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Energy 31 (2006) 1197–1214

ENERGY

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Simulating a combination of feebates and scrappage incentives to reduce automobile emissions

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Received 3 March 2004

Abstract

This article explains a computer simulation analysis of financial incentives to promote the sale and use of cleaner vehicles. The analysis focuses first on feebates, a combination of fees and rebates to promote the sale of cleaner new vehicles. The analysis assumes that buyers of new cars may chose between vehicles fueled by gasoline, alcohol, electricity and compressed natural gas. The market shares for new car sales are based on a discrete-choice model estimated from a stated preference survey in California. The analysis is conducted for a hypothetical air shed to illustrate the feasibility of the simulation method. The simulation analysis shows that feebates can lead to important reductions in hydrocarbon emissions, but the reductions will appear gradually as the newer vehicles displace the older vehicles in the air shed. The analysis then focuses on the emissions reduction that could be achieved by scrappage payments to induce early retirement of older cars. The analysis shows that scrappage payments can lead to large, immediate reduction in emissions. The article concludes with a simulation analysis of a combination of scrappage payments and feebates to achieve both immediate and sustained reductions in vehicle emissions. The simulations demonstrate that the emissions reductions could be achieved with rebates and scrappage payments drawn from a single fund financed by the fees imposed on the sale of new cars with high emissions.

1. Problems from vehicle emissions

Automobile emissions contribute to environmental problems within individual air sheds and within the global climate system. Within an urban air shed, the most serious problem is smog. Smog is the

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0360-5442/$ - see front matter
doi:10.1016/j.energy.2005.05.024

Table 1
Vehicle types

CVs	Conventional vehicles fueled by gasoline
AL	Alcohol vehicle, probably fueled by methanol
EVs	Electric vehicles, operated totally from batteries
HEVs	Hybrid electric vehicles, with both gasoline and batteries
CNG	Vehicles fueled by compressed natural gas

common term for tropospheric ozone, which is formed by the photochemical reaction between hydrocarbons (HC) and oxides of nitrogen in the presence of heat and sunlight. The health effects of smog have been recognized for over four decades, but the danger to human health remains. According to Gordon [12] "more than 100 of the cities in the US around 1990 were choking on smog, and roughly half of all Americans lived in areas that exceeded the ozone standard at least once a year." In the South Coast Air Basin of California, vehicle emissions account for nearly 60% of nitrogen oxide emissions and nearly half of the HC emissions [15].

Within the global climate system, the most serious problem with automobiles is their release of greenhouse gasses, which accumulate in the atmosphere, trapping the heat energy radiating from the atmospheric system. The potential problems of global warming are serious, and they are widely appreciated. Somewhat less appreciated is the interrelationship between global climate change and urban air pollution. For example, the California Air Resources Board (CARB) reports that "higher temperatures result in more emissions, increased smog, respiratory disease and heat-related illness" [3]. In California, vehicles account for more than 30% of greenhouse gas emissions, and California is the first state in the nation to pass legislation to restrict greenhouse emissions from vehicles. Under Assembly Bill 1493 passed in 2002, the Air Resources Board is to devise maximum feasible and cost-effective reductions for auto emissions greenhouse gases starting with cars manufactured in 2009. Automobile emissions can be reduced by shifting travel away from automobiles and by the design and operation of a cleaner population of vehicles. Both approaches are worthy of public policy. This article describes and simulates public policies to obtain a cleaner population of vehicles.

The population of automobiles is currently dominated by vehicles burning gasoline. The emissions of these conventional vehicles (CVs) can be improved by incentives to promote the sale of cleaner new CVs and to hasten the retirement of the older CVs. But there are important alternatives to the conventional vehicle fueled by gasoline. The alternative fuels include alcohol, compressed natural gas and electricity. This article focuses on five types of vehicles, which are likely to dominate the population of vehicles operating in our urban air sheds over the next two decades. Table 1 lists the vehicle types, along with the abbreviations used in this article.

2. Policies to reduce emissions from new vehicles

A variety of public policies have been used to promote the sale of new vehicles with less emissions. They include increased government research and development to speed the development of alternative vehicles, purchase programs to create an early market for cleaner vehicles in government fleets and federally required market shares in privately owned fleets. State agencies have implemented a variety of emissions standards targeted at both individual vehicles and the entire population of new cars sold each year. States have also proposed changes in registration fees, and they have encouraged cities to implement changes in driving and parking privileges for cleaner vehicles. The electric utilities have also contributed proposals including demonstration programs and incentives to reduce the purchase price of an EV.

This article begins with an analysis of feebates, one of the most intriguing of the proposals for new vehicles. The 'fee' in feebates stands for a fee imposed on the purchase price of a dirty vehicle. The 'bate' stands for a rebate to the person who purchases a clean vehicle. The idea is to finance the rebates for the clean vehicles with the fees imposed on the dirty vehicles. Feebate proposals have been considered at both the state and federal levels [4]. Feebates are appealing because they work to supplement the market forces that create the supply and demand for vehicles. The size of the feebates may be adjusted to represent the value of each vehicle within the overall plan issued by the agency responsible for compliance with the Clean Air Act. That value can be quite high. For example, Ford [7] estimated that an EV is worth $10,000 in the heavily polluted South Coast Air Quality Management District (SCAQMD) (acronyms are listed in Table 2). This estimated was published in 1992 based on CVs with more emissions than the CVs produced today. The 1992 study compared emissions from a CV (and its supporting refineries and gas stations) with the emissions from an EV (and its supporting power plants). The EV system had much smaller emissions and would deliver $10,000 in value to the achievement of the goals set forth in the SCAQMD plan. With feebates, this cost could be brought to the consumers' attention by setting a feebate to total $10,000. For example, the fee on the purchase of a new CV might be set at $2000 while the rebate to encourage the purchase of a new EV could be set at $8000. If two out of ten consumers purchased an EV, the $16,000 in rebates could be financed by the other eight consumers who pay a $2000 fee. In other words, a feebate program could be 'revenue neutral'. Consumers would be free to choose whichever vehicle best meets their needs, and manufacturers would be free to produce the most profitable mix of vehicles. Feebates would promote new technologies without requiring the program administrator to play favorites. Feebate programs could be implemented in a 'fuel neutral' and a 'technology neutral' manner. Each vehicle could be evaluated solely in terms of its emissions, and the feebates could be adjusted accordingly.

But feebates can pose serious challenges to the administrative body, as indicated by Arizona's unfortunate experience in 2002. Arizona offered large tax credits to encourage installation of a second tank to permit fueling with propane or compressed natural gas. Unfortunately, the legislation lacked clear eligibility requirements, and it did not include limits on the number of participants and the state funding. According to the Washington Post (national weekly edition, 12-18-2000, p. 29), what was "intended to be a $10 million program turned into a $200 million debacle".

The Arizona experience with vehicle incentives alerts us to anticipate the possible financial problems of a feebate program. Specifically, we should ask if rebate payments could be financed from the

Table 2
Acronyms

CARB	California air resources board
CEC	California energy commission
EPA	Environmental protection agency
HC	Hydrocarbon emissions
NAAQS	National ambient air quality standards
SCAQMD	South coast air quality management district
VAVR	Voluntary accelerated vehicle retirement program

collection of fees without bankrupting the program. Although an administrator may aim for the cash inflow from fees to balance the cash outflow for rebates, there is no way to achieve an exact balance. Consequently, feebate programs should be expected to achieve an approximate balance over time, with the variations in cash flow accumulated in a program fund. Estimating the appropriate fees and rebates to maintain the balance in the program fund at reasonable levels is a challenging task because of the inevitable uncertainties the market shares of the vehicles.

This challenge has been addressed in previous computer simulations by Ford [8], which demonstrated that a reasonable balance in the fund can be maintained despite the inherent uncertainties in market shares. Previous modeling has also been demonstrated that an administrator could maintain control of a feebate fund if consumer attitudes change in an unpredictable manner [10]. The previous work convinces us that a feebate program could be controlled provided the administrator is given adequate funding to initialize the program and the flexibility to alter the fees and rebates from year to year. The previous analysis suggests that the administrator could set fees and rebates to approximately balance cash flows. However, we should not expect the administrator to maintain fees and rebates at values, which reflect the estimated environmental value of the cleaner vehicles to the air shed.

Feebate programs target the new vehicles that are purchased each year. Their impact on the total emissions in an air shed builds slowly over time as the new vehicles gradually displace the older vehicles. But some vehicles can remain in operation for over 20 years, and their emissions per mile of travel can increase with each passing year. Previous simulations have demonstrated that feebates can deliver important reductions in vehicle emissions, but the reductions will only appear after a decade or two. The slow, gradual reduction in vehicle emissions could be a serious problem if administrators are under pressure to deliver results within a short time frame. If prompt reductions in vehicle emissions are to be achieved, policy makers must turn to programs to reduce the emissions from the existing population of vehicles.

3. Policies to reduce emissions from existing vehicles

The older vehicles in the population are responsible for a surprisingly high portion of the total emissions. To illustrate, consider the population of vehicles in operation in 1998 in southern California, as studied by Dixon and Garber [5]. The population of vehicles is displayed in Fig. 1 according to

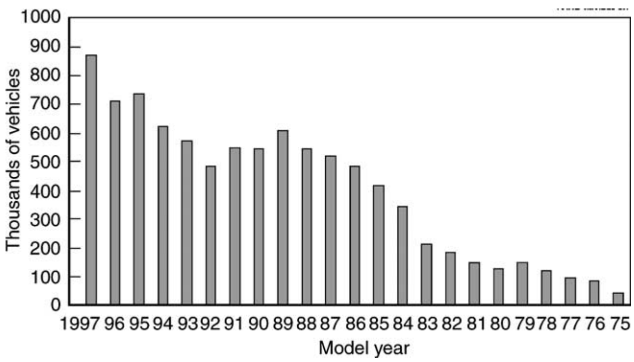

Fig. 1. Age distribution of vehicles in southern California in 1998 from Dixon and Garber [5].

the 'model year', the year when the vehicle was manufactured. Fig. 1 shows around 850,000 vehicles from the 1997 model year, vehicles which were in their first year of operation in 1998. The bar chart shows a general decline in the number of vehicles as we move to older model years. (The variations in the downward trend may be attributed to the volatility in new car sales.) Fig. 1 shows a marked decline in the 1983 model year, showing less than 200,000 vehicles with 15 years of age. Dixon and Garber [5] estimated that the vehicles with 15 or more years of age accounted for only 11% of the vehicle miles of travel. Despite their small numbers and their limited use, these older vehicles contributed 39% of the vehicle emissions. The large contribution of the older vehicles arises from several factors described by the EPA [6], Taylor [21] and Van Wee [22]. These include the increasingly strict standards for new vehicles, the increase in emission rates with age and the tendency for vehicle to have longer lives.

This article focuses on Voluntary Accelerated Vehicle Retirement (VAVR) programs, which use scrappage payments to encourage vehicle owners to retire their automobiles [1]. Scrappage programs are normally voluntary, so the vehicle owners are free to decide whether the scrappage payment is sufficient to induce them to retire their vehicles early. According to Dixon and Garber [5], scrappage programs have been used by industry and by state and local governments to reduce emissions as part of their overall effort to achieve compliance with National Ambient Air Quality Standards (NAAQS). Recently, several local and state governments have included scrappage programs in their state implementation plans while several private companies have begun programs to satisfy new or existing stationary source-specific requirements [6].

To illustrate the costs and benefits of a VAVR program, consider the vehicles from the tail end of the distribution in Fig. 1. There are approximately 1 million vehicles with 15 years or more of operation in this distribution. If a scrappage program could remove these vehicles from the population, there would be a 39% reduction in the vehicle emissions. Alberini [1] has estimated the fraction of vehicle owners that would participate in a VAVR program as a function of the size of the scrappage payment, as shown in Fig. 2. If the owners were paid $1500, for example, around half would agree to scrap their cars. A more aggressive payment of $3000 would lead to 90% scrappage.

Imagine that we turned to the most aggressive payment to achieve the largest possible immediate reduction in vehicle emissions. With a $3000 scrappage payment, around 0.9 million vehicle owners would agree to scrap their cars, for a total payment of $2.7 billion. The reduction in vehicle emissions would be approximately 90 of 39% or 35%. A 35% reduction in vehicle emissions is a major reduction,

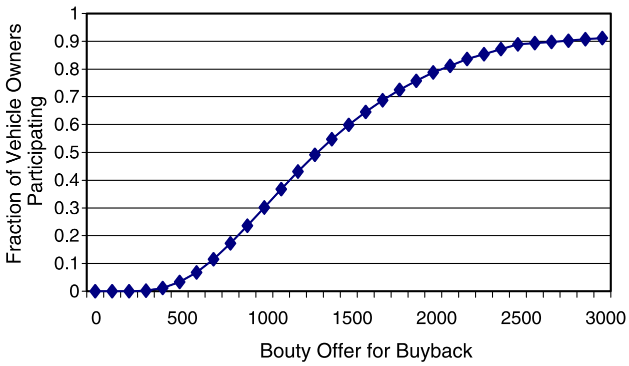

Fig. 2. Participation fraction as a function of the scrappage payment.

one that would require many years if we waited for the gradual benefits of a feebate program. But where would the $2.7 billion come from? If scrappage payments are to be financed without imposing a drain on states' general fund, the funding might come from vehicle licensing fees or a tax on gasoline. For this article, we examine the idea of funding a scrappage program from the fees imposed on new car sales.

4. Organization of the article

This article demonstrates the feasibility of computer simulation to study the combined operation of a feebate program and a scrappage program. Computer modeling has been put to good use by many previous researchers, with the most closely related modeling conducted by Leiby and Rubin [17]. They used a dynamic transitional model to estimate the costs of a transition to alternative fueled vehicles over the time period from 1996 to 2010. The computer model described in this paper differs from previous work in its focus on the combined impact of feebates and scrappage programs and the challenge of controlling the cash flows in the programs. We use computer simulation to examine the use of a single fund to provide the funding for both scrappage payments and feebates. Fees on the sale of new vehicles with high emissions could provide the funding needed for both rebates on new vehicles and scrappage payments for the early retirement of older vehicles. With a combined program, administrators could strive for both the short-term reduction in emissions from scrapping older cars and the long-term improvement in vehicle emissions from the promotion of cleaner new cars. The article begins with a description of the modeling methodology and the previous modeling of feebates. We then explain the expansion of the previous model to allow for a simulation of both feebates and scrappage programs in a realistic manner. Simulations are presented to show the impacts of running a feebate program or a scrappage program. The article concludes with a simulation to show the impact of running the programs in combination.

5. The system dynamics method

The analysis is based on the system dynamics approach pioneered by Forrester [11] and explained in recent texts by Ford [9] and Sterman [20]. System dynamics models are normally implemented with 'stock and flow' visual software to aid in model construction and testing. The model was implemented with the IThink software from isee systems (http://www.iseesystems.com/).

Stocks and flows are the basic building blocks of system dynamics models, and Fig. 3 shows the key stock and flows to represent cash flow in a feebate system. Fig. 3A shows the model variables as they appear in the Ithink software. Fig. 3B shows the corresponding variables that would appear in a differential equation to describe the balance in the fund. System dynamics models are comprised of a coupled set of nonlinear differential equations, with a separate differential equation for each stock in the model. The differential equations are 'solved' through numerical integration using the first-order method (Euler's method) provided with the Ithink software.

The balance in the fund is increased by the cash flow from fees collected and reduced by the cash flow from rebates paid. The balance is also increased by the interest earnings. This flow is a biflow, a flow that can add to or subtract from the stock. If the balance in the fund should fall below zero, for example, the interest earnings will be negative, and the fund will drop further into 'the red'. The double lines in Fig. 3A represent the flow of cash into or out of the stock. The clouds represent the sources or sinks for

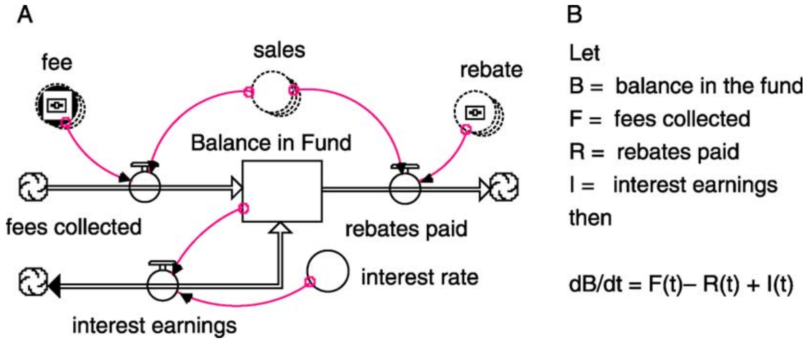

Fig. 3. (A) Stocks and flows to simulate cash flow in a feebate system. (B) Equivalent differential equation for balance in the fund.

the cash. (The clouds represent stocks that are beyond the boundary of the model.) The remaining variables in Fig. 3A are called 'converters' with the Ithink terminology. Converters are used to help explain the flows. For example, the flow of interest earnings is influenced by the value of the interest rate. The fees collected each year depends on the sales of new cars and the fees imposed on those sales. Similarly, the rebates paid each year depends on the sales of new cars the rebated allowed on those sales. The fee, rebate and sales variables in Fig. 3A are 'array variables' based on a dimension [*V*], which takes on, the five subscripts, one for each of the vehicle types listed in Table 1.

6. The previous model for feebates

The stocks and flows in Fig. 3A are part of a textbook model, which allows students to experiment with a feebate program. The model was designed for highly interactive simulation, a form of simulation sometimes described as a 'management flight simulator'. The value of management flight simulators has been described for a wide variety of systems by Morecroft and Sterman [18]. Flight simulators are models designed with a user-friendly interface to encourage interactive and frequent simulations. The textbook model [9] was designed in this manner, but the interface is not the subject of this article. For our purposes, it is more useful to describe the main sectors of the previous model and how these sectors have been expanded to simulate the impact of scrappage programs.

Fig. 4 shows the variables used to simulate the number of cars in operation and their emissions in the previous model. The total sales are an exogenous input which is normally set to grow in exponential fashion. The sales of cars are based on market shares, which are explained shortly. The stock of cars is represented by a conveyor, a special category of stock whose outflow is controlled by the timing of the inflow and the length of the transit time [9]. In this case, the transit time is set to the lifetime of each vehicle. The previous model assumed that vehicles would operate around 10 years before they are retired. During their lifetime, they influence annual travel, annual emissions and total emissions.

This article focuses on HC emissions, one of the important precursors to ozone formation. The standard emission of hydrocarbons is set at 0.25 g/mile, the 'certification value' for CVs sold during the mid 1990s [7]. To illustrate the calculations in Fig. 4, consider the HC emissions from 10 million CVs driven 10,000 miles/year. The total annual travel would be 100 billion miles, and the annual HC emissions would be 25 billion grams. This article reports emissions in metric tons, where 1 metric ton is a million grams. In this example, the annual HC emissions would be 25,000 metric tons.

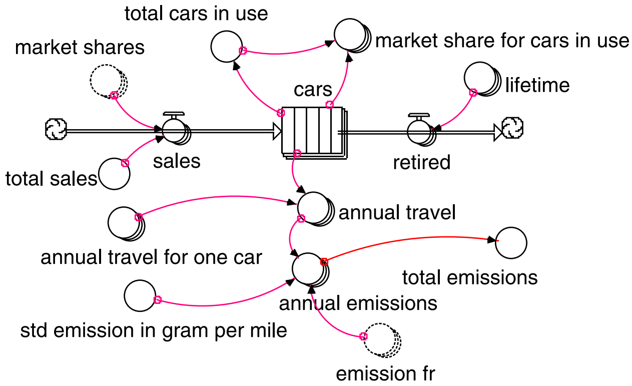

Fig. 4. Simulation of cars and emissions in the previous model.

The emission fractions are listed in Table 3. These are user inputs to represent the per mile HC emissions of each type of vehicle relative to the CV. For example, a hybrid electric vehicle is estimated to emit 37% as much as a CV. The table also lists the estimated value of each vehicle based on the previous discussion of an EV's value in a heavily polluted air shed. Recall that an EV was valued at \$10,000 relative to a CV. With an emissions fraction of 37%, a HEV would be valued at \$6300 relative to a CV. The dollar estimates in Table 3 are useful if one were to set fees and rebates to reflect the environmental values of the vehicles.

The market shares variable in Fig. 4 is shown as a ghosted variable, the Ithink term for a variable, which is calculated elsewhere in the model diagram. Fig. 5 shows the collection of converters used to find the market shares. The market shares equations are adapted from a discrete-choice model published by researchers from the University of California [2]. The array variable, U, stands for the utility of each vehicle. Market shares are found by:

- market_shares[V]=numerator[V]/denominator
- numerator[V]=exp(U[V])
- denominator=ARRAYSUM(numerator[*])

which is the Ithink equivalent of the multinomial logit equation commonly expressed as:

$$\mathrm{MS}_v = \frac{e^{U_v}}{\sum_{i=1}^{n} e^{U_i}}$$

Table 3
Emissions fractions

Vehicle type	Emissions (%)	Value
Conventional gasoline, CV	100	0
Electric vehicle, EV	0	\$10,000
Alcohol or methanol, AL	81	\$1900
Hybrid electric vehicle, HEV	37	\$6300
Compressed natural gas, CNG	42	\$5800

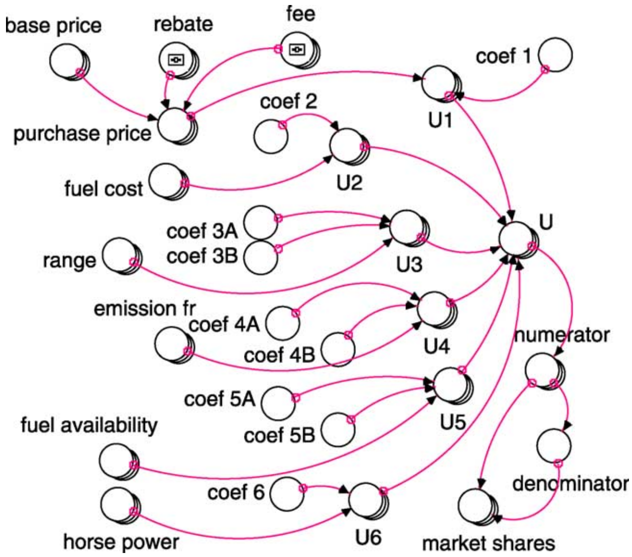

Fig. 5. Finding market shares with the discrete-choice model.

The utility of each vehicle is expressed as a sum of separate utilities based on the six attributes:

- $U[V] = U1[V] + U2[V] + U3[V] + U4[V] + U5[V] + U6[V]$
- $U1[V]$ = coef_1*purchase_price[V]/1000
- $U2[V]$ = coef_2*fuel_cost[V]
- $U3[V]$ = coef_3A*(range[V]/100) + coef_3B*((range[V]/100)^2)
- $U4[V]$ = coef_4A*emission_fr[V] + coef_4B*emission_fr[V]^2
- $U5[V]$ = coef_5A*fuel_availability[V] + coef_5B*fuel_availability[V]^2
- $U6[V]$ = coef_6*horse_power[V]

A single coefficient means that utility is a linear function of the attribute. For example, $U1[V]$ is a linear function of the purchase price. Two coefficients indicate that utility is a nonlinear function of the attribute. The researchers received approximately 700 responses to a mail-back survey. The respondents described their preferences for vehicles with different prices, fuel costs, ranges, etc. The researchers estimated the model to provide the best explanation of the stated preferences. The model was well structured, clearly explained and used in studies by the California Energy Commission (CEC).

Table 4 shows an example of the market shares that would be calculated from the discrete-choice model. The assumptions vehicle attributes are the same as listed in previous studies [7–10] even though vehicle technologies have changed in many ways since the previous studies were published. We also maintain the previous assumption that an EV delivers $10,000 in value toward meeting clean air goals. These assumptions are maintained to allow for a clearer comparison between the new simulations and the previously published simulations. With the vehicle attributes listed in Table 4, the CVs would capture 52% of new vehicle sales. Because of their high purchase price and their low range, EVs would capture only 6% of new vehicle sales.

Table 4
Example of vehicle attributes and the estimated market shares

Attribute	CV	AL	EV	HEV	CNG
Emission fraction	1.00	0.81	0.00	0.37	0.42
Purchase price	$15,000	$18,000	$25,000	$27,000	$20,000
Fuel cost (c/miles)	4.7	7.2	5.3	6.4	2.6
Horse power	121	134	65	85	115
Range (miles)	450	250	100	200	200
Fuel availability (%)	100	20	50	100	25
Market share (%)	52	12	6	8	22

But the EV market share would increase if a rebate were made available to lower the purchase price paid by the consumer. This article will show the impact of a $7000 rebate for EVs with a $3000 fee on CVs. (The combination of the fee and rebate adds to $10,000 to reflect the value of an EV.) With such a feebate, the market share for EVs would be increased by nearly three-fold, from 6 to 17%. The market share for CVs would fall from 52 to 37%. The other three vehicles are not targeted with a fee or rebate, but their market shares would change somewhat because of the changed attractiveness of the CV and EV. Based on the discrete-choice model, the market shares of the other three vehicle types would increase by a few percentage points, due largely to the fee imposed on the CV.

The original feebate model is an interconnected combination of the cash flows shown in Fig. 3, the vehicle flows in Fig. 4 and the market shares in Fig. 5. Fig. 3 shows the model variables to keep track of the accumulated impact of fees, rebates and interest charges on the balance in the state fund. The cash flows are measured in constant dollars, and the interest rate is 6.5%/year. Further information on the previous model is provided by Ford [8–10].

7. Expanding the previous model to simulate scrappage programs

The previous model cannot simulate scrappage programs because all vehicles, young and old, are combined into the single stock shown in Fig. 3. To improve the realism of the model, the single stock of vehicles has been replaced by 30 separate stocks to include vehicles ranging from 1 to 30 years of age. Disaggregating the model in this manner allows one to simulate scrappage programs targeted at vehicles of specific ages. The disaggregated model can also be used to represent the change in vehicle travel and emissions as the vehicles become older.

Fig. 6 shows a portion of the disaggregated model to represent the vehicles in their 16th and 17th year of operation. The first stock is fed by an aging flow, which appears to come from a cloud in this abbreviated diagram. In the actual model, the ‘Aging 15’ flow drains the stock of vehicles in their 15th year. Similarly, the ‘Aging17’ flow feeds into a stock of vehicles in their 18th year. The stocks are subject to a retirement flow, which is influenced by a natural retirement fraction plus the fraction of old vehicles that would participate in a buy back program. The participation fractions are based on the nonlinear relationship shown previously in Fig. 2. The natural retirement fractions become larger as the vehicles become older and older. We have selected natural retirement fractions for vehicles in three decadal groups. For example, the label ‘old vehicles’ in Fig. 6 applies to vehicles in their 11th to 20th year of operation. Vehicles in their 21st to 30th year of operation are labeled ‘very old’ and are subject to

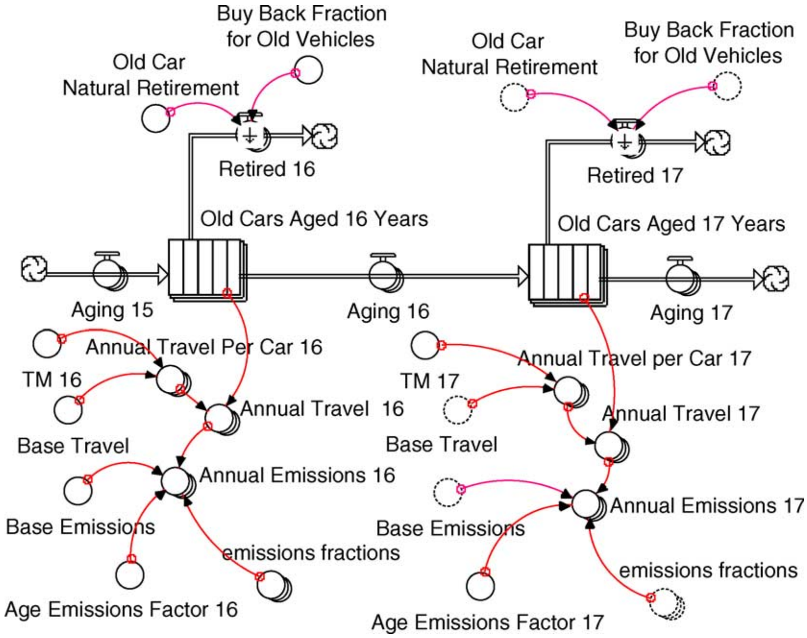

Fig. 6. New variables to keep track of vehicle aging, retirements, travel and emissions.

a different natural retirement fraction and a different buy back fraction. We decided to group vehicles in decadal groups for purposes of scrappage analysis following the examples set by Hahn [13] and by Kavalec [16]. We found that the model generates a realistic age distribution by setting the annual retirement fractions to 5% for the vehicles in their first decade, to 8% for vehicles in their second decade and to 10% for vehicles in their third decade.

The lower portion of Fig. 6 shows new variables to provide a more detailed estimate of annual travel and annual emissions. The base travel represents the average travel when a vehicle is at its certification age (approximately 50,000 miles on the odometer). The 'TM' variables are travel multipliers, which adjust the annual travel to account for the changes in travel as vehicles age. To illustrate, TM1 is set to 1.3 to represent first year vehicles used 30% more than a vehicle at its certification age. The TM16 in Fig. 6 is set at 0.6 to represent 40% less travel for a vehicle in its 16th year. These and other travel multipliers are based on emission analysis [7] which relied on a survey of national travel behavior [19].

Fig. 6 shows the age emissions factors to adjust the annual emissions from the base emissions. Recall that the emissions rates from Table 3 are based on a vehicle at its certification stage. Newer vehicles have less emissions; older vehicles have more emissions. To illustrate, the emissions factor for vehicles in their first year is set at 0.55 to represent 45% less emissions per mile of travel. The age emissions factor 16 in Fig. 6 is set at 2.5 to increase the emissions rate by two and a half times relative to the base emissions rate. These and other emissions factors are based on the emission analysis [7] which relied on deterioration, factors in a working paper by the CARB [14].

Fig. 6 shows 2 of the 30 stocks used to keep track of the aging of the vehicles. The expansion from 1 to 30 age stocks leads to a more complicated, and cumbersome model. But the added details are needed if the model is to provide a realistic simulation of the vehicle age distribution and the changes in travel and emissions as the vehicles age over time. The new model may now be used to simulate the impact of a user specified scrappage payment. The model finds the fraction of vehicles owners that would respond to a buy back payment based on the nonlinear relationship in Fig. 2. The designated vehicles are removed from the population, and scrappage payments are drawn from the balance in the fund shown in Fig. 3.

The final change in the previous model is an adjustment in new vehicle sales to account for the possibility that scrappage programs will lead to an increase in new car sales. We assume that vehicle sales is 1 million vehicles in the first year of the simulation, and the sales grow at the rate of 3%/year over the 20-year simulation. The 3% annual growth is an illustrative assumption, which should be interpreted as representing growth from an increasing population, increasing affluence and a natural rate of retirements. With scrappage payments, however, retirements are higher than normal and one might expect an increase in new car sales. Dixon and Garber [5] explain that the effect of scrappage on new car sales is difficult to estimate, and the fraction could range from 50 to 90% depending on the model year and the longevity of the scrappage program. We set the induced sales fraction at 75%, and we return to this highly uncertain parameter in sensitivity testing later in the article.

8. Benchmark simulation

Fig. 7 shows HC emissions in a 20-year simulation. We call this a 'benchmark' simulation because our purpose is to provide a reference result to judge the impact of feebate and scrappage programs. The simulation begins with a population of 1 million CVs, so we should anticipate approximately 25,000 metric tons/year of HC emissions (based on the simple calculation described previously). Fig. 7 shows that the simulation begins with total emission only slightly higher than 25,000 tons/year. The lower curve in Fig. 7 is the total of emissions from vehicles that have been in operation for less than 10 years. These '1st decadal' vehicles account for approximately half of the total emissions at the start of the simulation. The second curve in Fig. 7 adds in the emissions from the vehicles in their second decade of operation. And the third curve adds in the emissions from the vehicles in the third and final decade of

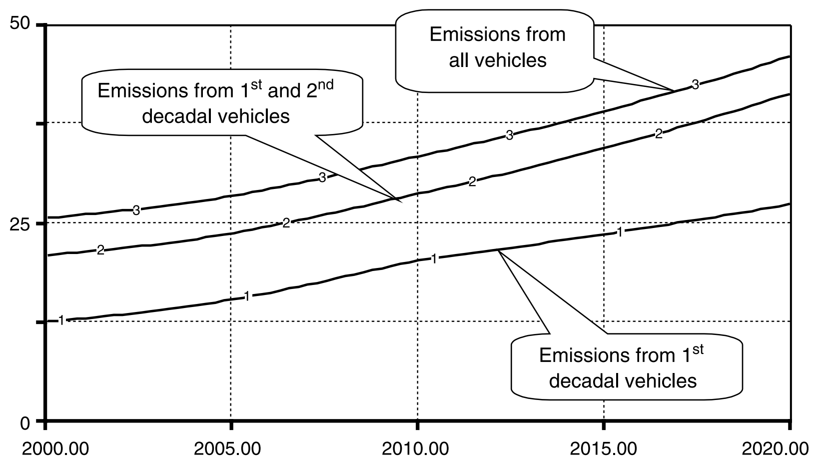

Fig. 7. Annual hydrocarbon emissions from different categories of vehicles in a benchmark simulation (scaled from 0 to 50,000 metric tons).

operation. Fig. 7 is not a forecast of future emissions. Rather, our purpose is to provide a clear benchmark to be used in evaluating feebate and scrappage policies. In the interest of clarity, we assume that new car sales grow at the constant rate of 3%/year. Also, we assume that the vehicle attributes remain at the values shown in Table 4. We assume that no changes in the discrete-choice model, so the new vehicle market shares will remain at Table 4 values for the entire simulation. Fig. 7 shows total HC emissions growing to 46,000 metric tons/year by the end of the simulation. The growing population of vehicles causes the growth. By the end of the simulation, annual HC emissions have grown by 80%, even though the air shed has benefiting from 20 years of sales of alternative fueled vehicles.

9. Impact of a separate feebate program

Fig. 8 compares the HC emissions in a feebate simulation with the benchmark simulation. The feebate program is implemented at the start of the simulation with a fee on CVs at $3000 and a rebate for EVs at $7000. The total of the fee and rebate is $10,000, which matches the estimated value of an EV in a heavily polluted air shed. Recall that this feebate would increase the EV market share from 6 to 17% and cut the CV market share from 52 to 37%. With these changes, we expect to see gradual improvement over the 20-year simulation. By the year 2020, the HC emissions in the feebate simulation have reached 39,000 metric tons/year. This feebate policy has delivered a 15% reduction in HC emissions by the end of the simulation.

Fig. 9 shows the balance in the fund. We assume that the program is capitalized at $100 million. The fee of $3000 on CV sales is simulated to generate approximately the cash flow needed to finance the payment of $7000 in rebates for EV sales. But the cash flows do not balance exactly, and the fund declines to a negative $1000 million after ten years. At this point, the fund is $1 billion in the red. To reverse the trajectory, we adjust the fee upward by 10%. The fee on CVs is now $3300. We will lower the rebate to $6700 at this point with the idea that the total feebate should be $10,000. Fig. 9 shows that the fund would gradually recover during the second half of the simulation. The simulation is concluded with the fund at negative $144 million. The simulation concludes with the fund at approximately the same

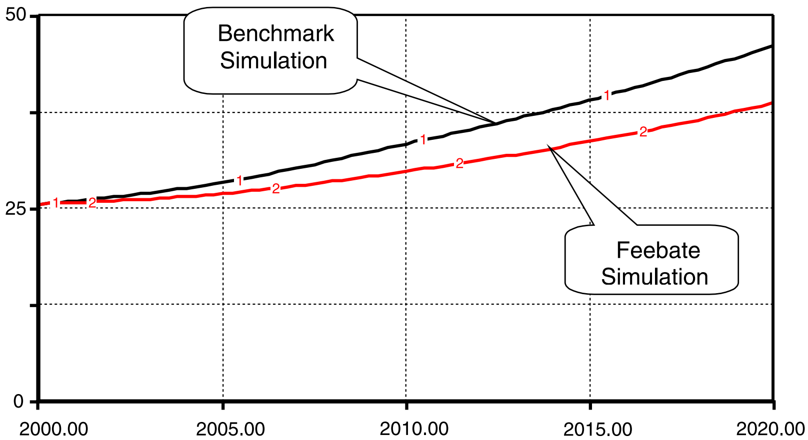

Fig. 8. Comparison of annual HC emissions to see the impact of feebates.

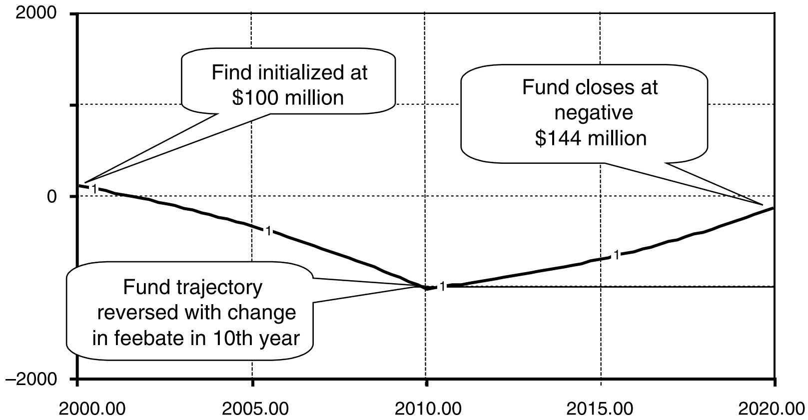

Fig. 9. Balance in the fund with the feebate policy (the scale is from −2000 to 2000 million dollars).

value as the initial capitalization. The feebate program may be labeled as approximately 'revenue neutral' when evaluated.

The feebate simulation confirms what has been discovered in analysis with the previous model. Feebates can lead to important reductions in emissions over the long-term, but the improvements appear in a gradual manner as the newer vehicles displace the older vehicles in the air shed. We turn now to scrappage programs, which are designed to deliver a more immediate reduction in emissions.

10. Impact of a separate scrappage program

Fig. 10 compares total HC emissions from the benchmark simulation with four simulations with scrappage payments set at: $500, $1000, $1500 and $2000. The comparison shows a large increase in the emission reductions if the administrator is willing to increase the payment to $1000 or higher. (This nonlinear response arises from the shape of the participation curve in Fig. 2.) Fig. 10 reveals that

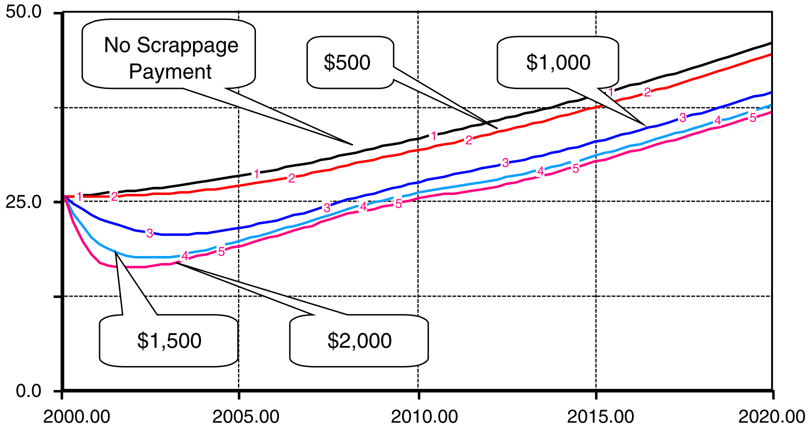

Fig. 10. Annual HC emissions with different scrappage payments.

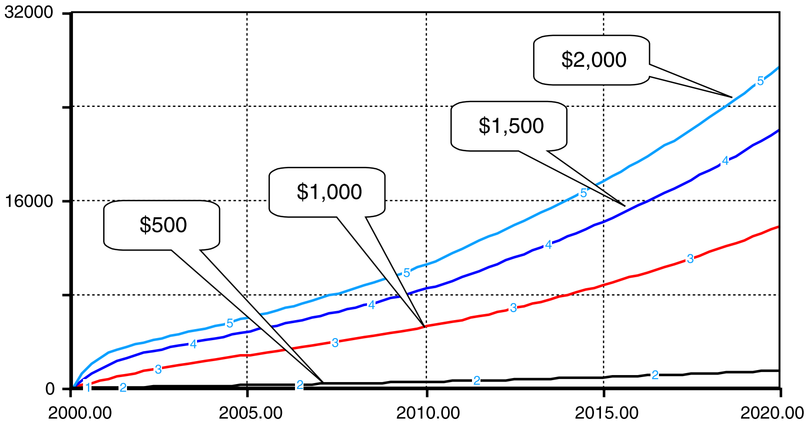

Fig. 11. Comparison of cumulative costs with different scrappage payments. (The costs are scaled from 0 to 32,000 million dollars.)

a scrappage program can deliver quite large and immediate reductions in emissions if the administrator sets the per car payment at $1500 or $2000. The $1500 payment delivers sizeable reductions in the short term. By the end of the simulation, HC emissions are at 38,000 metric tons/year. This final value is similar to the value at the end of the feebate simulation.

Fig. 11 shows the cumulative cost of running the scrappage programs over the 20-year simulation. (The cumulative cost is measured in millions of dollars and includes the interest charges at 6.5%/year on the negative balance in the fund.) The $500 program is the least costly, with cumulative costs of $1.4 billion. The $2000 program would run up a total, cumulative cost of over $27 billion by the end of the simulation. The $1500 program leads to $22 billion in cumulative costs.

Fig. 12 provides a sensitivity test on the $1500 scrappage program. The total HC emissions from the benchmark simulation are shown along side of five simulations of the $1500 scrappage policy.

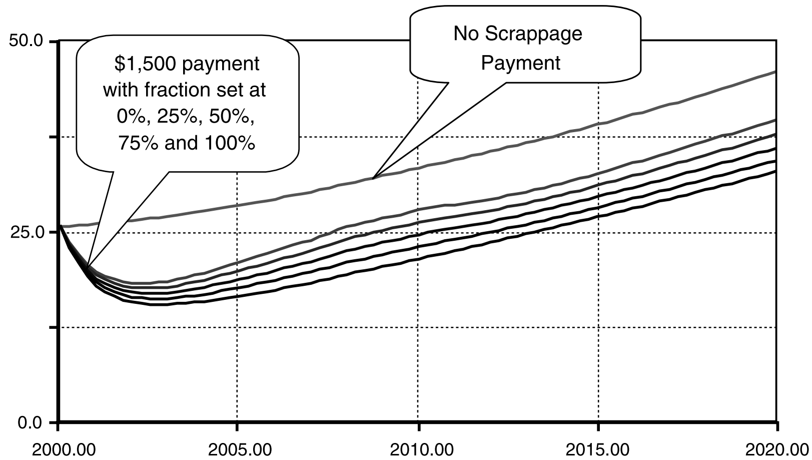

Fig. 12. Annual HC emissions in the benchmark simulation and in simulations with different assumptions on the percentage induced sales from a $1500 scrappage payment.

The simulations show the impact of setting the fraction of scrapped vehicles that lead to additional new car sales at 100, 75, 50, and 25% and at zero. The comparison shows that a scrappage policy delivers immediate reductions in HC emissions regardless of the assumption on induced sales. By the end of the simulation, however, the induced sales assumption causes significant variations in the estimated reduction. With no induced sales, the HC emissions in 2020 are at 33,000 metric tons/year, 28% lower than in the benchmark simulation. With 100% induced sales, the HC emissions in 2020 are at 40,000 metric tons/year, 13% below the benchmark result. This comparison shows that scrappage payments can deliver emissions benefits even with the assumption that every scrapped vehicle is immediately replaced with an additional new car sale. This benefit is achieved by the scrappage of higher emitting vehicles and the fact that 48% of the induced sales are alternative-fueled vehicles, as indicated in Table 4.

We now consider a combination of the $1500 scrappage policy with the feebate policy simulated previously. Our goal is to obtain reductions in HC emissions in both the short-run and the long-run, while financing the incentives from the fees imposed on CV sales. We start the simulation with $100 million in the fund, a $1500 scrappage payment. The fee on CVs is set at $3000. We assume that there is no rebate for EVs in the first year of the simulation, as it may be prudent for the administrator to observe the trends in the fund before paying for rebates.

11. Impact of a combination of feebates and scrappage programs

Fig. 13 shows that the balance in the fund would grow during the first year of the simulation. With this extra buffer, we introduce the $7000 rebate for EVs. We now have a combination of the two policies that were simulated in stand-alone fashion previously. Fig. 13 shows that the fund balance would decline rapidly during the second year. At this point, it would be appropriate to raise the fee or lower the rebate. For this simulation, we do both. We raise the fee to $3300 and lower the rebate to $6700. As in previous simulations, we are striving to keep the total rebate at $10,000. This adjustment slows but does not halt the downward trajectory. So we make a further adjustment in the fourth year of the simulation. The fee is now at $3600 and the rebate at $6400, and we continue with these values until the year 2015. During this time, the fund remains approximately in balance at around $1 billion in the red. The fee is then increased

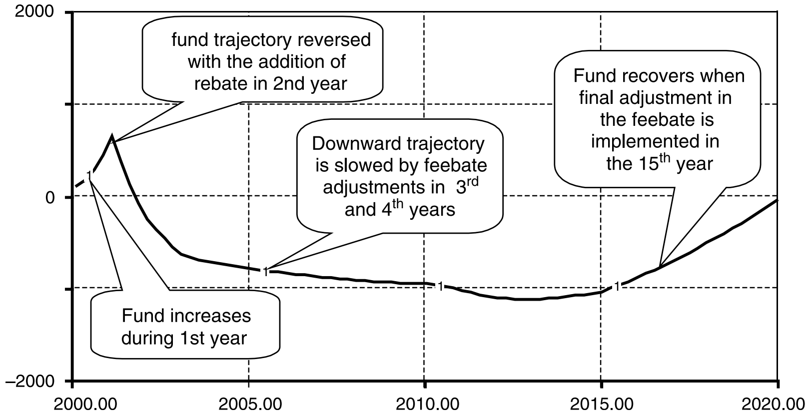

Fig. 13. Balance in the fund with a combined scrappage and feebate policy (the scale is from −2000 to 2000 million dollars).

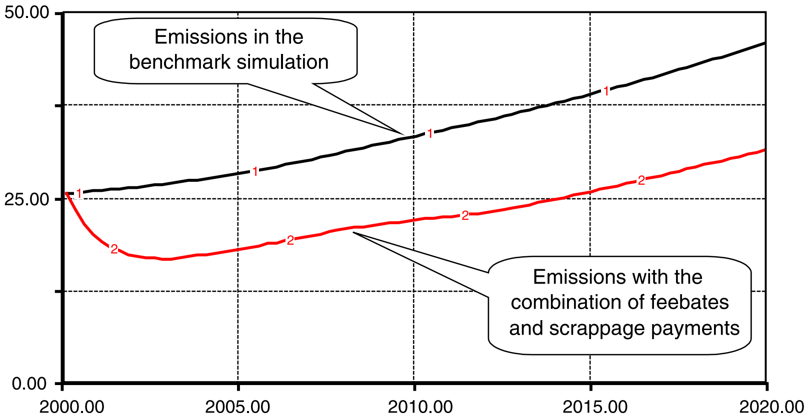

Fig. 14. Comparison of annual HC emissions to see the impact of a combination of feebates and scrappage payments.

to $3700 and the rebate is lowered to $6300 for the remainder of the simulation. This final adjustment allows the balance to climb toward zero. The simulation concludes in the year 2020 with the balance at a negative $55 million.

Fig. 14 shows the emissions reduction achieved by the combination policy. Annual HC emissions grow to around 46,000 metric tons in the benchmark simulation. The $1500 scrappage payment is responsible for the large reduction in emissions shown in the first few years of the simulation. By 2003, the HC emissions are at 17,000 metric tons/year, well below the 27,000 metric tons/year in the benchmark simulation. The short-term results are immediate and gratifying.

Fig. 14 shows that the emissions reduction would grow even further over the remainder of the simulation. By the year 2020, annual HC emissions are at 31,000 metric tons with the combination policy. The policy has reduced emissions by 33% compared to the benchmark simulation. The reduction is over twice as large as the reductions achieved with either the feebates or the scrappage payments implemented in a stand-alone fashion. And the reduction is achieved in a revenue neutral fashion, as indicated by the fund balances shown in Fig. 13.

12. Summary and final comments

This article has demonstrating the benefits of combining a feebate program with a scrappage program to reduce the emissions from vehicles in a large, urban air shed. The approach was demonstrated for a hypothetical air shed by focusing on HC emissions. For clarity of presentation, we focused on a feebate program aimed at CVs and EVs. We imposed a fee on CV sales with a rebate for EV sales, and we strived to maintain the total feebate at $10,000, an estimated value of an EV in a highly polluted air shed. In fairness to the vehicles fueled by natural gas and alcohol, they too should be subjected to feebates, with the size of the incentive based on their emissions. The model described here could be used to test feebates spread across all five types of vehicles. We expect that simulations with the more comprehensive feebate policy would show that the feebates could be controlled to maintain a reasonable balance in the fund. But we do not expect that the values of the fees and rebates could also be maintained at values reflecting the environmental values of the cleaner vehicles.

The modeling approach is this article describes emission of hydrocarbons in a hypothetical air shed. The approach could be adapted to simulate emissions in a real air shed, and the model could be expanded to include the emission of regulated pollutants such as nitrogen oxides. The model could also be expanded to represent the emission of carbon dioxide, which has become the focus of recent legislation in California.

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