	Honda	Mazda	Merc	Mitsu	Toyo	Volvo	VW
Small	0.148	0.135	0.257	0.285	0.325	0.214	0.187	N/A	0.224	0.146	0.192	0.208
Medium	0.197	0.162	0.516	0.242	0.336	0.207	0.220	0.1	0.165	0.410	0.3	N/A
Large	0.12	0.15	0.833	0.389	0.537	N/A	N/A	0.083	N/A	0.175	N/A	N/A

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TABLE MPG(I,J)   Current MPG

	Audi	BMW	Chry	Ford	GM	Honda	Mazda	Merc	Mitsu	Toyo	Volvo	VW
Small	21.8	18.5	22.0	25.5	23.6	26.6	23.9	N/A	23.3	26.2	19.9	23.0
Medium	19.6	16.6	18.4	19.2	19.0	20.1	19.4	19.0	18.7	17.3	18.4	N/A
Large	16.0	13.6	11.9	16.7	16.3	N/A	N/A	15.6	N/A	19.7	N/A	N/A

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* Coefficients of Cost Function (by Vehicle Group     *
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TABLE C(I,J,M)   Coefficients of Cost Functions

	CONST	HCCO	NOx	MPG
Small.Audi	8.7581	-0.1265	-0.2486	-0.7871
Small.BMW	8.9011	-0.1286	-0.2526	-0.8000
Small.Chry	7.3601	-0.1063	-0.2089	-0.6651
Small.Ford	7.7026	-0.1113	-0.2186	-0.6923
Small.GM	7.4752	-0.1080	-0.2121	-0.6718
Small.Honda	8.5241	-0.1232	-0.2419	-0.7661
Small.Mazda	8.9115	-0.1288	-0.2529	-0.8009
Small.Merc	N/A	N/A	N/A	N/A
Small.Mitsu	8.5303	-0.1232	-0.2421	-0.7667
Small.Toyo	8.5980	-0.1242	-0.2440	-0.7727
Small.Volvo	8.9488	-0.1293	-0.2540	-0.8043
Small.VW	8.7724	-0.1267	-0.2490	-0.7884
Medium.Audi	9.1642	-0.1324	-0.2601	-0.8236
Medium.BMW	9.0523	-0.1308	-0.2569	-0.8136
Medium.Chry	7.7777	-0.1124	-0.2207	-0.6990
Medium.Ford	7.9639	-0.1151	-0.2260	-0.7157
Medium.GM	8.0133	-0.1158	-0.2274	-0.7202
Medium.Honda	8.5882	-0.1241	-0.2437	-0.7719
Medium.Mazda	9.1747	-0.1326	-0.2604	-0.8246
Medium.Merc	9.7962	-0.1415	-0.2780	-0.8804
Medium.Mitsu	8.7787	-0.1268	-0.2491	-0.7890
Medium.Toyo	8.8563	-0.1280	-0.2513	-0.7960
Medium.Volvo	8.8734	-0.1282	-0.2518	-0.7975
Medium.VW	N/A	N/A	N/A	N/A
Large.Audi	9.6517	-0.1395	-0.2739	-0.8674
Large.BMW	9.9707	-0.1441	-0.2830	-0.8961
Large.Chry	8.2992	-0.1199	-0.2355	-0.7459
Large.Ford	8.5007	-0.1228	-0.2413	-0.7640
Large.GM	8.2177	-0.1187	-0.2332	-0.7386
Large.Honda	N/A	N/A	N/A	N/A
Large.Mazda	N/A	N/A	N/A	N/A
Large.Merc	10.0633	-0.1454	-0.2856	-0.9044
Large.Mitsu	N/A	N/A	N/A	N/A
Large.Toyo	9.1357	-0.1320	-0.2593	-0.8211
Large.Volvo	N/A	N/A	N/A	N/A
Large.VW	N/A	N/A	N/A	N/A :

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VARIABLES
     TC
     HC(I,J)
     CO(I,J)
     Nox(I,J);

POSITIVE VARIABLE
     HC(I,J)
     CO(I,J)
     NOx(I,J);

EQUATIONS
     THC          Total HC Emissions under Emission Trading
     TCO          Total CO Emissions under Trading
     TNOx         Total NOx Emissions under Trading
     COST         Total Emission Control Cost ;

COST..    TC =E= SUM((I,J), (LOG(HC(I,J))*C(I,J,'HCCO')
          +LOG(CO(I,J))*C(I,J,'HCCO')
          +LOG(NOx(I,J))*C(I,J,'NOx')
          +LOG(MPG(I,J))*C(I,J,'MPG')
          +C(I,J,'CONST'))*CV(I,J));

THC..   SUM((I,J), HC(I,J)*CV(I,J)) =L= SUM((I,J),
        CHC(I,J)*CV(I,J));
TCO..   SUM((I,J), CO(I,J)*CV(I,J)) =L= SUM((I,J),
        CCO(I,J)*CV(I,J));
TNOx..  SUM((I,J), NOx(I,J)*CV(I,J)) =L= SUM((I,J),
        CNOX(I,J)*CV(I,J));

MODEL Emission /All/;

HC.L(I,I)  = 0.2;
CO.L(I,J)  = 2.0;
NOx.L(I,I) = 0.2;

HC.LO(I,J) = 0.01;
CO.LO(I,J) = 0.1;
NOX.LO(I,J)= 0.01;

Solve Emission  Using NLP Minimizing TC;
Display  HC.L, CO.L, NOx.L;
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NOTE TO EDITORS