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Fighting Air Pollution in Southern California by Scrapping Old Vehicles

Lloyd Dixon
Steven Garber

Prepared for the
Public Policy Institute of California and the RAND Institute of Civil Justice
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PREFACE

In 1994, California adopted a voluntary accelerated vehicle retirement program as part of its State Implementation Plan for Ozone. Though unfunded, the program proposes to buy and scrap 75,000 vehicles that are 15 years old or older every year from 2001 through 2010. The research described in this report evaluates this program. The study is the first to examine programs of this type by developing market-based predictions of how vehicle prices and emissions will be affected while directly accounting for in-migration of older vehicles.

This research was jointly funded by the RAND Institute for Civil Justice and the Public Policy Institute of California. It should help policymakers and policy researchers assess the desirability of the current and other vehicle scrappage programs.

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SUMMARY

Air pollution damages health and reduces the quality of life in California in general and California’s South Coast Air Basin in particular. The federal Clean Air Act requires California to develop and implement programs to enable the South Coast to meet national air-quality standards for ozone by the year 2010. California’s plan for doing so is contained in the 1994 State Implementation Plan (SIP) for Ozone (California Air Resources Board (CARB), 1994). The SIP details a strategy for meeting air-quality goals by 2010 based in part on promising to implement some policies that have yet to be identified; meeting air-quality standards in the South Coast by 2010, or even several years later, is hardly assured.

Emissions from older light-duty vehicles (LDVs)—passenger cars and light-duty trucks—are a major part of the ozone problem. Ozone is formed when reactive organic gases (ROG) and oxides of nitrogen (NOx) react chemically in the presence of sunlight. In the South Coast, LDVs are believed to account for approximately 45 percent of total ROG and NOx emissions from all sources, and LDVs at least 15 years old account for roughly 40 percent of LDV emissions of these gases.

This report examines the effects of an innovative and controversial program included in the SIP that is aimed squarely at older LDVs. This is a “voluntary accelerated vehicle retirement” (VAVR) program to buy and scrap as many as 75,000 LDVs that are at least 15 years old every year from 2001 through 2010. According to the SIP, the goal of this “M1 program” is to reduce total emissions of ROG and NOx in the South Coast by 25 tons per day in 2010. The state has taken steps to design the program, but the necessary funding for full-scale implementation—roughly $100 million per year for 10 years—has not been secured. The fate of the program is very much in doubt.

Two concerns about the effects of this program have been widely acknowledged:

- how much prices of used vehicles will increase and
- the degree to which potential emission benefits will be attenuated by migration into the South Coast of older vehicles attracted by higher prices.

At their cores, both of these concerns pertain to how markets for LDVs will respond to the program. Our study is the first to develop market-based predictions of price effects or to analyze emission effects while also directly accounting for in-migration. Our analysis, then, provides a

---

1The South Coast Air Basin includes all of Orange County and the western, urbanized portions of Los Angeles, Riverside, and San Bernardino Counties.
more complete and reliable assessment of the desirability of the VAVR program than previously available.

**ANALYTIC APPROACH**

We analyze program effects with both conceptual (theoretical) and quantitative (empirical) methods. The conceptual analyses use supply and demand models adapted to allow for vehicles of different ages or “vintages” located in the South Coast and in the rest of California. These analyses provide a foundation for developing quantitative predictions by identifying factors that will determine various program effects and by providing a logical framework for constructing and evaluating quantitative models.

There is no precedent for a large-scale VAVR program operating over several years. Thus, no historical data are available to analyze the effects of such a program directly. Instead, we develop a multi-year simulation model of used-vehicle markets in the South Coast and the rest of the state. Parameter values are based on diverse and extensive, but sometimes sketchy, empirical information. We use the model to predict for each year from 2001 through 2020 the effects of the M1 program on

- used-LDV prices in California,
- numbers and age distributions of LDVs operating in the South Coast,
- daily quantities of total ROG and NOx emissions from LDVs operating in the South Coast, and
- costs per ton of emissions reductions.

We first predict the effect of the program using a base-case set of assumptions and then assess the degree of uncertainty about program effects.

Figure S.1 provides an overview of how predictions are computed. The model starts each year with sets of LDV stocks distinguished by vehicle vintage (age) for both the South Coast and for the rest of California. In the scenario with the VAVR program, 75,000 older LDVs are removed from the South Coast stocks each year from 2001 through 2010. Then, under both this scenario and a without-program scenario, LDV stocks in the South Coast and in the rest of California in each year from 2001 through 2020 are adjusted to account for

- LDVs brought into California by people moving into the state (“exogenous immigration”), and
- used LDVs scrapped through all channels other than the VAVR program (“natural scrapping”).
Figure S.1—Overview of Calculation of Used LDV Prices, LDV Quantities, and Emissions in any Calendar Year

Next, LDV prices and locations in equilibrium are computed using a supply-and-demand framework. To generate stocks of LDVs for the end of the period, we then add vehicles to represent new-LDV sales in California. Emission levels in the South Coast and in the rest of the state are calculated from end-of-year vehicle stocks, which are then carried over in the model to begin the prediction process for the next year.

We employed data from several sources to choose base-case parameter values and the ranges of values used to assess degrees of uncertainty about program effects. Used-LDV prices extracted from the Kelley Blue Book Internet site were employed to estimate average used-vehicle prices in California in 1999. Average prices for new LDVs in 1999 were specified using data from the American Automobile Manufacturers Association. Vehicle registration counts by model year and zip code from California’s Department of Motor Vehicles were used to determine the age distributions and locations of LDVs in the South Coast and in the rest of California. Characteristics of demand for new and used LDVs are specified relying on econometric estimates reported in previous studies. Analyses of natural scrapping are based on year-to-year vehicle survival rates for LDVs of different ages developed by the California Air Resources Board (CARB). Emission effects are calculated using CARB projections of vehicle emissions per mile and miles driven per day for vehicles of different ages during the years 2001 to 2020.
FINDINGS

We first summarize lessons learned about effects of VAVR programs that are planned to operate for several years. We then summarize our quantitative predictions about effects of the VAVR program planned for the South Coast.

General Lessons About VAVR Programs

Increases in prices of used vehicles will be similar for all vintages. While concern about program-induced increases in prices has focused on vehicles old enough to qualify for the program, prices of newer used vehicles will also be affected because the markets for used vehicles of all ages are linked. In fact, we should expect the program to increase prices of all vintages by approximately the same dollar amount. This conclusion follows from the proposition that price differences across vehicles of different ages are determined by their physical differences and consumer valuations of these differences, neither of which will be greatly affected by the program.

Migration of vehicles into the program region will include vehicles of all vintages. The prospect of higher prices creates an incentive to bring LDVs into the region where the program operates. With similar dollar increases in prices for all vintages, the incentive to bring vehicles into the region is similar for all vintages since the extra transactions costs of selling LDVs over longer distances should be similar across vintages. Thus, any migration induced by the program will include both newer and older vehicles. The implications for emissions are significant: Even if large numbers of vehicles enter the region to replace those sold to the program, the replacement vehicles will be on average newer, and thus cleaner, than the vehicles scrapped through the program.

Increases in prices of used vehicles will tend to increase sales of new ones. Even a large, multi-year VAVR program should not affect prices of new vehicles, which—in markets with substantial competition among several manufacturers—will be determined by the costs of producing, transporting, and selling new vehicles. Used vehicles are substitutes for new vehicles, so an increase in used-LDV prices without an increase in new-LDV prices will increase sales of new LDVs.

Price and emissions effects of the program will stabilize over time. The cumulative effects of a program that scraps the same number of vehicles per year will increase over time, at least during the early years of program operation. The incremental effects in each successive year will become smaller and smaller, and the total effects will eventually cease to grow. This is because, over time, the program reduces stocks of older LDVs and thus also decreases the number of vehicles that retire naturally. Total effects may even decline before the program is discontinued.
Price and emissions effects will persist after the program ceases to operate. Once the program is discontinued, the number of vehicles leaving the fleet every year will abruptly decrease, and the size of the fleet will start to increase. Lingering effects of the program on emissions and vehicle prices will be felt until the size and age-composition of the fleet return to where they would have been if the program had never operated.

Effects of Scrapping 75,000 LDVs Per Year for 10 Years in the South Coast

In addition to empirically based parameter values, the quantitative model employs several assumptions suggested by our conceptual analyses. In the quantitative model, we assume the following:

- The program will increase the prices of used LDVs of different vintages by the same amount.
- Vehicle migration into the South Coast is composed of the same fraction of LDVs of each vintage.
- The migration and price effects of the program are unaffected by LDVs outside of California.2
- Vehicles migrate as long as there are any price differences across the state.3

Base-Case Predictions

Table S.1 presents base-case estimates of effects of the M1 program. Our base-case predictions of price and emission effects are subject to several sources of uncertainty that are also examined.

For the base case, we predict that by 2010 average used-LDV prices will be $66, or 1.1 percent, higher than they would be if the program is not implemented.4 The number of vehicles in the South Coast is predicted to be lower by about 60,000 during the last year of the program, which is the net effect of a large decrease in the number vehicles 15 or more years old (147,000) and a somewhat smaller increase (87,000) in the number of newer vehicles. South Coast emissions of ozone precursors are predicted to be lower by 13 tons per day in 2010, about 3.8 percent of the total projected LDV emissions without the program. The program will also reduce emissions in the rest of the state, but by a considerably smaller percentage.

---

2Any such effects appear to be minor because the vast majority of LDVs in California are located far from borders with other states.

3This assumption seems to be a useful approximation because much of the migration could be accomplished by chains of transactions in which the buyer is typically nearer to the South Coast than the seller but not far enough away to substantially increase the transactions cost of a sale.

4All dollar values are expressed in real, 1999 terms.
Table S.1
Base-Case Predictions of the Effects in 2010 of Scrapping 75,000 Older Vehicles per Year from 2001 to 2010 in the South Coast

<table>
<thead>
<tr>
<th>Outcome in 2010</th>
<th>Effect of VAVR Program</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Used-LDV price</td>
<td>$66 per vehicle</td>
<td>1.1</td>
</tr>
<tr>
<td>Vehicles in South Coast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total LDVs</td>
<td>-60,000 vehicles</td>
<td>-0.5</td>
</tr>
<tr>
<td>0 to 14 years old</td>
<td>87,000 vehicles</td>
<td>0.9</td>
</tr>
<tr>
<td>15+ years old</td>
<td>-147,000 vehicles</td>
<td>-6.9</td>
</tr>
<tr>
<td>Emissions of ROG plus NOx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Coast</td>
<td>-13 tons per day</td>
<td>-3.8</td>
</tr>
<tr>
<td>Rest of California</td>
<td>-3 tons per day</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

As illustrated in Figure S.2, the VAVR program is predicted to increase used-LDV prices over the first five years of the program, but at a decreasing rate. Price effects are predicted to be $79 in the fifth year of the program (2005), and then to decline gradually for the remaining five years of program operation to the $66 per vehicle reported in Table S.1. Figure S.3 displays a similar pattern for emissions. Emission reductions are also predicted to be largest for 2005, at a reduction of 18.8 tons of combined ROG and NOx per day. The predicted reductions decline gradually during the remaining five years of program operation to the 13 tons per day reported in Table S.1. After the program is discontinued in 2010, effects on used-LDV prices and emissions in the South Coast decline rapidly and are essentially eliminated by 2013 and 2014, respectively.

Figure S.2—Effects of the Program on Used-LDV Prices
Figure S.3—Effect of the Program on Emissions in the South Coast

Credible Ranges for Program Effects

Any single estimate of a price or emission effect is subject to considerable uncertainty. Estimates of the ranges in which program effects can be confidently expected to fall are much more informative for policy purposes. To provide such information, we develop “credible ranges” for effects of the program in 2010. (See Table S.2.) We believe it highly likely that the effects of the program will fall in these ranges. Our credible range for the effect of the program on used-LDV prices in 2010 is $22 to $271 per vehicle.

Our credible range for South Coast emission reductions in 2010 is 8 to 28 tons per day. Thus, the M1 program target of 25 tons per day in 2010 incorporated in the SIP may not be achievable by scrapping 75,000 LDVs per year from 2001 to 2010. Several assumptions used throughout our analyses tend to make the model underpredict emissions reductions, however, and we thus expect that the South-Coast emissions effects of the program are likely to be closer to 28 tons per day than to 8 tons per day in 2010.

Cost Effectiveness of the Program

Would such emission reductions be worth their cost to California? To examine this issue, we consider the cost per ton of emission reductions of ROG plus NOx and develop a credible
Table S.2
Credible Ranges for Effects of Scrapping 75,000 Older Vehicles per Year from 2001 to 2010 in the South Coast

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Credible Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average price increase for used vehicles in 2010 ($/vehicle)</td>
<td>$22 to $271 per LDV</td>
</tr>
<tr>
<td>Emissions reductions in 2010 (tons per day ROG + NOx)</td>
<td>8 to 28 tons per day</td>
</tr>
<tr>
<td>Cost effectiveness of operating program from 2001 to 2010 ($/ton ROG+NOx)</td>
<td>$3,700 to $33,300 per ton</td>
</tr>
</tbody>
</table>

range for this “cost-effectiveness ratio.” These calculations include costs of the program over its entire history (2001 through 2010) and emissions reductions through 2020.

Our credible range for cost per ton of emission reduction is $3,700 to $33,300. (See last row of Table S.2.) These values compare favorably with ranges of cost-per-ton estimates for many elements of California’s strategy for reducing LDV emissions that have already been implemented. More important for policy purposes, the cost effectiveness of the VAVR program is likely to be quite good relative to other still-available options for further reducing emissions of ozone precursors in the South Coast. Moreover, most of the values in our credible range of cost per ton for the VAVR program are similar to available dollar-per-ton estimates of the social (health and other) benefits of reducing South Coast emissions of ozone precursors.

In sum, the planned VAVR program appears to be a promising way to promote air quality in the South Coast.

Distribution of Costs Due to Price Increases

Potential price effects of the program have received policy attention primarily because of concerns that price increases could be very large, and that the burden would fall primarily on low-income households. Our estimates indicate that price effects will not be nearly as large as some seem to fear. Nonetheless, the high ends of our credible ranges of price effects ($295 in 2005 and $271 in 2010) could be substantial relative to the wealth or income of many households.

What households or individuals would be harmed by increases in the price of used vehicles? Not individuals who own vehicles that they will sell rather than scrap; the extra amount they will have to pay as buyers to replace such vehicles should be similar to the extra amount they will collect as sellers. Price increases will, however, hurt individuals or households that do

---

5 Cost-effectiveness ratios are often used to compare policy options. If well constructed, such ratios can be very useful for policy analysis, but they are not without their shortcomings.
not own a vehicle but want to buy a used one (e.g., young people); want to increase the number
of used vehicles that they own; or own a used vehicle that they plan to “drive into the ground.”
These groups will include many low-income households.

MOVING FORWARD

Our analysis leads us to conclude that the planned VAVR program should be
implemented. An improved version would, of course, be even better. We conclude by suggesting
aspects of the program that should be further examined and by commenting on obstacles to
program implementation.

Potential for Improving Program Design

The program has extensive functional and equipment requirements for eligibility aimed at
rejecting vehicles with little remaining life. However, the requirements can provide incentives for
owners to repair vehicles or add equipment so that the vehicle can be promptly scrapped. Such responses
would create pure economic waste. It seems worthwhile, then, to review these requirements and
to eliminate any that may be unimportant or redundant for predicting remaining vehicle life.

Perhaps more important is the fact that current VAVR program criteria exclude from
eligibility vehicles that are not in good smog-check standing. Appropriately, CARB seeks to avoid
double counting of benefits for SIP accounting purposes and not to attribute to the VAVR
program emission reductions that are actually attributable to the Smog Check II program. We
fear, however, that this is a case of the SIP-accounting tail wagging the air-quality dog. In
particular, the M1 eligibility rules may prevent many dirty vehicles that would not be scrapped
because of the Smog Check program from being removed through the M1 program. A desirable
function of a VAVR program is to provide an outlet for vehicles that fail to pass smog check but
will remain on the road for extended periods nonetheless. Excluding relatively dirty vehicles
from the M1 program eligibility could be counterproductive.

Overcoming Political Obstacles to Implementation

A coalition of early M1 program advocates was expected to identify and secure funding
for the program—roughly $100 million per year for 10 years. This has not occurred. Use of state
tax dollars may ultimately be required if the program is to be implemented.

Many other elements of California’s strategy for reducing LDV emissions—such as
reformulated gasoline, tighter emission standards for new vehicles, and the zero-emission vehicle
mandate—do not require expenditures of much public money. Such measures are actually
financed through resulting price increases for gasoline and new LDVs, which are costly to
consumers, and lost manufacturers’ profits, which are costly to shareholders. Such “hidden taxes” have the political advantage of not requiring explicit allocations of public monies.\footnote{As well as the fact that a portion of these costs are borne by non-Californians, such as shareholders of oil and automobile companies.}

Poor air quality in the South Coast has detrimental health and quality-of-life consequences. The M1 program promises to make an important contribution to air quality for a good price. If the program is not implemented, less cost-effective programs—or even ineffective ones—may replace it in the continuing struggle to move the South Coast towards compliance with federal air-quality standards. If so, Californians will suffer in terms of health, wealth, or both.
ACKNOWLEDGEMENTS

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1. VEHICLE RETIREMENT AND CALIFORNIA’S AIR POLLUTION CHALLENGE

AIR QUALITY IN LOS ANGELES AND CALIFORNIA’S OBLIGATIONS

Air pollution damages health and reduces the quality of life in California in general and the Los Angeles area in particular. This report analyzes the effects of an innovative and controversial air quality program whose fate is likely to be determined in the next few years. Under this program, up to 75,000 older cars and light trucks in Southern California would be bought and destroyed every year for 10 years. While it is widely acknowledged that key effects of the program could depend crucially on vehicle-market responses, our analysis is the first to predict these effects using a framework that accounts explicitly for such reactions.

Federal and state laws require aggressive measures to improve air quality. For example, the federal Clean Air Act (CAA) requires states with areas failing to meet National Ambient Air Quality Standards (NAAQS) to formulate and implement programs to meet these standards. One pollutant covered by the NAAQS is ozone, which is formed when reactive organic gases (ROG) and oxides of nitrogen (NOx) react chemically in the presence of sunlight. Ozone damages human health, vegetation, and structures.

States containing areas that do not meet federal ozone standards are required to submit for approval by the federal Environmental Protection Agency (EPA) State Implementation Plans (SIPs) for achieving compliance with ozone standards in accordance with schedules required by the CAA. In California, the South Coast Air Basin—which includes all of Orange County and the western, urbanized portions of Los Angeles, Riverside, and San Bernardino Counties—is California’s only “extreme non-attainment area” and thus has a target date for compliance of 2010, which is later than for others areas in the state. California’s 1994 SIP for Ozone (CARB, 1994) focuses on plans to attain compliance in the South Coast because that area is the key to compliance for the state.

ROG and NOx are emitted from both mobile sources (e.g., automobiles, trucks) and stationary sources (e.g., factories, power plants, dry-cleaning establishments). Light-duty vehicles (LDVs)—passenger cars and light-duty trucks\(^1\)—are a critical part of the problem because they are believed to account for approximately 45 percent of combined ROG and NOx emissions in the

\(^1\)Light-duty trucks are defined as those having a gross vehicle weight rating (GVWR) of 8,500 pounds or less.
South Coast.\textsuperscript{2} LDVs release ROG and NOx into the air through both exhaust (tailpipe) emissions and evaporation of fuel.

This report analyzes a policy adopted in the 1994 SIP that targets a particularly important source of LDV emissions: older LDVs.

OLDER VEHICLES AND AIR QUALITY

Emissions from relatively old LDVs are an important source of California’s ozone problem. For example, in the South Coast in 1998, LDVs at least 15 years old accounted for only 11 percent of total vehicle miles driven by LDVs but 39 percent of the total LDV emissions of ROG and NOx.\textsuperscript{3} While vehicle inspection and maintenance (called “Smog Check” in California) programs attempt to limit emissions rates as LDVs age, these programs have historically been disappointments.\textsuperscript{4}

On average, older LDVs emit much more ROG and NOx per mile than newer ones, because older LDVs were subject to less-stringent emission standards when they were new and emissions rates of vehicles tend to increase with accumulated mileage. While older LDVs are driven on average fewer miles per day, emission rates per mile increase with age much more rapidly. The net effect of these two forces is depicted in Figure 1.1—which displays per-vehicle emissions in 1998 of ROG plus NOx (in grams per day) for an average LDV of each model year (MY) from 1976 through 1998.\textsuperscript{5}

\textsuperscript{2}Calculated using data from the California Air Resources Board (CARB, 1999a, pp. 36, 84).

\textsuperscript{3}Estimated using data on South Coast vehicle stocks described below and data on miles driven per day and emissions rates per mile of LDVs of different model years from CARB’s EMFAC 2000 model (CARB, 1999b).

\textsuperscript{4}California has recently instituted Smog Check II, which is hoped to substantially reduce emissions from older LDVs. The effectiveness of Smog Check II has important implications for the benefits of the voluntary accelerated vehicle retirement (VAVR) program as currently designed and for the most efficacious designs of VAVR programs.

\textsuperscript{5}The figures for each model year are the products of CARB estimates of emission rates (grams/mile) of ROG plus NOx and miles driven per day.
THE VOLUNTARY VEHICLE RETIREMENT PROGRAM

The voluntary accelerated vehicle retirement (VAVR) program included in the 1994 California SIP for Ozone—often referred to as “measure M1” or the “M1 program”—is an innovative program aimed squarely at emissions generated by older vehicles in the South Coast.\(^6\) The VAVR program was projected in the SIP to reduce total emissions of ROG plus NOx in the South Coast by 25 tons per day in 2010.\(^7\) It became California law in October 1995 when Governor Wilson signed Senate Bill 501 (SB 501), which assigned responsibility for various early design and implementation tasks to the California Air Resources Board (CARB).

According to the SIP and SB 501, beginning in 1999 as many as 75,000 older, high-emitting LDVs operating in the South Coast would be purchased from their owners and destroyed every year through (at least) 2010.\(^8\) The basic idea is to reduce emissions from older vehicles by “accelerating their retirement.” The VAVR program is behind its original schedule, and eventual implementation is in doubt.

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\(^6\)An excellent recent overview of the program and policy issues is CARB (1998a). We rely heavily on this report in describing the current status of the program.

\(^7\)CARB (1994, p. B-2). The 25 tons per day is comprised of 14 and 11 tons per day of ROG and NOx, respectively. These amounts are about 2 and 3 percent of 1998 daily South Coast LDV emissions of ROG and NOx, respectively, as estimated from CARB (1999b).

\(^8\)The SIP is a plan through 2010 only. As a result, whether the VAVR program would continue after the year 2010 is not addressed in the SIP, and we know of no substantial discussion of this issue.
Under the program, private entities—called “enterprises”—will purchase eligible vehicles from their owners and destroy the vehicles. The program is voluntary: (a) No LDV owner is required to sell a vehicle to an enterprise; (b) no business is forced to participate as an enterprise; and (c) sales are to be made at prices mutually agreeable to the buyers and sellers.

Briefly, CARB rules (CARB, 1998a, pp. 10-11) specify that to be eligible for retirement through the program a vehicle must

- be registered with the Department of Motors Vehicles (DMV) within the South Coast Air Quality Management District (SCAQMD)\(^9\) for 24 consecutive months prior to the sale,
- not be out of compliance with Smog Check rules or due for a smog check within the next 90 days,\(^10\)
- pass a functional and equipment inspection requiring the vehicle to be in reasonably good condition,\(^11\) and
- be at least 15 years old.\(^12\)

The objectives of these requirements are to screen out vehicles that would be scrapped soon anyway, be expected to accumulate little mileage in the future even if not scrapped soon, or be expected to be scrapped because of Smog Check requirements even if not purchased through the program.\(^13\)

The incentive for private businesses (enterprises) to participate in the program is the intention of the state to buy emission-reduction credits that can be generated by destroying program-eligible LDVs. (CARB, 1998a, p. A-13).\(^14\) To participate in the program as an enterprise, a business must either be an auto dismantler licensed by the state or have a binding agreement

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\(^9\)The SCAQMD includes the entire South Coast Air Basin (SCAB) plus the remaining parts of Los Angeles, Riverside, and San Bernardino counties.

\(^10\)I.e., not identified as an unrepaired high emitter or gross emitter or operating with a repair-cost waiver. If the vehicle is due for a smog check within 90 days, it can become eligible for scrapping through the VAVR by passing Smog Check.

\(^11\)For example the LDV must have been driven to the inspection site under its own power, the hood must open, all doors must be present and at least one operational, all originally supplied dashboard lights and gauges must be present, windshield wipers must work, and there can be no holes in the windshield or rear window (CARB, 1998a, p. A-4).

\(^12\)This requirement is not stated explicitly as a program rule. However, emission credits for retirements in 1999 are listed for no model year later than 1984 and for retirements in 2000 none later than 1985 (CARB, 1998a, Appendix B).

\(^13\)Uncertainty about the degree to which the Smog Check program will be successful in forcing repair or retirement of high-emitting LDVs—and the wisdom of disqualifying from the VAVR program LDVs that are not in Smog Check compliance—are discussed in the conclusion to this report.

\(^14\)Emission-reduction credits purchased by the state will be used to meet the emission goals of SIP measure M1.
with a licensed dismantler to dispose of LDVs purchased under the program (CARB, 1998a, p. 12). For the scrapping of a vehicle to qualify for emissions credits and the enterprise to obtain revenues by selling credits to the state, the vehicle must be permanently destroyed by crushing or shredding and “vehicle parts or engine components may not be removed for resale or reuse” (CARB, 1998a, pp. 13–14).

The emissions credits generated by scrapping an LDV will depend on its age and are based on CARB’s estimates of emissions levels from LDVs of that age. To date, CARB has specified emissions credits for LDVs scrapped in 1999 and 2000.\footnote{CARB (1998a, Appendix B) sets out the rules for the M1 program. These rules also apply to VAVRs that air districts may choose to operate to generate emission credits for other purposes (e.g., to be purchased by operators of stationary emissions sources to use as offsets against emission reductions that would otherwise be required from these sources). Thus, even though the SIP M1 VAVR program—which is the focus of this report—had not been scheduled to begin until 2001, CARB issued emission credit levels for 1999 and 2000 based on the rules that had been adopted to apply to the M1 program.}

Figure 1.2 displays the emissions credits levels for ROG and NOx and their sum that applied to LDVs of the indicated ages in 1999. Note that credits for NOx are not very sensitive to LDV ages, but that credits for ROG do vary considerably with vehicle age, ranging from roughly 100 to 400 pounds per LDV scrapped. Little attention has been paid to the processes that will determine the prices the state will pay for emissions credits, but it seems that these processes will be geared towards achieving program targets at the lowest budgetary cost.\footnote{Once program funding is in place, CARB staff will “develop and initiate a standard state procurement process for purchasing available emission reduction credits” (CARB, 1998a, pp. 23–24).}
Figure 1.2—ROG and NOx Emissions Credits for LDVs Scraped in 1999

Despite the fact that the SIP contains the program and SB 501 directs CARB to take the first steps, funding for the program has not been established, and implementation is in doubt. The SIP measure was adopted by CARB with the understanding that “a broad-based coalition of businesses and industries lead [sic] by the Western States Petroleum Association (WSPA) and the California Chamber of Commerce” would “secure the funding to implement” the program (CARB, 1998a, p. 4). As of this writing in October 2000, this had not occurred.

While there have been several limited-duration VAVRs involving many fewer vehicles, a program of the size and duration of the one planned for the South Coast is unprecedented.

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17 Very recently, however, the State of California has funded a smaller, statewide effort to scrap high-emitting vehicles that will operate in conjunction with the Smog Check program administered by the Bureau of Automotive Repair (BAR) of the California Department of Consumer Affairs. More specifically, over the course of four years, BAR's Consumer Assistance Program is expected to repair or scrap 50,000 “major polluters” and pay $1,000 for each vehicle scrapped (California Department of Consumer Affairs, 2000).

18 VAVR programs implemented in the United States have all involved many fewer vehicles than the 75,000 per year proposed for the South Coast. They include a program instituted by UNOCAL in the South Coast in 1990 involving more than 8,000 vehicles and subsequent programs involving fewer than 500 vehicles each in Kern County (California), Chicago, Delaware, and Sacramento. See Alberini, Edelstein, Harrington, and McConnell (1994, pp. 2-7) for an overview of the Kern County and Chicago programs and Alberini, Edelstein, Harrington and McConnell (1994) and Alberini, Harrington and McConnell (1993, 1994, 1995) for extensive discussion and analysis of the Delaware program. Engineering-Science Inc. (1994) evaluates and provides details about the Sacramento program.
Thus, there is no analogous historical experience available to predict program effects. The current study predicts these effects using a simulation model that takes into account some program pitfalls that have been recognized but not analyzed satisfactorily.

CONCERNS ABOUT THE PROGRAM

Several concerns have been raised about the effectiveness and side effects of the program. Two key concerns about program effectiveness in reducing emissions in the South Coast are (a) because vehicles retired through the program may be very near the ends of their useful lives, accelerating their retirement will have minor effects on emissions; and (b) market responses to the program may cause older vehicles from outside the South Coast to migrate into the South Coast, thus eliminating or attenuating potential reductions in stocks of older vehicles in the region.²⁰

A potential side effect of the program that is also a source of much concern is the possibility that elimination of large numbers of older vehicles will increase prices of older vehicles. This possibility is of special concern because buyers of older vehicles are believed to be disproportionately of low income.²¹ Moreover, large price increases could lead owners to perform substantially more maintenance on older vehicles, thereby extending their lives.²² While these potential pitfalls are well-recognized,²² existing quantitative analyses of the SIP program—aimed at predicting emissions effects—have ignored market responses.²³ Since in-migration of older

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²⁰Moyer, Pera, and Wool (1995) suggest that scrapping programs “geographically focused on non-attainment areas”—as the M1 program is—“will simply create a market demand for the import of low-cost vehicles from outside the region” (p. 2). Potential in-migration of vehicles “to qualify for the program” is mentioned by Alberini, Edelstein, Harrington, and McConnell (1994, p. 81), who studied a small-scale pilot program. Hahn (1995, p. 238) refers to the possibility of importation “replacing scrapped vehicles with imported clunkers” in the context of analyzing a hypothetical, one-time, large-scale program, and suggests tax-based countermeasures. Dixon and Garber (1996, pp. 189–192, 388–397) analyze in-migration theoretically in a static supply and demand framework, and focus on the potential for in-migration of older LDVs.

²¹E.g., Moyer, Pera, and Wool (1995, p. 2). In the economics literature it is often assumed that an owner will invest in a repair required to keep a vehicle on the road if and only if the value of the repaired vehicle, net of the repair cost, exceeds the scrapping value of the vehicle (see, e.g., Manski and Goldin, 1983).

²²For example, SB 501 requires assessments of net emission benefits to consider “. . . in-migration of other vehicles into the area and any tendencies to increased market value of used vehicles and prolonged useful life of existing vehicles, if any.”

²³Sierra Research (1995) predicts emissions impacts of the M1 program without considering potential effects on vehicle prices or migration of vehicles. Moyer, Pera and Wool (1995), on which CARB relies in its staff report on design of the program, discuss many of the issues we analyze without performing a “true market analysis of the effects of large scrapping [programs].” They also suggest that “[p]robably such a market assessment cannot be done” (p. 8). Kavalec and
vehicles threatens the air-quality goals of the program and potential price increases are of concern in and of themselves, this lack of analysis is troubling.\footnote{Another concern raised about the program is that targeting high emitters would involve incentives to tamper with vehicles to increase emissions and qualify for the program. As currently designed, the program does not require high emissions for eligibility, and tampering does not appear to be a concern.}

PREVIOUS ANALYSES OF THE PROGRAM

Previous quantitative analyses of the SIP M1 program—Sierra Research (1995), Kavalec and Setiawan (1997), and CARB (1998a)—have focused on emissions. In estimating emissions effects, previous analysts have not taken into account reactions of vehicle markets to elimination of LDVs through the program. By failing to confront directly potential in-migration of LDVs into the South Coast, existing analyses may provide unreliable indications of emissions effects of the program. Moreover, by its very nature the issue of potential price effects of the program requires analysis of LDV markets. A brief description of how CARB has analyzed the emissions effects of the program provides perspective on pitfalls in the standard approach and the potential value of the current study.

The CARB approach to estimating emissions effects compares the emissions of the scrapped vehicles with emissions of a hypothetical “replacement vehicle.” CARB (1998a, pp. 18–22) assumes that

- the emissions rate per mile of a vehicle retired through the program equals the average rate per mile for vehicles of the same age, as embedded in CARB’s emissions models;
- the emissions rate per mile of the hypothetical replacement vehicle is the average emissions rate of all vehicles in the LDV fleet;
- the remaining life of the vehicle, had it not been retired, would have been 3 years;
- had it not been retired, the vehicle would have been driven the same number of miles per year as the average vehicle of its age; and
- the replacement vehicle is driven the same number of miles per year as the retired vehicle would have been driven.

Setiawan (1997) simulate the effects of the program concentrating on an “unlimited supply” case where “the availability of vehicles from outside the region or in lots completely offsets any price increase” (p. 97). Dixon and Garber (1996) analyze potential economic effects of the M1 program using a static supply and demand framework. The present study extends that theoretical analysis in several ways and develops quantitative predictions.
In some studies, emissions rates of scrapped LDVs are simply assumed with little explanation or foundation.\textsuperscript{25} Sometimes they have been estimated on the basis of tests of vehicles actually scrapped.\textsuperscript{26} What to assume about the emissions rate and miles driven by the replacement vehicle is particularly troublesome because—as is widely recognized—a single replacement vehicle is a fiction adopted to finesse a daunting complication. In particular, if a person who sells a vehicle to the VAVR program then buys a replacement vehicle, the seller of the latter vehicle may in turn buy a replacement vehicle, and so forth. Thus, the ultimate effect of the chain of transactions triggered by the sale of an LDV to the program is extremely difficult to conceptualize and has defied any satisfactory analysis.

**CONTRIBUTION OF THIS STUDY**

This study uses an economic market framework to analyze the effects of the program. Based on recent policy discussions, the program is assumed to begin operation in the year 2001 and to operate through 2010. Use of an economic framework allows us to predict price and emissions effects while taking explicit account of other market reactions to the program, such as in-migration. The analysis does not require the concept of a replacement vehicle because focusing on equilibrium at the market level enables us implicitly to account for the chains of transactions that will be set off when LDVs are sold to the program.

We analyze effects of the program on an annual basis starting in 2001 on various outcomes, including

- prices of used LDVs in the South Coast and elsewhere in California,
- migration of LDVs into the South Coast,
- the size and age composition of LDV stocks in the South Coast, and
- daily emissions of ROG and NOx from LDVs operating in the South Coast and elsewhere in California.

Lack of the requisite information prevents us from predicting the average remaining lives of vehicles that will be scrapped through the program. Instead, we analyze quantitatively how the effects of the program depend on average remaining lives.

\textsuperscript{25}For instance, Sierra Research (1995) assumes that scrapped vehicles will be “high emitters.” At the time that study was conducted, the program was envisioned as targeting high-emitting LDVs, but the study contained no analysis of how such LDVs might be attracted to the program (and LDVs with lower emission rates excluded from participation) without creating incentives to tamper.

\textsuperscript{26}CARB planned to use data from a 1000-vehicle VAVR pilot program to adjust assumed emission rates of retired vehicles, if necessary (CARB, 1998a, p. 20).
ORGANIZATION OF THE REPORT

The next section presents conceptual (theoretical) analyses. These analyses identify issues that must be confronted in an economic analysis of program effects and provide guidance for structuring and interpreting our quantitative analyses. By way of background, Section 3 presents descriptive empirical information on the sizes, locations, and age compositions of LDVs in California. Section 4 provides an overview of our approach to predicting program effects quantitatively; Section 5 provides more details on our methods. The results of our quantitative analyses are presented in Sections 6, 7, and 8. The first of these three sections concentrates on a base-case set of assumptions to develop point estimates of the sizes of program effects and conceptual insights about determinants of program effects and the evolution of these effects over time. Section 7 presents results from altering various assumptions, which allows us to develop insight into what assumptions are more and less critical to our basic conclusions and to assess ranges of uncertainty about the effect of the program on various outcomes. Section 8 presents and discusses our estimates of the cost effectiveness of the VAVR program. The final section summarizes our results and draws conclusions about the attractiveness of including a VAVR program in California's strategy for improving air quality in the South Coast.
2. MARKET EFFECTS OF THE PROGRAM: CONCEPTUAL ANALYSES

We seek to understand effects of the planned South Coast VAVR program on vehicle prices, the number and age distribution of vehicles operating in the South Coast, and ROG and NOx emissions in the South Coast over the course of several years. The goal is to generate predictions that reflect the potential ranges of effects and will be useful to policymakers. This section presents some conceptual (theoretical) analyses that provide a foundation for the subsequent quantitative analyses.

ROLE OF CONCEPTUAL ANALYSIS
In this section we use a series of economic models that incorporate principles of supply and demand. The analyses in this section:

- identify the kinds of factors that will determine the directions and sizes of various program effects,
- provide a logical framework for constructing and judging the appropriateness of our quantitative models, and
- establish two powerful implications of basic economic reasoning that prove invaluable in developing quantitative models.

LESSONS FROM A BASIC SUPPLY AND DEMAND ANALYSIS
The economic responses to the program of direct concern are market-level outcomes such as prices and quantities of LDVs operating in the South Coast. Analyzing price, migration, and emissions effects requires extensions of basic supply and demand models. In particular, the analysis must accommodate three types of complications: (a) vehicles of several ages (synonymously, "vintages" or "model years"); (b) vehicles operating both inside and outside the South Coast; and (c) time-dependent or dynamic effects.

The formal conceptual analyses presented here focus on effects of the program across LDVs of different vintages and over different regions. The models used for these conceptual analyses are much simpler than our quantitative models. In particular, the theoretical models distinguish between only two groups of vintages, older and newer LDVs, and explicitly consider only one time period.

In all of the conceptual analyses, we assume that LDVs not explicitly distinguished by type (i.e., age or region) are physically identical. The quantity measure is the number of LDVs in operation, not, for example, the number bought and sold during the time period. We use this
definition of quantity because to understand price determination it is crucial to take into account all LDVs potentially available for sale.\footnote{We are modeling price and quantity determination in a situation lacking opportunities for production—i.e., a period starts with a stock of (used) LDVs produced previously. In much more commonly analyzed situations of nondurable commodities—where quantities are determined by current-period production—the appropriate quantity concept is the number of units of the good that are produced and sold during the period.} For LDVs that are not bought and sold during the period of analysis, price is interpreted as the price a private buyer and a private seller would agree upon if a transaction were to take place.\footnote{Owners who do not sell their vehicles may be thought of as both demanding and supplying their own vehicles.}

To set the stage, consider Figure 2.1, which pertains to the effects of the program if there were only one type of used LDV (all of which are physically identical), one region, and one time period. In the figure, quantity (the number of LDVs operating during the period) is measured on the horizontal axis. Price—the market value of each LDV in dollars per vehicle—is measured on the vertical axis. In this and subsequent figures, the superscripts w/ and w/o denote with and without the VAVR program, respectively. The quantity of LDVs potentially operating in the region is predeterminant by stocks of LDVs previously produced and carried over into the current period (i.e., all LDVs are used). The program reduces the supply of LDVs that can operate during the period by purchasing and destroying a fraction of them.

The equilibrium price with the program is the price that equates quantity demanded with the quantity of LDVs available after the program eliminates some number of LDVs from the stock. Given the downward sloping demand curve, the decrease in supply increases LDV prices (i.e., the price with the program exceeds the price without the program) and reduces the quantity of LDVs on the road by the number of LDVs scrapped through the program.
Even this extremely simple model points to two factors that are crucial to predicting effects of the program in the real world: the size of the program (number of LDVs scrapped) and the sensitivity of quantities demanded to price (the slope of the demand curve). Economists typically measure price sensitivity of demand in terms of "price elasticities of demand," specifically, the percentage change in quantity demanded divided by the percentage change in price that induces that change in quantity demanded.

**INTERDEPENDENCE OF LDV MARKETS OVER VINTAGES**

The model depicted in Figure 2.2 introduces a crucial complication: difference in LDV ages or *vintages*. The age of an LDV can be thought of as the current calendar year minus the model year (MY) of the vehicle. Here we assume for simplicity that there are only two LDV vintages: "older LDVs" (those old enough to be eligible for scrapping through the program, i.e., at least 15 years old) and "newer LDVs." We continue to assume that there is only one region, "the South Coast." The interconnected markets for older and newer LDVs are depicted in the upper and lower panels of Figure 2.2, respectively. Each market is viewed as competitive—i.e., modeled in terms of supply and demand. The quantity of LDVs of each type in the absence of the program is again assumed to be fixed.
Figure 2.2—Effects of Program with Older and Newer LDVs, South Coast Closed to Migration
The markets are interconnected because older and newer LDVs are substitutes for each other, which means that the higher the price of one type of vehicle is, the greater will be the demand for the other type. More formally, as the price of one type of LDV increases, the demand curve for the other type shifts outward. For example, the higher the price of newer LDVs is, the greater is the quantity of older LDVs demanded at any older-LDV price.

What does this model add to our conceptual understanding of the effects of the VAVR program? The program decreases the fixed quantity of older LDVs by buying and scrapping them. This decrease leads to a tendency to increase the price of older vehicles, as illustrated in Figure 2.1. But, unlike the case of the simplest model, the process does not end there. In particular, the tendency for prices of older LDVs to rise also tends to increase the demand for newer LDVs—i.e., to shift out the demand curve in the lower panel. This increase in demand for newer LDVs will tend to increase the price of newer LDVs, which in turn will tend to increase the demand for older LDVs.

What is the overall—i.e., equilibrium—effect of these forces? Figure 2.2 depicts an equilibrium situation. Here the position of the higher demand curve for each vintage—the position of which is determined by the price of the other vintage—is consistent with equilibrium (the intersection of supply and demand curves) in the other market.

This model has the same conceptual predictions for older LDVs as the simpler model (Figure 2.1): The program reduces the quantity of older LDVs by the size of the program and increases the prices of LDVs old enough to be eligible for scrapping through the VAVR. The new, and crucial, lesson from the present model is, as depicted in the bottom panel of Figure 2.2, that the program will increase the prices of newer LDVs as well. This conclusion follows from the principle that increased prices for older vehicles increase the demand for newer vehicles because older and newer vehicles are substitutes.

How much should we expect the prices of older and newer LDVs to increase? Even the relatively simple model in Figure 2.2 suggests that this depends on several factors. In particular, holding constant the size of the program, the sizes of the price increases depend on the sensitivity of quantity demanded to price in each market (two "own-price elasticities of demand") and the extent to which a price increase in each market increases the demand for the other LDV type (a pair of "cross-price elasticities of demand").

WHAT VEHICLES WILL BE SOLD TO THE VAVR PROGRAM?

Of particular interest is the number of LDVs scrapped through the VAVR program in any year that will come from each vintage of LDVs aged 15 years or more in that year. A precise answer cannot be given because of lack of information about future program rules and about
various characteristics of the LDV stock. The issue can be analyzed—and guidance developed for our quantitative analysis—as follows.

First, consider the fundamental motivations of LDV owners and enterprise operators. Because the program is voluntary, the owner of an LDV eligible for scrapping through the program will participate only if the price offered by an enterprise, often referred to as the “bounty,” is viewed as attractive in comparison with the owner’s alternative uses of the vehicle. For an owner who would keep an LDV if it is not sold to the program, the bounty, net of the inconvenience or transactions costs of selling the vehicle to the program, would have to exceed the value the owner places on the vehicle. For an owner who would sell an LDV even if it is not sold to the program, the bounty would have to exceed what the owner believes can be obtained from sale of the vehicle through channels other than the VAVR program, adjusted for any difference in transactions costs between selling to the program or to some other buyer.

The size of the bounty offered for any particular LDV will depend on how much money the enterprise operator expects to obtain by selling the resulting emissions credits to the state. The value of credits is yet to be determined, but it can be expected that the bounties offered for an eligible LDV will be roughly proportional to the emissions credits that would be generated by scrapping that vehicle.\(^3\) As illustrated in Figure 1.2, this value varies across LDVs of different ages. With prices established for emissions credits, the value to enterprises of attracting LDVs into the program should be higher for model years that generate more credits.

In any year of program operation, the age distribution of LDVs that will be sold to the program depends on the following factors:

- the bounty offered for LDVs of each model year during that calendar year,\(^4\)
- the number of LDVs of each model year that are eligible for scrapping (or are able to evade enforcement efforts to prevent scrapping out of compliance with the program rules) in that calendar year, and
- for each program-eligible model year, the fraction of LDVs for which the bounty offered is more attractive to their owners than the available alternatives.

The considerable increase in emissions credits with the age of vehicle over a broad range of ages (see Figure 1.2) suggests that vehicles that are scrapped through the VAVR program will disproportionately be particularly old LDVs.

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\(^3\)The maximum value of an LDV to an enterprise is the value of the emissions credits available for scrapping that LDV plus the salvage value of the crushed or shredded vehicle, minus the transactions costs required, such as inspecting the LDV, either destroying the vehicle or arranging for someone else to destroy it, and doing the required paperwork.

\(^4\)With competition among enterprises for LDVs to scrap through the VAVR program, the bounty for a vehicle will equal its value to enterprises.
THE PROGRAM WILL INCREASE PRICES OF ALL VINTAGES BY SIMILAR DOLLAR AMOUNTS

Even in the model depicted in Figure 2.2 with only two LDV vintages, price effects depend on own-price elasticities of demand for LDVs of each of the two vintages and the two cross-price elasticities of demand between the vintages.

In the quantitative model, we distinguish more than 20 vintages in order to take account of differing projected emissions rates by age, and we predict emissions levels in each year from 2001 through 2020. Developing quantitative models with 20 vintages based on separate own-price elasticities for each vintage and separate cross-price elasticities for each pair of vintages would involve roughly 400 demand parameters.\(^5\) Doing so would be unwise because of the extreme complexity of the model and the likelihood of major inaccuracies.

Fortunately, economic reasoning suggests that introducing such complexity is unnecessary, even if it were possible. In particular, basic requirements for market equilibrium suggest that the program will increase prices of all vintages by the same dollar amount. This condition is employed in our quantitative analyses. It is important, then, to understand its basis and to appreciate that the reasoning is much more general than the case of only two vintages depicted in Figure 2.2, and that it also applies even if there is more than one geographic region.

The prediction follows from conditions required for LDV markets to be in equilibrium. First consider what determines the difference in price between any two vintages of LDVs in the absence of a VAVR program. This price difference depends on two fundamental factors: (a) the physical differences between the two LDV vintages, such as performance, appearance, maintenance costs, and expected remaining life; and (b) the dollar value that prospective buyers of these two vintages place on these physical differences. In any market equilibrium, the difference in price between any two vintages must equal the dollar value the relevant potential buyers place on those physical differences. If, for example, the price difference between older and newer LDVs is less than the dollar value consumers place on their physical differences, then buyers will view newer LDVs as a bargain. But attempts to take advantage of such bargains by selling older LDVs to buy newer ones would increase the price of newer LDVs and decrease the price of older LDVs until there were no such potential bargain. In sum, prices cannot be in equilibrium across any pair of vintages unless the price difference reflects consumer valuations of their physical differences.

\(^5\)Let N denote the number of vintages distinguished. This detailed modeling approach would involve N own-price elasticities and N(N-1) cross-price elasticities.
How does the existence of the VAVR enter into this analysis? The operation of the VAVR would change the sizes of price differences across any pair of vintages only to the extent that the program induces changes in the following factors:

- differences across pairs of vintages in the average desirability of the physical attributes of LDVs of those vintages,
- dollar values that consumers assign to such differences in the average desirability of physical attributes, and
- the groups of consumers owning or competing to buy LDVs of given vintages.

The VAVR program could affect all of these factors to some degree. However, the approximation errors involved in employing the assumption of equal price effects of the program on all vintages of LDVs appear to be minor, and the sensitivity analyses we performed appear very likely to swamp in importance these approximation errors. Consider, in turn, the potential importance of the three factors enumerated just above.

First, in the real world, the physical attributes of LDVs vary within a vintage, and the prices of interest for analytic purposes are average prices for each vintage. Would the VAVR program be expected to change the distribution of physical characteristics within a vintage in a way that would alter the average desirability of existing LDVs of that vintage? Substantial changes in average desirability would require that both (a) LDVs of a given vintage that are scrapped by the program are substantially different in terms of average physical desirability than those not scrapped by the program, and (b) the number of LDVs of a vintage that are scrapped is substantial relative to the overall number of such LDVs. The extent to which (a) occurs depends on program rules. As summarized in Section 1, under current rules, LDVs scrapped through the program must be in reasonably good condition. As discussed earlier in this section, the program should be expected to attract and destroy—from among those LDVs that are eligible given their physical conditions—LDVs that are of relatively low value to their owners. Thus, we expect that the program will tend to attract and scrap LDVs that are neither especially desirable nor especially undesirable among LDVs of their vintage. It is unclear, then, even whether the average physical desirability of LDVs of any age-eligible vintage would increase or decrease due to scrapping LDVs through the VAVR program. Moreover, regarding (b), the number of LDVs planned for scrapping through the VAVR program is a small fraction of the number of age-eligible LDVs in the stock. In particular, up to 75,000 LDVs are to be scrapped through the VAVR program annually. This maximum represents only 1.5 percent of the 4.90 million age-eligible LDVs in California in 1998 (see Table 3.1 below). Thus, it seems unlikely that the program will

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6We consider the annual size of the program relative to the size of vehicle stocks, rather than the cumulative program size, because the stock of age-eligible vehicles will be continuously
cause substantial changes in the average desirability of LDVs of any vintage, or, by implication, substantial changes in the difference across any pair of vintages in average physical desirability.\textsuperscript{7}

Second, consumer valuations of any given differences in average physical characteristics across any pair of vintages—i.e., how much more a typical consumer would be willing to pay to purchase an LDV of a vintage that is viewed as more attractive than another—would change because of the VAVR program only if the program had substantial effects on real incomes. The program would have substantial impacts on real incomes only if price effects of the program were to decrease substantially the welfare of many consumers competing to buy LDVs of any given vintage. In light of the size of the price effects we estimate, the program should substantially decrease the welfare of only a small fraction of consumers, if any, in any market segment and thus should have only minor impacts on real incomes.

Third, the program could substantially alter average price differences across vintages if it were to change substantially the groups of consumers competing in the markets for particular vintages in a way that changes the average incomes of these groups. This is because consumers' willingness to pay to purchase LDVs depends on their ability to pay, which depend on their incomes. Because the program will reduce the sizes of stocks of age-eligible vehicles relative to those of newer LDVs, some consumers competing to buy LDVs will shift to newer vintages. This shift will affect the average incomes of consumers competing to buy LDVs of a particular vintage to the extent that consumers shifted into a market for newer LDVs have average incomes lower than those of consumers who would compete to buy vehicles in that market segment in the absence of the VAVR program. However, such changes in the groups of consumers competing to buy LDVs would affect all vintages similarly. Moreover, (as just described) the program will scrap only a small fraction of age-eligible vehicles. Thus, reallocation of consumers to newer vintages would have only minor effects on differences in average prices across vintages.

In sum, the assumption of equal price effects is grounded in economic reasoning and what is known about the program, and this assumption is likely to be a good approximation to the actual effects of the program.

\textsuperscript{7}The program would tend to increase the desirability of some vintages relative to others because LDVs of some vintages will command higher bounties from the VAVR program. We would not expect such an “option value” to have a substantial effect on the average desirability of vehicles of any vintage because, as just explained, only a small fraction of age-eligible LDVs can be sold to the program. Consequently, the probability of being able to exercise an option to sell to the program is quite small.
INTERDEPENDENCE OF VEHICLE MARKETS OVER SPACE

The model depicted in Figure 2.3 adds a different complication to the simple model in Figure 2.1: different geographic locations of LDVs. Here we assume that there is only one type (vintage) of LDV, older LDVs, and only two regions, inside and outside the South Coast.

![Market: Older LDVs in South Coast](example-image)

Figure 2.3—Effects of Program with Older LDVs Only, South Coast Open to Migration

Figure 2.3 depicts the market for older LDVs in the South Coast, with the number of LDVs operating in the South Coast measured on the horizontal axis and the average price (market value) of those LDVs measured on the vertical axis. As assumed in the model depicted by Figure 2.1, (a) the demand curve is for older LDVs in the South Coast, (b) the supply from the South Coast (i.e., the number of LDVs that begin the period in the region) is fixed, and (c) the program reduces that supply by the size of the program (number of LDVs scrapped).

The new feature of the model depicted in Figure 2.3 is the existence of another source of supply of (older) LDVs to the South Coast. These are older LDVs that start the period outside the South Coast but would, if economic incentives warrant, be brought into the South Coast for sale to consumers who would operate them there. LDVs that start a period outside the South Coast but move into the South Coast because of the program are said to in-migrate.

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8This possibility is a concern often raised about the program.
As depicted in Figure 2.3, the supply of LDVs from outside the South Coast is assumed to be upward sloping, which means that the higher the price of LDVs in the South Coast, the higher would be the number of LDVs that would in-migrate. This assumption reflects the general ideas that owners of LDVs outside the South Coast would be willing to sell them to the highest bidder; the costs of selling vehicles increase with the distance between the seller and the buyer; and for more vehicles to migrate, they would have to come from greater distances.

The model depicted in Figure 2.3 formalizes the concept of in-migration. This very simple model provides two key predictions that pertain much more generally: (a) the program will reduce the number of LDVs operating in the South Coast by fewer than the number of LDVs purchased and scrapped by the program; and (b) the program will increase prices in the South Coast by less than would occur if in-migration were not possible. By adding to stocks of LDVs in the South Coast, in-migration attenuates the stock-reducing direct effect of a vehicle-scraping program. The price-moderating effect of in-migration follows from the fundamental economic principle that larger supplies (in our case, LDV stocks) tend to reduce prices.

A key issue for our quantitative modeling is the conditions under which LDV markets will be in equilibrium across geographic areas or, equivalently, the conditions under which there will be no remaining tendencies for LDVs to migrate from one region to another. For example, should we expect LDVs to migrate if there are any substantial price differences over space, or are there important frictions that would prevent migration of vehicles to eliminate any substantial geographic price differences?

How nearly geographic reallocations of LDVs will equalize prices between the South Coast and the rest of California depends on

- the nature of the transactions that in combination would result in in-migration into the South Coast, and
- the extent to which transactions costs increase with geographic distance between buyers and sellers (e.g., costs of information or of transporting LDVs over distances).

Suppose, for example, that the requisite in-migration would be accomplished primarily by chains of transactions in which buyers of LDVs are typically nearer to the South Coast than sellers (so that transactions tend to move LDVs in the direction of the South Coast) but that buyers are not located very far away from sellers. Under these circumstances, approximate price equalization over space seems very likely because extra transactions costs due to geographic separation of buyers and sellers would be minor.

Available empirical information about spatial patterns of transactions and the relevant extra transactions costs is insufficient to construct supply curves corresponding to the one depicted in Figure 2.3. In our quantitative work, we emphasize the case where prices are
equalized over space, because this equilibrium condition is simple and a useful approximation to reality. We also explore empirically how different the effects of the program might be because of equilibrium price differences over space by considering the extreme and implausible case where no in-migration occurs in response to the VAVR program.

VEHICLES OF ALL VINTAGES WILL MIGRATE INTO SOUTH COAST

Another key issue for constructing a quantitative model—and for assessing the emissions effects of the VAVR program—is the distribution of vintages that in-migrate because of the program. Analysis discussed presently suggests that the set of in-migrating LDVs will be composed of (approximately) the same fraction of the stock of each vintage outside the South Coast. This condition is imposed in our quantitative model. Thus, we explain its basis in a way that indicates that the reasoning is sufficiently general to apply to multiple vintages and geographic areas.

The incentive for owners or entrepreneurs to bring LDVs into the South Coast for sale is the prospect of obtaining higher prices or profits. The disincentive to migration is the potential extra transactions costs of selling vehicles over a distance relative to selling an LDV to a buyer who is located near a seller. Most obviously and tangibly, there are extra costs of transporting LDVs over longer distances. In addition, there can be additional costs of obtaining information and matching buyers and sellers located at some distance from each other.

In equilibrium, price differences for the same vintage at two different locations cannot exceed the extra transactions costs of selling in the higher-price area a vehicle that is currently located in the lower-price area. Assume that prices are equalized over regions before the program is implemented. The equilibrium requirement that prices rise by the same dollar amount for all vintages in response to the program implies that the incentive to migrate (the price premium between two locations) is the same for all vintages. Thus, the probability of a particular LDV migrating should be insensitive to its vintage, so we should expect similar proportions of LDVs of each vintage to migrate, unless the extra costs of selling over any distance differ considerably by vintage.

If distance-sensitive transactions costs differ by vintage, we should expect vintages with relatively low extra distance-sensitive transactions costs to account for a disproportionate share of in-migration. For newer vehicles, automobile dealers and wholesale auctions are likely to play an important role in reallocating LDVs over space. In particular, in response to upward pressure on prices within the South Coast, dealers located in the South Coast can be expected to purchase

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LDVs at auction for resale in the South Coast.\textsuperscript{10} It is expected that these LDVs would be transported in groups rather than being driven (at a higher cost) individually into the South Coast. Because older LDVs are relatively unimportant to car dealers,\textsuperscript{11} it is possible that older LDVs would more often migrate one at a time by being driven into the South Coast,\textsuperscript{12} a form of in-migration that would involve higher time costs per LDV.\textsuperscript{13} If price premiums become sufficiently high, however, businesses may emerge (or expand) that buy older LDVs outside the South Coast and transport several at a time for sale in the South Coast.

In sum, if distance-sensitive transactions costs do vary over vintages, migration of older vintages may involve higher distance-sensitive transactions costs than newer vintages. In our quantitative analysis, however, to be conservative in assessing program effectiveness, we assume that in-migration is composed of the same fraction of the stocks of each vintage outside the South Coast.\textsuperscript{14}

WHAT DETERMINES EMISSIONS IMPACTS IN THE SOUTH COAST?

As in the SIP, we quantify emissions in terms of tons per day of ROG plus NOx emitted by LDVs. Total predicted LDV emissions in the South Coast on any day can be calculated from

- the number of LDVs of each vintage predicted to be operating in the South Coast,
- emissions rates for LDVs of each vintage (in grams of ROG plus NOx per mile), and
- miles driven per day by LDVs of each vintage.

Once the size and age composition of the LDV fleet in the South Coast are predicted, emissions predictions can be calculated.

\textsuperscript{10} Whether migrating vehicles would be brought into the South Coast before or after sale at auction is unclear, but is unimportant for our purposes.

\textsuperscript{11} Genesove (1991, Table 1, p. 30) contains data from 1979 indicating that less than 3 percent of vehicles sold to consumers by new car dealers are more than 10 years old, and that the corresponding figure for used-car dealers is less than 10 percent.

\textsuperscript{12} Conceptually, in-migration is defined as LDVs locating in the South Coast in the presence of the program that would have been located outside the South Coast in the absence of the program. Viewed from this general perspective, more subtle forms of in-migration would include owners who are moving out of the South Coast choosing to sell their LDVs before leaving to take advantage of higher prices, or people moving into the South Coast bringing LDVs with them who would have chosen not to do so in the absence of the VAVR program.

\textsuperscript{13} The time costs per hour of owners of older LDVs may be lower, however, than the wage rates of drivers of multiple-LDV carriers.

\textsuperscript{14} For example, if there are twice as many model-year 1998 as MY 1988 LDVs outside the South Coast, twice as many MY 1998 LDVs are assumed to in-migrate.
WHAT HAPPENS OVER TIME?

To this point, we have considered program effects during only a single period or year. The VAVR program is planned to operate for 10 consecutive years. In our quantitative analyses, we generate sequences of predictions over several years. We do this by using a series of one-year (static) supply and demand analyses that are linked over time through the quantities of LDVs that are predicted to exist at the end of a year and are thus carried over into the beginning of the following year. More specifically, three types of events affect the quantities of LDVs that begin a year:

- Natural vehicle scrapping or retirement by which LDVs are scrapped through normal channels, i.e., not through the VAVR program.
- New LDV purchases in California, which add to LDV stocks.
- Exogenous in-migration representing LDVs brought into the South Coast and the rest of California by people who move into the state.
3. CALIFORNIA AND SOUTH COAST VEHICLE STOCKS IN 1998

The extent to which the VAVR program affects prices and emissions levels in the South Coast depends on various characteristics of the LDV stock in the South Coast and elsewhere in California. In this section we describe data on LDV stocks and their locations.

We obtained data on LDVs registered in California by model year and zip code from the California Energy Commission (CEC), which had obtained and cleaned raw information from the Department of Motor Vehicles (DMV). These data include vehicles on the road in October 1997 that were registered in California at the time or within the following six months.¹

To develop a sense of the sizes of LDV stocks within the South Coast and at various distances from the South Coast, we created counts of LDVs—distinguished by model year—within the South Coast air district and elsewhere in California.² These counts were created using zip codes. LDVs located in zip codes within the South Coast were aggregated. For each zip code outside the South Coast, we calculated its distance from the South Coast as the minimum distance from the center of the zip code to the center of any zip code within the South Coast.³ These zip codes were then sorted into various distances from the South Coast.

To make our results more useful to policymakers, we then scaled up our vehicle counts to make them comparable with figures used by CARB to analyze the VAVR program. (CARB uses the LDV stock in the South Coast Air Basin for 1998.) We adjusted the data just described, increasing all counts of vehicles of all vintages for the South Coast and elsewhere in the state proportionately so that our totals for the South Coast match CARB South Coast totals for 1998.⁴

¹Because CEC does not have the information necessary to identify weights for especially old trucks, our data include trucks up to 10,000 pounds of GVWR, while the definition of light-duty trucks used by CARB includes vehicles up to 8,500 pounds only. Given our methods, this discrepancy could substantially affect our results only if the ratio of the number of trucks less than 8,500 pounds to trucks between 8,500 and 10,000 pounds were very different between the South Coast and the rest of California.

²The South Coast Air Basin and the South Coast Air Quality Management District are not the same area; the district includes the basin plus nonurbanized areas in three counties. The VAVR rule adopted by CARB specifies that LDVs operating in the district are eligible, so we defined the South Coast as the set of zip codes in the district. This distinction is unlikely to be of substantial importance for our purposes, because the areas that are contained in the district but not the basin contain relatively few LDVs and are relatively far from areas outside the district that contain substantial numbers of LDVs.

³Distances between pairs of zip codes were computed from longitudes and latitudes at the centroid of each zip code. Data linking California zip codes to longitudes and latitudes were obtained from the SAS Institute and CD Light.

⁴This process involved inflating all LDV counts by about 9.5 percent.
Table 3.1 presents basic descriptive information about the sizes and locations of LDVs in California during 1998. Age categories are chosen to distinguish between LDVs that would not be eligible for scrapping in the VAVR program under the rules recently adopted by CARB, namely, LDVs less than 15 years old in 1998 (model years 1984 through 1997) and those that might be eligible depending on their condition and smog-check status. Throughout the report, we refer to LDVs less than 15 years old as newer LDVs and those at least 15 years old as older or age-eligible LDVs.

Table 3.1
Estimated Numbers of Used California LDVs by Age and Location in 1998
(millions of vehicles)

<table>
<thead>
<tr>
<th>Location</th>
<th>Newer LDVs (Less than 15 years)</th>
<th>Older LDVs (15 or more years)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Coast</td>
<td>8.05</td>
<td>1.62</td>
<td>9.67</td>
</tr>
<tr>
<td>California except South Coast</td>
<td>10.61</td>
<td>3.27</td>
<td>13.89</td>
</tr>
<tr>
<td>Within 25 miles of South Coast</td>
<td>0.71</td>
<td>0.14</td>
<td>0.85</td>
</tr>
<tr>
<td>25 to 50 miles from South Coast</td>
<td>1.08</td>
<td>0.20</td>
<td>1.29</td>
</tr>
<tr>
<td>50 to 75 miles from South Coast</td>
<td>0.84</td>
<td>0.20</td>
<td>1.04</td>
</tr>
<tr>
<td>75 to 100 miles from South Coast</td>
<td>0.23</td>
<td>0.07</td>
<td>0.30</td>
</tr>
<tr>
<td>Total California</td>
<td>18.66</td>
<td>4.90</td>
<td>23.56</td>
</tr>
</tbody>
</table>

As reported in the table, there were roughly 23.6 million LDVs operating in California in 1998. Of these, about 41 percent were operating in the South Coast and another 15 percent were operating within 100 miles of the South Coast. Of the roughly 9.67 million LDVs operating in the South Coast in 1998, about 17 percent were at least 15 years old.

Figure 3.1 provides more detailed information about the age distribution of LDVs in the South Coast in 1998. Such age distributions reflect the levels of new LDV sales during past years, which are sensitive to economic conditions at the time; rates at which LDVs of different vintages are removed from the road through aging, accidents, and out-migration; and rates of immigration. As can be seen from the figure, the number of LDVs of any age on the road is generally lower for higher ages. Moreover, the absolute numbers of LDVs of ages 20 and over are relatively small, specifically, 100,000 or fewer LDVs per model year out of a total in the South Coast of about 9.7 million LDVs.

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5We do not report figures for model year 1998 because our data are based on DMV records as of October 1997 (rescaled to match 1998 CARB totals), after which time many new 1998 model year LDVs were sold.
Figure 3.1—Stocks of LDVs in South Coast in 1998
4. PREDICTING EFFECTS OF THE PROGRAM: OVERVIEW

This section provides an overview of our methods for predicting effects of the program. Details are presented in Section 5.

The outcomes of primary interest are

- prices of used LDVs in the South Coast and in the rest of California,
- numbers of LDVs operating in the South Coast,
- age distribution of LDVs operating in the South Coast, and
- quantities of daily ROG and NOx emissions from LDVs operating in the South Coast.

We develop predictions of these outcomes over the years 2001 to 2020 and assess ranges of uncertainty for our predictions.

There is no precedent for the VAVR program planned for the South Coast.¹ Most important, VAVRs operated to date have been much smaller and shorter-lived. Thus, effects of the program cannot be estimated by relying on analysis of historical data.

Instead, we construct quantitative models of the outcomes of interest—with parameter values calibrated using available empirical information—and compute simulations to serve as predictions. Degrees of uncertainty about the predictions are assessed by sensitivity analysis, which involves rerunning the model using alternative parameter values. These alternatives are chosen to span the range of conditions that would plausibly characterize the environment in which the VAVR program will operate in the real world.

This section is structured as follows. We first comment on the utility of using simulation models to analyze the issues of interest. We then define what we mean by the "effects of the VAVR program." The section concludes with discussions of the elements of our model and our approach to gauging the degrees of uncertainty about our predictions.

COMPLEXITY AND SIMPLIFYING ASSUMPTIONS

In the model, we distinguish vehicle stocks in each year both by vintage (model year) and geographic location (the South Coast and elsewhere in California). Thus, there are several outcome variables in any year. Moreover, these outcomes are jointly determined (logically interconnected) in any year and also linked over years. Thus, there are too many variables and

¹Moreover, if a program similar to the one planned for the South Coast had been operated in a different region, the effects of that program might not be very revealing about the effects of the South Coast program because of differences in such factors as the sizes of the two regions, demand conditions for LDVs, durability of LDVs, and the age and geographic distributions of LDV stocks.
their interconnections are too complex for intuition or simple calculations to provide a reliable
guide for policy. In response to this complexity, we analyze the effects of the program by
constructing models of the program and the market environment in which it will operate and use
the models and computer-aided calculations to derive predictions about the effects of the
program.

Models are, by definition, simplifications of reality. Simplification is useful—indeed, 
necessary—when the aim is to predict the outcomes of complex processes. The model is
composed of several equations representing various forces or phenomena suggested by the
conceptual analyses described in Section 2. Empirical information is used as available to assign
numerical values to the parameters of these equations.

It is most useful for policy purposes to develop predictions that can be compared to official
CARB estimates of emissions effects. Thus, the sizes of the markets represented by the model are
specified so that the model predicts emissions levels in the South Coast in the absence of the
program that are comparable to CARB predictions. This involves building into the model, as
explained in the next section, growth over time.

PREDICTED EFFECTS OF THE VAVR PROGRAM: DEFINITIONS

The VAVR program that we analyze is specified to represent, despite remaining
uncertainties about various details, the program that is planned for implementation. Specifically,
the program is assumed to involve voluntary scrapping of 75,000 age-eligible LDVs (LDVs at
least 15 years old) every year from 2001 through 2010.

For any set of parameter values, the model is run, and predictions are computed,
alternatively assuming the following:

- No LDVs are scrapped through the program in any year. We refer to this as the
  without-program scenario.
- 75,000 South-Coast LDVs are scrapped through the program each year from 2001
  through 2010. We refer to this as the with-program scenario.

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2Models allow (a) a complex phenomenon to be decomposed into pieces (assumptions)
that can be represented reasonably accurately by drawing on empirical information, theory, and
intuition; (b) logical implications of the pieces to be rigorously derived (e.g., through computer-
aided calculations); (c) assumptions to be varied to assess the sensitivity of predictions to
assumptions; (d) the reasonableness of the assumptions, and thereby the likely accuracy of the
predictions, to be assessed; and (e) the appropriateness of the interpretations and conclusions to
be judged.
While the program is assumed to cease buying and scrapping vehicles after 2010, effects of the program persist after that year because scrapping in earlier years affects vehicle stocks, prices, and emissions in later years.

For each scenario, the model generates predicted values for various outcomes for every year from 2001 through 2020. The effect of the program on any outcome in any year is defined as the value predicted for that outcome in that year with the program (i.e., if the program were implemented) minus the value predicted for that outcome in that year without the program (i.e., if the program were not implemented). For example, for a given model run (set of assumptions), the predicted effect of the VAVR program on the average price of used LDVs in the South Coast in the year 2010 is the predicted value of that average price in 2010 with the program minus the predicted value of that average price in 2010 without the program.

ELEMENTS OF THE MODEL

For each year beginning with 2001, the model calculates average used-LDV prices, quantities of LDVs of different model years located in the South Coast and in the rest of California, and LDV emissions levels in the two regions, all of which are interpreted as pertaining to the last day of the year. To represent the average value of any of these quantities during a calendar year, we report the average of the end-of-year values for that year and for the previous year.

Figure 4.1 provides a schematic overview of the model and how end-of-year predictions are computed. Under either scenario, the year starts with a set of LDV stocks, namely, the number of LDVs of each vintage assumed to be present in the South Coast and in the rest of California at the beginning of the year. In the scenario with the VAVR program, the operation of the program is represented in each year from 2001 to 2010 by deducting from the LDV stocks in the South Coast 75,000 LDVs that are at least 15 years old during that calendar year. The distribution of model years of the LDVs scrapped through the program is specified by assumption. In the without-program scenario LDV stocks are not adjusted at this point.
Figure 4.1—Overview of Calculation of Used-LDV Prices, LDV Quantities, and Emissions in Any Calendar Year

Next, vehicle stocks are updated to account for migration into the South Coast and the rest of California resulting from population growth. In particular, in the without-program run, stocks of vehicles of all vintages are increased by 1.5 percent each year in both the South Coast and the rest of California.\textsuperscript{3} For the with-program scenario, the same numbers of LDVs of various vintages are added to the LDV stocks as are added in the without-program scenario. We refer to these increments in LDV stocks throughout the state as \textit{exogenous} in-migration because they are determined outside the model.\textsuperscript{4}

Next we decrease stocks of LDVs to represent \textit{natural scrapping} of LDVs, by which we mean all vehicle retirements other than those effected by purchasing and scrapping LDVs through the VAVR program. Natural scrapping is projected in the without-program scenario using data from CARB on the fraction of currently operating LDVs of a given age that will continue to operate for at least one more year. More specifically, for each cohort of LDVs of a particular model year, we use the CARB data to predict how many will be retired in each successive calendar year for which the model is run. These values are used to represent levels of natural scrapping of each model year in each calendar year in the without-program run.

\textsuperscript{3}This growth factor is chosen to be consistent with CARB’s assumptions about growth in vehicle stocks and with recent data on new vehicle registrations in California.

\textsuperscript{4}Exogenous in-migration contrasts with increments in South Coast LDV stocks due to migration of LDVs from the rest of California, which are effects of the program determined within the model.
Fewer LDVs will be scrapped naturally in any year if the VAVR program is implemented. This is because with the VAVR program in operation, some LDVs that would have been scrapped naturally in a given calendar year will have previously been scrapped through the VAVR program. Our adjustments to natural scrapping to represent the previous operation of the program are based on assumptions about the remaining lives of the LDVs that are scrapped through the program, as detailed in Section 5.

After the used-LDV stocks are adjusted to account for exogenous in-migration and natural scrapping, we then compute for each scenario equilibrium prices of used LDVs and equilibrium quantities of LDVs of each vintage inside and outside the South Coast. This is done using a supply and demand framework by

- constructing for the South Coast and the rest of California separate demand functions for all used LDVs aggregated over model years,
- specifying conditions for equilibrium across the two regions, and
- reallocating the stocks of California LDVs over the regions to satisfy an equilibrium condition.

The demand functions for each of the two regions are calibrated for 2001—the first year for which the model is run—using values of stocks of LDVs for each region in 2001 that accord with CARB projections. The equilibrium condition we typically employ is that average used-LDV prices are the same across the two regions in every year. In the with-program scenario, the South Coast gains LDVs through the reallocations because the retirement of South Coast LDVs by the program would—absent geographic reallocation of LDVs—tend to increase prices in the South Coast. Moving LDVs from outside the South Coast to inside the South Coast is thus required to equalize used-LDV prices. These movements of LDVs to the South Coast represent in-migration due to the program.

All prices are expressed in 1999 dollars; that is, they do not build in any effects of inflation after 1999. Equilibrium prices are determined on the basis of demand conditions in the current period and LDV stocks, which depend on events in previous years. The calculations predict prices of used LDVs in the South Coast and the rest of California, which are assumed to be the same within each scenario for the end of each of a sequence of years beginning with 2001. The predicted price reported for a given calendar year and scenario is the average of the predicted

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5LDVs are durable commodities that, once produced, last for more than one year. Thus, it is crucial to specify market conditions in any year based on an accurate reflection of quantities of LDVs that are carried over from earlier years. In contrast, prices can adjust freely in each year to accommodate current quantities of used-LDV stocks, new-LDV sales, demand conditions, etc. Thus, we compute equilibrium prices in any year based on market conditions in that year, which depend on several factors including stocks carried over from the previous year.
prices from the ends of the current and previous years. The effect of the program on used-LDV prices in any year is the predicted average price of used LDVs with the program minus the predicted average price without the program.

To calculate stocks of LDVs for the end of any year, a quantity of new LDVs is added to represent sales in that year. As a result of the VAVR program, new-LDV sales will increase in California to the extent that the program increases used-LDV prices, because new LDVs are substitutes for used LDVs. To determine the quantities of new-LDV sales with and without the program, reference levels of new-vehicle sales are first specified outside the model. The reference level for 2001 is estimated using historical data on new-LDV sales in California and levels for subsequent years based on a growth rate for demand of 1.5 percent per year. These reference levels are interpreted as the levels of new-LDV sales that would occur if price differences between used and new LDVs were constant over time. Changes in used-vehicle prices predicted by the model are then used to adjust the reference levels to predict actual levels of new-LDV sales. New-vehicle sales are assumed to rise as used-LDV prices increase because there is sufficient competition in California new-LDV markets to expect new-LDV prices to be determined largely by their production, transportation, selling, and other costs, which should be unaffected by the program; and the increase of used-LDV prices caused by the program would increase demand for new LDVs, which are substitutes for used LDVs. Higher used-LDV prices in the with-program scenario than in the without-program scenario thus mean that new-LDV sales will be higher in the with-program scenario.

The effect of the program in any year on the quantity of used LDVs—or quantities of LDVs of any particular vintage or set of vintages—is defined analogously to its effect on prices, namely as the difference in any year between corresponding values in the with- and without-program scenarios.

Emissions levels are expressed, as in the SIP, in terms of daily tons of ROG plus NOx emitted from LDVs operating alternatively in the South Coast and in the rest of the California. End-of-year emissions levels are calculated from end-of-year LDV stocks using CARB estimates for the relevant calendar year of

- emissions rates, in grams per mile, of LDVs of each vintage, and
- miles driven per day of LDVs of each age.

The total vehicle miles driven by LDVs in any region in any year are assumed to be the same with or without the VAVR program in operation. More specifically, to calculate emissions in the with-program scenario in any year, we adjust miles-per-day figures for LDVs of each model year by the same proportion so that total miles driven per day are the same as in the without-program scenario for that year.
MAINTAINED ASSUMPTIONS, BASE CASE, AND SENSITIVITY ANALYSES

Several assumptions of the model are used in all simulation runs, except a few runs designed to gauge the importance of these assumptions. These "maintained assumptions" are detailed in the next section. Several other assumptions differ over successive runs because the empirical basis for them is far from definitive, and we want to assess the robustness of our estimates to changing them.

First, a set of base-case assumptions is specified. We chose assumptions that appeared reasonable given available information. In several instances, base-case values are chosen to err on the side of attributing lesser emissions benefits to the program. We devote substantial attention to presenting and interpreting results for the base case in order to understand various features of the model and to develop conceptual insights that provide general lessons about effects of large-scale, multi-year VAVR programs.

We then consider alternative values for six parameters to assess the sensitivity of the results to plausible changes in parameter values. Sensitivity is assessed first by rerunning the simulations varying one parameter at a time over a range judged to span values that are plausible. Doing so

- aids understanding of the workings of the model,
- provides a means of assessing the reliability of the model, and
- is instructive about the importance of individual parameters in determining the degree of uncertainty about effects of the program.

Because we are uncertain about appropriate values of several parameters, however, varying one parameter at a time, as just described, does not provide a reliable indication of the full range of program effects that is plausible. Accordingly, we also consider the sensitivity of our predictions to changing multiple parameters jointly from their base-case values. More specifically, we construct alternative cases that lead to relatively large and relatively small effects of the program to develop what we refer to as "credible ranges" for these effects.

These parameters are the number of LDVs scrapped by the program each year, average remaining life of LDVs scrapped through the program, the elasticity of demand for new LDVs, the elasticity of demand for used LDVs, and the average prices of new and used LDVs in California in 1999.
5. PREDICTING EFFECTS OF THE PROGRAM: DETAILS

In this section, we detail our maintained assumptions, base-case parameter values, and the assumptions used in the sensitivity analyses and their rationales. Some readers may wish to skip directly to Section 6, where we begin to present results.

ASSUMPTIONS USED THROUGHOUT THE ANALYSIS

Several assumptions and numerical values are unchanged over almost all simulation runs. These “maintained assumptions” are explained here.

The VAVR Program

The VAVR program is assumed to operate each year from 2001 through 2010. Under the with-program scenario, in each of these years we remove the same number of LDVs from the stock of age-eligible LDVs (LDVs at least 15 years old in that year) in the South Coast. The LDVs assumed to be scrapped through the program in any calendar year are allocated across the eligible model years in proportion to their predicted levels in the South Coast at the beginning of the year.\(^1\) This assumption is likely to tend to understate the emissions effects of the program, because emissions credits increase with age over a broad range of ages (see Figure 1.2), which suggests that bounties will increase with age and, in turn, vehicles scrapped through the program are likely to be disproportionately old among age-eligible vehicles.\(^2\) The assumption is made, nonetheless, because it tends to be conservative in projecting the emissions benefits of the program, and we see no basis for developing an alternative assumption that is not largely arbitrary.

Sizes of LDV Stocks Before the Program Begins

The stocks of used LDVs of each model year assumed to be present in the South Coast and in the rest of California at the beginning of 2001 are derived from the stocks projected for 1998 (see Table 3.1). Specifically, these stocks are inflated proportionately by multiplying them by

\(^1\)That is, the same fraction of the South Coast stock of each age-eligible vintage is removed from the LDV stock.

\(^2\)More specifically, as discussed in Section 2, enterprises participating in the VAVR program will sell emissions credits to the state, and LDVs generating more emissions credits will be worth more to these enterprises, all other things being equal. Competition among enterprises for LDVs to buy and scrap will tend to increase bounties for LDVs generating more emissions credits and, in turn, to increase the numbers of such vehicles offered to the program.
1.239, which aligns our total LDV stocks for the South Coast in 2001 with those assumed by CARB in its analyses.\(^3\)

**Growth over Time**

To generate predictions that can be compared directly with emissions estimates of CARB, our model allows for economic and population growth over time in California and in the South Coast. Factors that are assumed to change for reasons outside the model—that is, because of the passage of time, not because of the program—are the levels of demand for new and used LDVs and the numbers of LDVs that migrate into the South Coast and the rest of California because of population growth. We use a growth rate of 1.5 percent per year for demand for used LDVs in both the South Coast and the rest of California. We also assume in both the with- and without-program scenarios that exogenous in-migration of LDVs in any year equals 1.5 percent of the stocks of each vintage for both regions. The value of 1.5 percent per year was chosen to be consistent with CARB’s projections of 1.5 percent growth per year in total vehicle miles traveled (VMT) by LDVs in the South Coast.\(^4\)

**Total Vehicle Miles Traveled by LDVs**

We assume in all model runs that total VMT by LDVs is the same in the with- and without-program scenarios for both the South Coast and the rest of California. As a result, the effects of the program on the age distribution of vehicles are the key to the emissions effects of the program, because the vehicle-age distribution determines the distribution of a constant total VMT among various vintages with different emissions rates per mile and miles driven per year. The constant-VMT assumption is consistent with the view that all trips that would have been made using vehicles that are scrapped through the VAVR program will be replaced by other LDV trips.

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3. In our analysis we ignore stocks of LDVs outside of California, thereby implicitly assuming that migration and price effects of the program are unaffected by those stocks. Responses to the program, however, would not end entirely at the border, because some LDV owners in Oregon or Nevada, say, would be on the verge of bringing their vehicles into California if prices in California were a bit higher. The potential effects of such responses seem rather minor, however, because there are no large stocks of LDVs outside California that are near population centers in California.

4. The model CARB used to do its analysis of the M1 program (documented in CARB, 1995), provided to us in electronic form by CARB in February 1999, assumed that total VMT in the South Coast would increase 31 percent between 2001 and 2020. This corresponds to a 1.5 percent compounded annual growth rate.

A 1.5 percent growth rate is also consistent with recent trends at the state level in annual new LDV sales and total registrations. In particular, linear regression with 20 annual observations, of either ln (new LDV sales) or ln (total CA registrations) on a constant and a time trend yield estimated coefficients of the trend variable near 0.014, suggesting an annual growth rate of 1.4 percent.
This assumption is commonly used in predicting effects of VAVR programs. It tends, however, to underestimate effects of the program in reducing emissions because it seems likely that some trips that would have been taken in LDVs that are scrapped by the program would not be replaced by other LDV trips.\(^5\)

**Price Levels**
All prices are expressed in 1999 dollars.

**Demand Functions for Used LDVs**
The model employs a separate demand function for all used LDVs aggregated over vintages for each year and for each of the two regions. Each of these demand functions is assumed to be of constant elasticity (log-linear) form,\(^6\) with the price elasticity of demand for LDVs assumed to be the same in both regions.\(^7\) The demand curve for each region in 2001 is calibrated by specifying its slope, which is the price elasticity of demand, and choosing its intercept so that the quantity demanded at the average price of used LDVs in 1999 is the quantity of used LDVs projected to be present in that region on January 1, 2001. The demand functions for subsequent years are determined by adding 0.015 to each of the two region-specific demand intercepts for the previous year, which approximates a 1.5 percent annual growth rate in demand because the quantities demanded are measured on a logarithmic scale.

**Migration of LDVs into the South Coast**
Reallocation of used LDVs between the South Coast and the rest of California is assumed to equalize used-LDV prices between the two regions. This price equalization could, in principle, be accomplished by reallocating the same total number of LDVs irrespective of their age compositions. Based on the reasoning detailed in Section 2, we assume that in-migration of LDVs into the South Coast in response to the program is composed of the same fraction of LDVs of each model year that is predicted to be present outside the South Coast.

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\(^{5}\)For example, some trips would not be replaced at all, some would be replaced by extra ride-sharing, and some would be replaced by transportation modes other than LDVs.

\(^{6}\)Formally, the demand functions are assumed to be of the form \(\ln Q_{it} = \alpha_i + \beta \ln P_{it}\)

where \(Q_{it}\) = the quantity of LDVs demanded in region \(i\) (where \(i = \) South Coast or the rest of California) in year \(t\), \(P_{it}\) = the price of used LDVs in region \(i\) in year \(t\), \(\beta\) = the price elasticity of demand for used LDVs (assumed constant over years and across regions in any given model run), and \(\alpha_i\) is the intercept of the demand function for region \(i\) in year \(t\).

\(^{7}\)The value of this elasticity is subjected to sensitivity analysis.
Quantities of LDVs Scrapped Naturally

Under the without-program scenario, natural scrapping is assumed to occur at rates used by CARB to forecast LDV stocks in future years. More specifically, we use our calculated stocks of LDVs by age and the fraction of vehicles of each age that are retired within one year (based on CARB data) to calculate the number of LDVs of each vintage that would be retired in each calendar year from 2001 through 2020 in the absence of the VAVR program. For the with-program scenario, however, using these rates would not be appropriate because previous scrapping of LDVs through the program means that some of the vehicles scrapped naturally in the without-program scenario have previously been scrapped (i.e., their retirements have been “accelerated” through the program). To calculate natural scrapping in the with-program scenario, then, we reduce natural scrapping levels used in the without-program scenario to account for LDVs that had previously been retired. Specifically, for each program run, we assume (a) a value for the average remaining life of LDVs scrapped through the program and (b) for all vintages subject to VAVR scrapping, that the remaining vehicle lives of LDVs scrapped through the program are uniformly distributed over one to M years, where M is twice the assumed average remaining life for the entire pool of LDVs scrapped through the program. Using these assumptions we calculate the number of LDVs of each model year that are scrapped through the program and the current or future year in which they would have otherwise been scrapped naturally. We then use, for each model year, the total number of accelerated vehicle retirements that would have otherwise occurred in a particular calendar year to reduce the natural scrapping levels used in the with-program run and use these reduced figures to represent the levels of natural scrapping that would occur with the program in operation.

\[\text{CARB estimates annual “retention rates” — the fraction of vehicles of each age that survive until the next year — using historical vehicle registration data from the DMV. Retention rates are as high as 0.98 for new vehicles (i.e., 2 percent of new LDVs disappear from the vehicle fleet within one year), decline gradually to 0.86 for vehicles 16 years old, and then rise gradually, reaching 0.90 for vehicles 23 years old. Retention rates for vehicles older than 23 years remain at 0.90 (CARB, 1995, p. 32). The annual scrapping rate is one minus the annual retention rate.}\]

\[\text{For example, suppose that we assume that 75,000 LDVs scrapped through the program in a particular year would have remained on the road an average of 1.5 years. Assuming that vehicles are scrapped continuously throughout the year implies that LDVs scrapped in the current year, the next year, and the year after that would have remained on the road for averages of 0.5 years, 1.5 years, and 2.5 years, respectively. Then assuming a uniform distribution over remaining lives and an average remaining life of 1.5 years for all 75,000 LDVs implies that 25,000 LDVs would have been scrapped naturally in the current year, another 25,000 would have been scrapped naturally the following year, and the remaining 25,000 would have been scrapped in the second year after the current one.}\]
**New-LDV Sales Levels**

In both the with- and without-program scenarios, new-LDV sales in each calendar year are projected by using the predicted change in average used-LDV prices to adjust the reference level of new-LDV sales for that year. This reference level is calculated for 2001 as the fitted value from a time-series regression of new-LDV sales in California.\(^{10}\) For years after 2001, the reference level is calculated by assuming the reference level grows by 1.5 percent per year. We interpret the reference level in each year as what new-LDV sales would be if new-LDV prices were to change over time by the same dollar amounts as used-LDV prices change. This interpretation is based on the following assumptions:

- new LDVs are sold under competitive market conditions, and therefore prices of new LDVs will be determined by their costs of manufacture, distribution, promotion, selling, etc.; and
- these costs are constant over time in real terms.

Thus, new-LDV sales will exceed reference levels if used-LDV prices increase over time (in real terms), as they will, for example, in the within-program scenario. We estimate the increase in new-LDV sales resulting from any increase in used-LDV prices by assuming the following:

- a given dollar increase in used-LDV prices will increase the demand for new LDVs by the same amount as would a decrease in new-LDV prices of the same dollar amount, and
- a value for the price elasticity of demand for new vehicles.

We consider three alternative values for this elasticity, as detailed below.

**Emissions Effects**

Emissions of ozone precursors from LDVs in the South Coast and in the rest of California depend on the number of LDVs, their age distribution, emissions rates per mile for each vintage, and the miles driven per day for each vintage. The number and age distribution of LDVs in each region in each year are predicted by the model. To translate these predicted stocks into predicted daily emissions, we employ data on emissions rates per mile for LDVs of various model years in various calendar years derived from CARB’s emissions model that we downloaded from its Internet site in November 1999 (CARB, 1999b). In the without-program case, we use CARB data

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\(^{10}\) We project new-LDV sales in 2001 by first regressing the logarithm of new-LDV sales in California between 1981 and 1997 (the last year for which data were available) on a constant and a time-trend variable. We then use the regression and a “smearing estimator” (for transforming the prediction in logarithms to a prediction in levels) to predict new-vehicle sales in 2001. The predicted level for 2001 captures long-term trends in new-car sales, rather than year-to-year fluctuations.
on daily miles driven per LDV of different ages. In the with-program case, we adjust daily
mileage per LDV of all vintages in both regions by the same proportion so that VMT in the South
Coast is the same in the with- and without-program scenarios.

BASE-CASE PARAMETER VALUES AND ALTERNATIVES

Average Used-Vehicle Price

The first parameter we consider is the average price of a used LDV in California in 1999.
The concept of interest is the average—over all used LDVs in their actual conditions—of the
values that individual LDV owners would agree upon if they were to transact directly with each
other. There is no ready source of such information. Appendix A details how we estimated a
value for this parameter and developed a plausible range for it. Here we briefly summarize the
approach.

Our basic data source for used-LDV prices is the Kelley Blue Book (KBB) website. During
December 1998 and January 1999, we collected “trade-in” prices for several model years for 82
selected LDV models in “good condition.” Weighted averaging of these prices over models and
model years yielded a figure of $4,218. We view this figure as likely to understate the average
price of interest. To get a sense of how much higher the average price might be, we also
considered KBB “retail prices” for 20 of the 82 models for which we collected trade-in prices.
These are dealer asking prices for vehicles in excellent condition, and thus considerably overstate
the price concept of interest to us. We estimated the average retail price to be $7,545.

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11These prices reflect data for the western United States.
12“Trade-in value represents what you might expect to receive from a dealer for this consumer owned vehicle.” (Kelley Blue Book website: www.kbb.com).
13“A ‘good’ vehicle rating means the vehicle is free of any major defects. The paint, body and interior have only minor (if any) blemishes, and there are no major mechanical problems. A good vehicle may need some reconditioning to be sold at retail, however major reconditioning should be deducted from the value. Many cars owned by consumers fall into this category” (Kelley Blue Book website: www.kbb.com).
14Trade-in and retail prices were the only two types of prices reported on the KBB website.
15“Suggested retail represents the price a dealership might ask for this make and model vehicle. This represents a fully reconditioned vehicle in excellent condition. The retail price is not a trade-in or private-party value, but rather assumes that the dealer has absorbed the cost of making the vehicle ready for sale, reconditioning, advertising, sales commissions, arranging for financing and insurance and standing behind the vehicle for any mechanical or safety problems. Many late model vehicles at this price have passed an inspection program or carry a warranty.” (Kelley Blue Book website: www.kbb.com).
To compute a best guess of the true average price, we averaged the two figures putting a weight of \(2/3\) on the average trade-in price.\(^{16}\) The resulting figure of $5,300 was rounded up to $5,500 to serve as the base-case value. Alternatives considered in the sensitivity analysis are $4,500 and $6,500, which we think of as lower and upper bounds on the parameter of interest.

**Average New-LDV Price**

The second parameter we examine is the average price of a new LDV in California in 1999. In the base case, we assume a value of $22,500, relying on data from the American Automobile Manufacturers Association summarized in Davis (1998, Table 4.11).\(^{17}\) As alternatives, we used $20,000 and $25,000, which we think of as lower and upper bounds.

**Size of the Program**

The M1 program specified in the SIP involves annual scrapping of as many as 75,000 LDVs per year. In our base case, in the with-program scenario we assume that in every year from 2001 to 2010 the VAVR program removes from vehicle stocks in the South Coast 75,000 LDVs of at least 15 years of age. To gauge the sensitivity of the effects of the program to the size of the program, we also consider annual scrapping rates of 50,000 and 100,000 LDVs.

**Elasticity of Demand for New Vehicles**

Trandel (1991) and McCarthy (1996) report estimates of the elasticity of demand for new vehicles in the United States. More specifically, Trandel (1991, p. 523) estimates a value of about -1.4 using 210 observations aggregated over vehicle models, for model years 1983 to 1985. McCarthy (1996, Table 2), uses 1,564 observations of households’ choices of models for model year 1989 and estimates elasticities of about -0.85. For the base case, we use a value of -1.0, weighting McCarthy’s estimate more heavily than Trandel’s because the former applies to a more recent model year. In sensitivity analyses we also consider values of -0.8 and -1.2, which we think of as lower and upper bounds.

**Elasticity of Demand for Used Vehicles**

Another parameter is the price elasticity of demand for all used LDVs in the aggregate. We were unable to locate any studies that seemed informative about the value of this elasticity, and this parameter is perhaps the one about which we are the most uncertain.

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\(^{16}\)We put more weight on trade-in prices because we believe the value of interest is considerably closer to trade-in than to retail.

\(^{17}\)Specifically, this source reports a value of $20,444 for the national average price of a new car in 1997 and average annual increases of 4.3 percent during 1987–1997. To arrive at a value for 1999, we used this rate of increase for two years and rounded up to $22,500.
To develop base-case and bounding values, we reasoned as follows. An established economic principle is that, all other things being equal, the demand for a commodity will be less elastic the less close the available substitutes are. New LDVs have reasonably close substitutes, namely late-model used LDVs. How close are the substitutes available for all used LDVs in the aggregate? New LDVs are reasonably close substitutes for newer, used LDVs. The only close substitutes for older LDVs are other used LDVs, however. Thus, used LDVs in the aggregate have poorer substitutes—and should have less elastic demand—than new LDVs. Therefore, the elasticity of demand for all used LDVs in the aggregate should be considerably less than -1—i.e., our base-case value for the elasticity of demand for new LDVs—in absolute value. As a base case value we use -0.5, and as alternatives, we consider -0.75 and -0.25.

**Remaining Lives of LDVs Scrapped Through the Program**

What average values are plausible for the average remaining lives of LDVs scrapped through the VAVR program?\(^{18}\) This is a matter of considerable uncertainty and controversy in the debate over the VAVR program. CARB (1998a, p. 21), arguing that it is appropriate to be conservative in estimating remaining lives of LDVs scrapped through the program (i.e., to err on the side of smaller values), concludes that a value of three years is appropriate. We use this value in our base case and consider two other values to assess the sensitivity of our results to the value of this parameter.

In fact, we think that the average remaining life of LDVs scrapped through the program may be less than three years, that is, that CARB may not have been conservative enough. While it is difficult to judge whether, given current LDV price levels, sufficient numbers of eligible LDVs would be offered to the program at the kinds of bounties currently envisioned,\(^{19}\) the following line of reasoning suggests that the program may, in fact, attract many LDVs with less than three years of remaining life:

- Difficulties in developing funding for the program are likely to lead to strong pressures to contain program budget costs.
- Controlling program costs will require restraint on the prices the state will pay for credits.

\(^{18}\)There is no information available (to anyone) on the fractions of LDVs of each cohort that are condition-eligible for the VAVR program, on their market values, or on what owners would be willing to accept to sell such vehicles to the program.

\(^{19}\)Kavalec and Setiawan (1997, p. 102) predict bounties between $785 and $965 for a program than targets vehicles 10 years old and older. CARB’s analysis suggests that it expects bounties to fall somewhere between $400 and $800 (CARB, 1998a, p. 34).
• Lower prices for credits would reduce the bounties that enterprises can pay for LDVs and still cover their costs.

• Limits on bounty levels, especially given program effects on price, may lead to relaxation of the current standards for eligibility, problems in enforcing whatever eligibility standards are implemented, or both.

In the sensitivity analysis, we consider average remaining lives of two and five years, which we think of as lower and upper bounds. A value less than two years does not seem plausible given the requirements on physical condition for LDVs to be eligible for the program. A value of more than five years does not seem plausible given the bounty levels of no more than $1,000 per LDV that are commonly envisioned.
6. PREDICTED EFFECTS IN THE BASE CASE

In this section we present predicted effects of the VAVR program under our base-case assumptions. These estimates provide an initial indication of the effects of the program. We present and discuss these estimates in some detail to develop insight into the factors that determine how the VAVR program will affect LDV markets in California. In the next section, we present and discuss the sensitivity of the predictions to various changes in parameter values and develop a quantitative sense of the ranges in which the effects of the program are very likely to fall.

We emphasize predictions for 2010, the year for which the SIP specifies the emissions targets for the program. We also consider annual effects beginning in 2001, the first year the program is assumed to operate. Because the effects of the program continue after 2010, we report results for the key outcomes annually through 2020, by which time the effects are predicted to be insubstantial. Effects of the program in different years are of direct interest because they affect the well-being of Californians. Moreover, examining the time patterns of predicted effects helps develop insights about the forces that are important in determining various effects of the VAVR program.

The section is organized as follows. First, we present and discuss predictions of the effects of scrapping 75,000 older vehicles in the South Coast each year between 2001 and 2010 on used-vehicle prices and the quantities and age compositions of vehicles operating in the South Coast and rest of California. Next, we discuss two key economic factors underlying these results. Finally, we examine predictions of the changes in emissions due to the program.

EFFECTS ON PRICES AND QUANTITIES OF USED LIGHT-DUTY VEHICLES

Table 6.1 presents estimated effects of the 10-year program in 2010. After the VAVR program has operated for 10 years, prices of used LDVs across the state are predicted to be $66 higher than they would be in the absence of the program.1 (Recall that all prices are expressed in constant 1999 dollars). The total number of vehicles operating in the South Coast in 2010 is predicted to be about 60,000 lower because of the program, which is only about 0.5 percent of the projected stock of almost 12 million LDVs in the region. This decline of 60,000 LDVs is composed of an increase of 87,000 LDVs less than 15 years old and a decrease of 147,000 LDVs at least 15 years old. Thus, the program is predicted to have an appreciable effect on the age distribution of LDVs in the South Coast, as discussed in the next subsection.

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1 The model was not designed to predict prices, quantities, and emissions in the future if the program were not implemented. Thus, for example, the simulated increase in used-LDV prices in the without-program scenario (from $5,500 in 2001 to $5,808 in 2010) should not be taken as a prediction of real used-LDV prices in the future.
Table 6.1
Base-Case Predictions of the Effects in 2010 of Scrapping 75,000 Older South Coast Vehicles per Year from 2001 to 2010

<table>
<thead>
<tr>
<th>Outcome</th>
<th>With Program</th>
<th>Without Program</th>
<th>Difference</th>
<th>Percentage Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Values in 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average used-LDV price ($/vehicle)</td>
<td>5,875</td>
<td>5,808</td>
<td>66</td>
<td>1.1</td>
</tr>
<tr>
<td>Vehicles in South Coast</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (thousands)</td>
<td>12,066</td>
<td>12,126</td>
<td>-60</td>
<td>-0.5</td>
</tr>
<tr>
<td>0 to 14 years old</td>
<td>10,087</td>
<td>10,000</td>
<td>87</td>
<td>0.9</td>
</tr>
<tr>
<td>15+ years old</td>
<td>1,979</td>
<td>2,126</td>
<td>-147</td>
<td>-6.9</td>
</tr>
<tr>
<td>Percent 15+ years old</td>
<td>16.6</td>
<td>17.9</td>
<td>-1.2</td>
<td>--</td>
</tr>
<tr>
<td>Vehicles in rest of California</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (thousands)</td>
<td>16,355</td>
<td>16,438</td>
<td>-83</td>
<td>-0.5</td>
</tr>
<tr>
<td>0 to 14 years old</td>
<td>12,782</td>
<td>12,825</td>
<td>-43</td>
<td>-0.3</td>
</tr>
<tr>
<td>15+ years old</td>
<td>3,573</td>
<td>3,613</td>
<td>-40</td>
<td>-1.1</td>
</tr>
<tr>
<td>Percent 15+ years old</td>
<td>21.8</td>
<td>22.0</td>
<td>-0.1</td>
<td>--</td>
</tr>
<tr>
<td>LDV emissions (tons of ROG plus NOx per day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Coast</td>
<td>339</td>
<td>352</td>
<td>-13</td>
<td>-3.8</td>
</tr>
<tr>
<td>Rest of California</td>
<td>552</td>
<td>555</td>
<td>-3</td>
<td>-0.5</td>
</tr>
<tr>
<td>B. Total new-LDV sales between 2001 and 2010 (thousands)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Coast</td>
<td>9,133</td>
<td>9,110</td>
<td>23</td>
<td>0.2</td>
</tr>
<tr>
<td>Rest of California</td>
<td>10,422</td>
<td>10,396</td>
<td>26</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The third set of rows of Table 6.1 shows that 83,000 fewer vehicles are predicted to be operating in the rest of California in 2010 because of the program. When combined with the 60,000 decline in the South Coast, the total decline in the number of LDVs operating in the entire state is less than one-fifth of the cumulative size of the program.

Figure 6.1 presents predicted effects of the VAVR program on used-LDV prices and the number of vehicles in the South Coast each year from 2001 through 2020. The effects of the program increase over the first five years (2001 to 2005), with the incremental changes in each successive year getting smaller and smaller. The predicted price effects decrease after 2006. In quantitative terms: The VAVR program is predicted to increase prices of used LDVs (see right-hand-side scale) by approximately $20 during the first year of the program (2001); the largest predicted effect is $79 in 2005 and 2006; and the predicted price effect is $66 for 2010 (as reported in Table 6.1). Effects on numbers of vehicles in the South Coast (left-hand scale) are also largest in 2005, showing a decrease of 70,000 LDVs, and then decline (to 60,000 LDVs) by 2010.
What accounts for the predicted increases and subsequent decreases in program effects during the operation of the program? Is this an artifact of the model, or should such a pattern be expected to occur in the real world? We believe the latter. Most important, program effects on the number of LDVs in the South Coast and their prices will cease to grow and will then decline because of two phenomena: reduced levels of natural scrapping because of previous scrapping through the program and increases in new-LDV sales induced by higher used-LDV prices. Once the program has operated for several years, the decline in natural scrapping due to the program in a particular year roughly equals the number of LDVs scrapped through the program in that year, and price and quantity effects cease to increase over time.\(^2\)

![Figure 6.1—Predicted Effects of Program on Price and Numbers of LDVs in the South Coast](image)

How persistent are effects of the program likely to be after it is discontinued in 2010? Figure 6.1 shows that program effects on used-LDV prices and stocks of vehicles in the South Coast dissipate rapidly after 2010. For example, by 2013 the differences between the with- and without-program scenarios for both price and quantity are near zero; i.e., the program effects on these outcomes have been virtually eliminated. After 2013, in fact, used-LDV prices are slightly lower and total LDV stocks moderately higher in the with-program scenario. The legacy of the

\(^2\)More formally, our model can be thought of as a dynamic system where the change in the number of vehicles (the "state" variable) from one year to the next is determined by vehicle retention rates (and other factors). These retention rates are less than one, implying that the system will tend to converge to a steady state in which the number of vehicles does not change over time. To highlight key factors that must be in balance to achieve a steady state, assume that
program in terms of LDV stocks reflects extra new-LDV sales in the with-program scenario and
the fact that such LDVs would remain on the road for several years after the program ends.
Larger used-LDV stocks after 2010 in the with-program case would also cause lower prices.\(^3\)

These results foreshadow an important implication of the pattern of emissions benefits
discussed below: A finite-lived VAVR program will have only transitory benefits on air quality.
A program that continues only through 2010 will help the South Coast achieve compliance with
the NAAQS in 2010 but will not do much for air quality in subsequent years if it is discontinued.\(^4\)

**PROGRAM EFFECTS ON AGE COMPOSITION OF THE FLEET**

The VAVR program will alter the age distribution of LDVs operating in the South Coast by
accelerating the retirement of older LDVs, and by inducing more new-LDV sales. For example,
for our base case, Table 6.1 reports that in 2010 the number of newer vehicles (LDVs less than 15
years old) operating in the South Coast is 0.9 percent larger with the program and the number of
older vehicles is smaller by almost 7 percent. The net result of these changes is that the percentage
of older vehicles in the South Coast fleet is predicted to be 16.6 percent with the program rather
than 17.9 percent if the program is not implemented.

As is also reported in Table 6.1, in the rest of the state the sizes of the stocks of older and
newer vehicles are both slightly lower in the with-program scenario, and there is a slight change
in the proportion of vehicles that are at least 15 years old. The age distribution does not improve
nearly as much as in the South Coast: Out-migration due to the program does not affect the age
distribution of the fleet outside the South Coast and, more important, unlike in the South Coast,
older LDVs in the rest of the state are not subject to accelerated retirement.\(^5\)

---

\(^1\) new car sales are not affected by the program, \(^2\) the average expected life of vehicles sold to
the program is the same as those that are not sold, and \(^3\) that vehicle demand is constant over
time. In a steady state—with or without the program—the number of vehicles that leaves the fleet
in each year must equal new-LDV sales in those years. Without the program, all vehicles
scrapped are scrapped naturally. With the program, total (program plus natural) scrapping
exceeds that without the program—and the size of the fleet falls over time relative to the without-
program scenario—each year until the decrease in the number of vehicles scrapped naturally
equals the number that exit through the program. Our model is more complicated than this
because new-car sales are endogenous, vehicles sold to the program have shorter expected lives
than those not sold, and demand grows over time, but a retention rate that is less than one still
governs the behavior of the system.

\(^3\) Simulations beyond 2020 that are not reported here show that effects of the program
eventually disappear as all LDVs added to the South Coast stock because of the program are
scrapped naturally. This outcome is suggested by Figure 6.1 where by 2020, 10 years after the
program is discontinued, the effects of the program are quite small and declining over time.

\(^4\) The effectiveness of the program may diminish over time even if it is continued after 2010
if the differences in emission rates of LDVs of particular pairs of ages narrows over time.

\(^5\) The age distribution outside of the South Coast improves slightly because of additional
new-LDV sales induced by statewide increases in used-LDV prices.
Figures 6.2 and 6.3 provide information about the evolution of the age composition of the South Coast fleet over time. Figure 6.2 decomposes annual program effects on total LDV stocks in the South Coast into annual effects on numbers of older LDVs, which decrease because of the program, and numbers of newer LDVs, which increase because of the program. As we saw with

![Figure 6.2—Predicted Program Effects on Numbers of Older and Newer LDVs in the South Coast](image)

![Figure 6.3—Predicted Percentage of South Coast LDVs at Least 15 Years Old](image)
program effects on price and total LDV stocks in Figure 6.1, Figure 6.2 shows that the predicted effects of the program increase at a decreasing rate during the first five or so years that the program operates, decline gradually for the remaining years of the program, and dissipate rapidly after the program is discontinued in 2010. Figure 6.3 plots annual percentages of the South Coast fleet that are at least 15 years old with and without the program. In this figure, the effect of the program in any year is the distance between the two curves. During the first few years of the program, the differences between the with- and without-program scenarios are due to the program attenuating the increases in this percentage that would occur in the absence of the program.

**TWO KEY ECONOMIC RESPONSES UNDERLYING PROGRAM EFFECTS**

Our model incorporates, and the base-case predictions quantify, the combined operation of several economic forces that are critical for understanding and predicting the effects of the VAVR program in the South Coast. These forces include

- responses of new-LDV sales to higher used-LDV prices, and
- in-migration of LDVs from outside the South Coast.

The fundamental logic of these forces and their quantitative significance in the base case are discussed in turn.

**New-LDV Sales Induced by the Program**

Increases in used-LDV prices induced by the program will increase the demand for new LDVs, which are substitutes for used LDVs, and increase unit sales of new LDVs because prices of new LDVs should be unaffected by the program. In our base case, the program-induced increases in used-LDV prices over the 2001 to 2010 period (see Figure 6.1) increase new-vehicle sales in California by a total of 49,000 units between 2001 and 2010 (Panel B of Table 6.1). Additional new-LDV sales attenuate tendencies of the program to increase used-LDV prices and decrease LDV stocks. Perhaps more important, these induced new-LDV sales help improve the age distribution of the fleet during the years when these extra LDVs are relatively young and have relatively low emissions rates per year.

The predicted levels of induced new-LDV sales also help us gauge the extent to which a VAVR program works by accelerating retirement of older LDVs. In particular, the results in Table 6.1 suggest that the program will decrease the number of LDVs in California in the year 2010 by approximately 143,000 units (60,000 fewer in the South Coast and 83,000 fewer in the rest of the state). Thus, the program removes 750,000 vehicles from the fleet over the course of 10 years.

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5See Sections 4 and 5.
ending in 2010, but during 2010 there are only 143,000 fewer vehicles in the state because of the program. Approximately 8 percent of this discrepancy of 607,000 LDVs is the predicted additional 49,000 new-vehicle sales, but most of the remainder represents LDVs retired through the program that would have been retired by 2010 anyway. More specifically, given our base-case assumptions—which include that LDVs scrapped through the program average 3 years of remaining life—563,000 of the 750,000 (about 75 percent) of the LDVs scrapped through the program would have been scrapped by the year 2010 anyway.

**Program-Induced Migration of LDVs into the South Coast**

The tendency for a VAVR program to increase LDV prices in the region where vehicles are purchased and scrapped attracts LDVs into the region. Our estimates suggest that in-migration of LDVs into the South Coast during the course of the VAVR program will be substantial. In particular, in the base case 184,000 vehicles are predicted to move into the South Coast between 2001 and 2010 because of the program. Thus almost one-quarter of 750,000 LDVs scrapped in the South Coast through the program are predicted to be replaced by in-migration induced by the program. The effects of in-migration on emissions depends on the age composition of the in-migrating LDVs. As discussed in Section 2, and as is built into the quantitative model, in any year in-migration should be composed of roughly equal proportions of existing vehicles of each vintage or model year. In fact, in our base case, it is predicted that 145,000 (or almost 79 percent) of the 184,000 vehicles that in-migrate will be less than 15 years old at the time that they migrate. In sum, in-migration replaces about one-quarter of the LDVs scrapped by the VAVR program, but only about 5 percent of the LDVs scrapped by the program are replaced through in-migration by LDVs that are old enough to be eligible for scrapping through the program.

**EFFECTS ON LIGHT-DUTY VEHICLE EMISSIONS**

The predicted effects of the program on emissions are determined by combining estimates of vehicle emissions per mile with our predictions concerning numbers of vehicles, fleet age compositions, and miles traveled per vehicle. In the base case, the program is predicted to reduce emissions of ROG plus NOx in the South Coast by 13 tons per day in 2010 or 3.8 percent of projected LDV emissions (see Panel A of Table 6.1). Thus, our base-case analysis suggests that a VAVR program that removes 75,000 vehicles per year would have substantial effects on

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7. A small part of the discrepancy is the additional new LDVs sold from 2001 to 2009 that are scrapped by 2010.

8. Predicted 2010 LDV emissions of ROG plus NOx in the South Coast in the without-program scenario (352 tons per day) are about 8 percent below the roughly 383 tons per day that we calculated from CARB (1999b).
emissions, but will fall almost 50 percent short of meeting the SIP goal for the M1 program of 25 tons per day by 2010. The program would also tend to reduce emissions outside the South Coast; in the base case, these reductions are predicted to be 3 tons per day for the rest of the state.

Policy attention tends to focus on 2010, the year that the federal Clean Air Act requires compliance with the national ambient air quality standards in the South Coast. The VAVR program will affect air quality, however, both before and after 2010, and improving air quality is the fundamental reason to consider programs like the VAVR. Figure 6.4 reports predicted effects on emissions in the South Coast annually from 2001 through 2020. As can be seen from the figure, these emissions effects have a similar pattern over time as those for the other outcomes. The predicted emissions reductions in the South Coast are largest in 2005 at about 18.8 tons per day, decrease gradually during the remaining five years of program operation, and then decrease rapidly after the program ceases to operate in 2010.

![Graph showing predicted effects of Program on emissions in the South Coast](image)

Figure 6.4—Predicted Effects of Program on Emissions in the South Coast

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However, as discussed above, our model incorporates several assumptions that tend to make us err on the low side in predicting emission reductions. We enumerate these assumptions and discuss implications in Section 7.
7. RANGES OF EFFECTS OF THE VAVR PROGRAM

The previous section presented point estimates of effects of a VAVR program that removes 75,000 older vehicles per year for 10 years from the LDV fleet in the South Coast. These estimates are, however, subject to many potential sources of error, and the precise effects of the program cannot be predicted with great confidence. In this section we explore various sources of uncertainty about program effects and estimate ranges into which the price and emissions effects of the program appear very likely to fall.

We begin by examining the sensitivity of our base-case predictions to changes in individual features of the model. This allows us to gauge the importance of various factors in determining effects of the VAVR program and to develop a preliminary sense of the degree of uncertainty about sizes of actual program effects. Next, we construct scenarios combining model assumptions that all tend to produce either large or small predicted effects on used-LDV prices and South Coast emissions, to gauge the degrees to which these effects might plausibly deviate from the base-case predictions.

SENSITIVITY TO CHANGES IN INDIVIDUAL MODEL FEATURES

Two types of sensitivity analyses are discussed in this section. First, we examine the sensitivity of the results to varying six individual parameters over the ranges of values presented in Section 5. We first discuss two parameters that turn out to have substantial effects on predictions of both used-LDV prices and emissions levels, and then turn to four parameters that mainly affect prices. We then examine the sensitivity of the predictions to three fundamental, maintained features of the model.

The results of the sensitivity analyses over individual parameter values are presented in Table 7.1. Each set of rows reports estimates for the base case (to aid comparison) and for the indicated alternative assumptions, while leaving all other features of the model as they are in the base case. The columns of the table present estimated program effects on four key outcomes in the South Coast in 2010: the average price of used LDVs, the total number of LDVs on the road, the percentage of LDVs that are at least 15 years old, and daily emissions of ROG plus NOx.
Table 7.1
Sensitivity of Predictions of Program Effects in South Coast in 2010
to Changes in Individual Parameter Values

<table>
<thead>
<tr>
<th>Parameters That Affect Both Price and Emissions</th>
<th>Used LDV Price ($)</th>
<th>Light-Duty Vehicles (thousands)</th>
<th>Percentage of Older Vehicles</th>
<th>Emissions from LDVs (tpd* ROG+NOx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of program</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50,000 per year</td>
<td>43</td>
<td>-40</td>
<td>-0.8</td>
<td>-9</td>
</tr>
<tr>
<td>75,000 per year (base case)</td>
<td>66</td>
<td>-60</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>100,000 per year</td>
<td>88</td>
<td>-80</td>
<td>-1.5</td>
<td>-18</td>
</tr>
<tr>
<td>Expected life of scrapped vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 years</td>
<td>39</td>
<td>-35</td>
<td>-0.7</td>
<td>-8</td>
</tr>
<tr>
<td>3 years (base case)</td>
<td>66</td>
<td>-60</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>5 years</td>
<td>126</td>
<td>-113</td>
<td>-2.1</td>
<td>-27</td>
</tr>
<tr>
<td>Parameters That Mainly Affect Price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elasticity of demand for new vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.8</td>
<td>69</td>
<td>-63</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>-1.0 (base case)</td>
<td>66</td>
<td>-60</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>-1.2</td>
<td>63</td>
<td>-57</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>Elasticity of demand for used vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.25</td>
<td>106</td>
<td>-43</td>
<td>-1.2</td>
<td>-14</td>
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<tr>
<td>-0.50 (base case)</td>
<td>66</td>
<td>-60</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>-0.75</td>
<td>47</td>
<td>-66</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>Initial average used-LDV price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$4,500</td>
<td>57</td>
<td>-63</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>$5,500 (base case)</td>
<td>66</td>
<td>-60</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>$6,500</td>
<td>75</td>
<td>-57</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>Average new-LDV price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$20,000</td>
<td>64</td>
<td>-58</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>$22,500 (base case)</td>
<td>66</td>
<td>-60</td>
<td>-1.1</td>
<td>-13</td>
</tr>
<tr>
<td>$25,000</td>
<td>68</td>
<td>-62</td>
<td>-1.1</td>
<td>-13</td>
</tr>
</tbody>
</table>

* Tons per day.

Sensitivity to Parameters That Affect Both Price and Emissions

Program Size. The first set of rows in Table 7.1 reports results varying the number of LDVs scrapped per year by the VAVR program. The effect of the program on used-vehicle prices and emissions in the South Coast in 2010 are roughly proportional to the size of the program over the range of program sizes examined. For example, increasing the program size by one-third, from 75,000 to 100,000 vehicles per year, increases the price effect by one-third, from $66 to $88, and increases emissions benefits from 13 to 18 tons per day, about one-third. Decreasing program size from 75,000 to 50,000 vehicles changes the predicted price and emissions effects by about the
same amounts, but in opposite directions. These estimates suggest that the SIP target for the M1 program of 25 tons per day in 2010 would require a program that scraps considerably more than 75,000 vehicles per year.

**Expected Life of Vehicles Scrapped Through the Program.** Predicted effects of the program are quite sensitive to our alternative assumptions about the average expected life of vehicles scrapped through the program. Predicted effects on both price and emissions decrease as the expected life of vehicles scrapped through the program falls. This result makes sense intuitively: The shorter the expected lives of the LDVs scrapped through the program, the sooner they would have been scrapped naturally and the less the program actually accelerates LDV retirement and affects vehicle markets. The estimates indicate that a VAVR program can generate substantial emissions reductions even if the vehicles scrapped have rather short expected remaining lives. In particular, for expected lives of two years—compared with three years as assumed by CARB and in our base case—our prediction is that the program would reduce emissions by 8 tons per day in the South Coast in 2010. While a program that attracts vehicles that are more representative of all age-eligible vehicles on the road would have greater emissions effects, it is likely that this would require higher bounties and higher emissions-credit procurement costs because LDVs with longer remaining lives should have more value to their owners. Thus, it may or may not be preferable to target LDVs with longer remaining lives.

**Sensitivity to Parameters That Mainly Affect Price**

**Elasticity of Demand for New LDVs.** Varying the assumed elasticity of demand for new LDVs from -0.8 to -1.2 has a minor impact on predicted program effects on used-LDV prices. Specifically, varying the value of this elasticity by 0.2 in either direction from its base-case value changes the year-2010 price prediction by only $3 per used LDV relative to a base-case prediction of $66. Moreover, varying the assumed price elasticity of new LDVs leaves the predicted effects of the program on emissions essentially unchanged.

**Elasticity of Demand for Used LDVs.** Varying the price elasticity of demand for used LDVs from -0.75 to -0.25 more than doubles the predicted effect of the program on used-LDV prices in 2010. This is because when demand is less elastic, a larger increase in price is required to reduce quantities demanded sufficiently to clear LDV markets when available LDV supplies are decreased by a given amount. At $106, the maximum price effect is just about 2 percent of the average used-LDV price in the base case ($5,500). A larger (absolute) price elasticity leads to a larger decrease in the size of the LDV fleet in the South Coast because the reduced tendency for used-LDV prices to increase leads to fewer induced new-LDV sales and less in-migration of LDVs into the South Coast. The effects on emissions of varying the elasticity of demand for used LDVs is about one ton per day.
Average Used-LDV Price in 1999. In the model, we parameterized demand in terms of a constant price elasticity. Given a value for the elasticity of demand, proportionate price effects can be calculated from proportionate effects on LDV stocks. The baseline price to which such a proportionate price effect applies—namely, the average price of used LDVs—is subject to considerable uncertainty, however. Varying the initial price of used LDVs from $4,500 to $6,500 produces a range of predicted price effects in 2010 of $57 to $75 per used LDV, which is about 1.2 percent of the corresponding initial assumed prices.¹

New-Vehicle Price. Higher new-vehicle prices mean that any given program effect on used-LDV prices is smaller relative to new-vehicle prices and thus has less impact on new-vehicle sales. Varying our assumption about the average price of new LDVs from $20,000 to $25,000 produces quite small changes in predicted effects of the program on used-LDV prices, numbers of vehicles, and emissions.

Sensitivity to Fundamental Model Features

Table 7.2 summarizes the results of changing three basic features of our model. The three alternative assumptions considered are (a) migration of LDVs into the South Coast is foreclosed; (b) the VAVR program affects prices and migration only of LDVs that are at least 15 years old; and (c) new-LDV sales are unaffected by the VAVR program. Each of these alternative assumptions is implausible. However, considering the effects of these assumptions helps gauge the degree to which the three maintained assumptions affect our results.

Table 7.2

<table>
<thead>
<tr>
<th>Sensitivity of Predictions of Program Effects in South Coast in 2010 to Changes in Basic Model Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used LDV Price ($)</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Base case</td>
</tr>
<tr>
<td>No migration into the South Coast</td>
</tr>
<tr>
<td>Price effect and migration limited to age-eligible vehicles</td>
</tr>
<tr>
<td>New-LDV sales unaffected by program</td>
</tr>
</tbody>
</table>

²Tons per day.

¹These percentages are not precisely the same because the percentage changes in LDV stocks also differ in the two cases.
LDV Migration into the South Coast. Migration of LDVs into the South Coast plays an important role in our analysis. In all cases considered to this point of the analysis, we assumed that used vehicles migrate to eliminate any used-LDV price differentials between the South Coast and the rest of California. For the reasons detailed in Section 2, price equalization appears to be a reasonable approximation to reality and an analytically attractive equilibrium condition. But assuming price equalization could tend to overpredict the amount of in-migration in response to the program. No empirical basis is apparent for altering the model to allow degrees of in-migration that would be insufficient to equalize used-LDV prices in the South Coast with those in the rest of California.\textsuperscript{2} To examine the potential importance of lesser degrees of in-migration and to gauge the extent to which in-migration undermines the potential benefits of a VAVR program, then, we go to the opposite extreme from our price-equalization equilibrium condition and compare predictions from the base case to an implausible alternative scenario in which in-migration is impossible.

As can be seen from Table 7.2, if in-migration were precluded, the predicted effect of the program on used-LDV prices in 2010 is $133, or just about twice that in the base case. Assuming away in-migration possibilities also leads to a major change in the predicted effects of the program on the size of the LDV fleet in the South Coast, and moderate effects on the proportion of the fleet at least 15 years old and the emissions benefits of the program. The directions of these changes in predictions all make sense intuitively. Specifically, without in-migration: (a) the program would reduce the size of the South Coast LDV fleet by a larger amount; (b) the program improves the age composition of this fleet even more because larger effects on used-LDV prices trigger more new-LDV sales; and (c) the larger age-composition improvement contributes to larger emissions benefits. The difference between predicted emissions benefits of 13 tons per day in the base case and 16 tons per day when we assume that in-migration is precluded indicates that in-migration undermines the potential emissions effects of the VAVR program in important, but not profound, ways. The effect on emissions is not profound because, as discussed in Section 6, much of the in-migration would be by newer LDVs.

Vintages of LDVs Subject to Price and In-Migration Effects. As explained in Section 2, the VAVR program should be expected to increase prices of used LDVs of all vintages and induce in-migration of LDVs of all vintages even though LDVs are eligible for the program only if they are at least 15 years old. In short, the age-eligibility requirement of the VAVR program does not

\textsuperscript{2}For example, we know of no empirical information concerning the extent of systematic differences, if any, in used-LDV prices in the South Coast and elsewhere in California. More important, current price differentials are likely to be largely uninformative about the differentials that might exist if LDV markets are subjected to the kind of disruption that would be caused by a VAVR program like the one modeled here.
alter the fact that the markets for used LDVs of all vintages and locations are interdependent. Nonetheless, the intuition of many previous analysts of VAVR programs has been that price and in-migration effects will be largely, if not totally, limited to age-eligible vehicles. In our analyses up to this point, we employed the assumption that the effects of the VAVR program on used-vehicle prices are the same dollar amount for all vintages. While, as detailed in Section 2, this assumption appears to provide a useful approximation to reality, it is only an approximation, and it is possible that effects of the program on used-LDV prices will be somewhat larger in dollar terms for older LDVs. We see no basis for assuming or estimating the degrees of any such cross-vintage differences in price effects. Instead, we examine the predictions of the model by assuming (implausibly) that the program has no effects on prices or in-migration of LDVs less than 15 years old. To develop these projections, we assume that the price elasticity of demand for older LDVs is -0.75 and the average price of older LDVs is $600.

The results are reported in the third row of Table 7.2. As can be seen from the table, assuming that the VAVR program affects only the markets for older LDVs, the absolute price effect for older LDVs is predicted to be about one-third of that for the base case ($21 versus $66), but higher in percentage terms (3.5 percent of $600 versus 1.2 percent of $5,500). These smaller absolute-price effects reflect the quite low average price of older LDVs ($600 versus $5,500 for all used LDVs in the base case) and the more elastic demand for older LDVs (-0.75 versus -0.5 for all used LDVs in the base case), the effects of which overpower the fact that the VAVR program reduces the number of older LDVs by a larger percentage than the percentage reduction in all used LDVs. Assuming that price and in-migration effects are limited to age-eligible vehicles reduces the predicted emissions effects of the program by more than two-thirds, namely, from 13 tons per day in the base case to 4 tons per day. However, we anticipate that any tendency for price and migration impacts of the program to be greater for older vehicles will have minor effects on program benefits.

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3See, for example, Dixon and Garber (1996, p. 190), Moyer, Pera, and Wool (1995, p. 2), and CARB (1998a, p. 23).
4Recall that we assumed in the base case that the price elasticity of demand for all used LDVs is -0.5. Since age-eligible (15 year old and older) LDVs are a subset of all used LDVs, the demand for age-eligible LDVs should be more elastic than that for all used LDVs.
5The value of $600 was developed as follows: For LDVs 15 and more years old, the average trade-in and retail prices developed from the Kelley Blue Book data (see Section 5 and the appendix) are $456 and $1,596, respectively. In averaging these figures, we put predominant weight on the trade-in value because we expect that many age-eligible vehicles are not in even good condition (as assumed in constructing the trade-in price series) and only a very small fraction of them are in excellent condition (as assumed in constructing the retail price series).
6The former percentage change underlies predicted price effects in the present case, and the latter underlies predicted price effects in the base case.
Finally, while we do not believe that this case is indicative of the actual effects of a VAVR program, it is important to recognize that if migration of LDVs into the South Coast is disproportionately composed of older LDVs, this would lead to larger reductions in LDV emissions in the rest of California. For example, for the extreme case currently under discussion, the predicted emissions reductions for California excluding the South Coast are 11 tons per day, as compared with 3 tons per day in the base case.

**Response of New-LDV Sales to Price Increases for Used LDVs.** Increases in new-LDV sales in response to higher used-LDV prices also play an important role in the analysis. Predicted increases in new-LDV sales were based on assuming that prices of new LDVs are—because of competitive market conditions—determined by costs of (producing, transporting, selling, etc.) new LDVs. Here we consider the alternative, but implausible, assumption that new-LDV sales are unaffected by the program, to explore the extent to which the base-case predictions are affected by additional new-LDV sales.

The last row of Table 7.2 shows that predicted program effects on used-LDV prices and the size of the South Coast LDV fleet are moderately sensitive to program-driven increases in new-LDV sales. Specifically, the alternative assumption produces a predicted price effect for used LDVs in 2010 of $83 compared to a base-case prediction of $66 and a predicted reduction of 79,000 in the size of the South Coast fleet compared with a base-case prediction of 60,000. Most important, perhaps, is the fact that predicted emissions effects are almost entirely insensitive to this assumption.

**CREDIBLE RANGES FOR PRICE AND EMISSIONS EFFECTS**

Predicting effects of the program on used-LDV prices and South Coast emissions is subject to many sources of uncertainty. The sensitivity analyses reported above examine several of these sources, but only one of them at a time. We now develop information about the ranges in which we can be reasonably confident that the price and emissions effects will fall. This analysis involves considering effects on our predictions of varying five parameters jointly from their base-case values.

Our goal is to develop ranges in which effects of the VAVR program on used-LDV prices and South Coast emissions can be expected to fall with high probability, much closer to 1 than to 0.5, say. We proceed by constructing what we call *credible ranges* for price and emissions effects using two sets of parameter values to develop the end points of the ranges. One scenario produces relatively small predicted price and emissions effects, and the other scenario produces relatively large ones.
To construct the scenarios, we maintain the fundamental features of the model that we believe are the best workable approximations to reality. Specifically, we maintain the base-case assumptions that (a) the VAVR program scraps 75,000 LDVs per year, (b) new-LDV prices are unaffected by the program, (c) the program increases prices of used LDVs of all vintages by the same amount, and (d) vehicle migration equalizes used-LDV prices across the state. We then vary the five parameters examined in Table 7.1 other than the program size over the ranges used for the individual sensitivity analyses, combining values that all tend to push predicted price and emissions effects in the same direction. Panel A of Table 7.3 details the parameter values comprising the base-case (for comparison purposes) and the two alternative scenarios. The parameter values detailed in the middle column all tend to produce relatively small predicted effects of the program on used-LDV prices and South Coast emissions reductions. The parameter values detailed in the last column all tend to produce relatively large predicted effects. In jointly varying all five parameters over what we consider to be their plausible ranges, we believe that our credible ranges are wide enough to compensate for uncertainty due to the approximations involved in the maintained features of the model.

First consider credible ranges for effects of the VAVR program on used-LDV prices and South Coast emissions for the year 2010. These ranges are developed from estimates reported in Panel B of Table 7.3. The first set of alternative parameter values (middle column) leads to the predictions that in 2010 used-LDV prices will be $22 higher and South Coast emissions of ROG plus NOx will be lower by 8 tons per day because of the VAVR program. The second set of alternative parameter values (last column) leads to predictions for 2010 of price effects of $271 per used LDV and emissions reductions of 28 tons per day. Thus, our credible range for the effect of the program on used-LDV prices in 2010 is $22 to $271 per LDV, and our credible range for emissions effects in 2010 is 8 to 28 tons of ROG plus NOx per day.

We have paid particular attention to the year 2010 because that is the deadline for the South Coast to comply with federal air quality standards. But program effects on prices and emissions in other years also affect the well-being of Californians and are thus of interest for policy purposes. As discussed in Section 6, our base-case parameter values lead to the prediction that the largest price and emissions effects of the program will occur before 2010, specifically, in the year 2005 (Figures 6.1 and 6.4).
Table 7.3
Alternative Scenarios and Implied Credible Ranges for the Effects of the Program in the South Coast

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Small Program Effects</th>
<th>Large Program Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Parameter Values</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected life of scrapped vehicles (years)</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Elasticity of demand for new vehicles</td>
<td>-1.00</td>
<td>-1.20</td>
<td>-0.80</td>
</tr>
<tr>
<td>Elasticity of demand for used vehicles</td>
<td>-0.50</td>
<td>-0.75</td>
<td>-0.25</td>
</tr>
<tr>
<td>Initial average used-LDV price</td>
<td>5,500</td>
<td>4,500</td>
<td>6,500</td>
</tr>
<tr>
<td>Average new-LDV price</td>
<td>22,500</td>
<td>20,000</td>
<td>25,000</td>
</tr>
</tbody>
</table>

| **B. Program effects in the South Coast in 2010** |           |                       |                       |
| Used-LDV price ($/vehicle) | 66        | 22                    | 271                   |
| Emissions (tons of ROG plus NOx per day) | -13       | -8                    | -28                   |

| **C. Program effects in the South Coast during year with largest effects** |           |                       |                       |
| Year                      | 2005      | 2004                  | 2008                  |
| Used-LDV price ($/vehicle) | 79        | 27                    | 295                   |
| Emissions (tons of ROG plus NOx per day) | -19       | -12                   | -30                   |

* Other parameter values and all basic model features are as specified in the base-case.

Thus we now consider credible ranges for the largest price and South-Coast emissions effects of the program in whatever year they might occur. These credible ranges are developed from estimates reported in the bottom panel of Table 7.3. For the parameter values that lead to predictions of relatively small price and emissions effects (middle column), the largest predicted price and emissions effects occur in the year 2004. For the parameter values that lead to predictions of relatively large price and emissions effects (last column), the largest predicted price and emissions effects occur in the year 2008. Using the estimates reported in the bottom panel of the table, our credible range for the largest price effect of the program is $27 to $295. Our credible range for the largest emissions effect of the program is a reduction of 12 to 30 tons of ROG plus NOx per day emitted from LDVs in the South Coast.

What do these estimates suggest about the significance of the effects of the VAVR program on used-LDV prices? Suppose that the price effect were as large as our largest estimate of $295. First, even this estimate of price effects—our largest—is much smaller than has been suggested by others. Second, this estimate suggests that average used-vehicle prices would be at most 5 percent
higher\(^2\) than they would be without the program. Third, a price increase of almost $300 would not be inconsequential, however, to some households.\(^8\) We return to this issue in Section 9.

What do our estimates suggest about emissions effects of the program and the likelihood of reaching the SIP goals for the program in 2010? Our estimates suggest that emissions effects in 2010 will almost certainly be at least 8 tons per day. However, we view this value as very, and probably unduly, pessimistic. Not only is the prediction based on the seemingly pessimistic assumption that the expected life of vehicles scrapped through the VAVR program will be only 2 years, perhaps much more important is the fact that at least four of our maintained assumptions tend to make the model err to the side of underpredicting emissions reductions. In particular, we have made the following assumptions:\(^9\)

- The program attracts the same proportion of LDVs of each eligible model year despite the availability of more emissions-reduction credits for scrapping older LDVs, which should translate into higher bounties for increasingly old, and generally dirtier, LDVs.
- Vehicles sold to the program are no dirtier than other vehicles of the same vintage despite the fact that the program may attract LDVs with above-average emissions for their age, for the same reason (i.e., lower value to their owners) that the program should be expected to attract vehicles with lower-than-average expected lives.
- Older vehicles are as prone to migrating into the South Coast as newer LDVs despite the fact that distance-sensitive transactions costs are likely to be higher for older LDVs.
- Total vehicle miles traveled (VMT) by LDVs in the South Coast will be unaffected by the program despite the fact that the program will reduce the number of LDVs in the South Coast.

Thus, we believe that the actual South Coast emissions effects of the program in 2010 are likely to be closer to 28 tons per day (the top of our credible range) than to 8 tons per day (the bottom of the range).

\(^2\)Based on an average used-LDV price of $6,500, which is assumed in developing the high end of the credible ranges for price effects.

\(^8\)For example, a price effect of $295 would represent almost a 50 percent increase in our estimated average price of $600 for age-eligible LDVs.

\(^9\)None of these assumptions affects our price-effect predictions.
8. COST EFFECTIVENESS OF THE VAVR PROGRAM

Programs to improve air quality are often assessed and compared in terms of cost per ton of emissions reduction. Such cost-effectiveness ratios are used as a convenient summary measure of program costs relative to benefits. In the case of ozone precursors—reactive organic gases and oxides of nitrogen—emissions are typically measured simply by adding tons per day of reductions in the two types of pollutants.

Such cost-effectiveness ratios are often claimed and widely believed to provide an accurate indication of economic efficiency consequences. They are useful, but they are not without their pitfalls. First, tons of ROG plus NOx avoided can provide a very inaccurate indication of ozone reduction, no less of the health and other benefits sought by such programs. Second, it is often not possible to quantify and incorporate into the ratio other important social costs and benefits of a program, for example, concurrent reductions in pollutants other than ozone precursors. Third, the economic efficiency criterion ignores distribution of costs and benefits across income groups or regions, for example, which can be important policy considerations. Finally, in practice, cost-effectiveness analyses are often poorly implemented because of misunderstandings about the conceptual foundations of economic efficiency.

Conceptually, the relevant costs are resource costs, which are the social values of the resources consumed because of a program. Often, however, costs that are considered in a cost-effectiveness analysis are financial or budgetary costs. Moreover, because costs and benefits accrue over different time periods and with different time patterns, for a cost-effectiveness ratio to be meaningful, costs and benefits must be expressed in comparable units. The standard way of making them comparable is by discounting both costs and benefits to present value.

In this section we use our predicted effects of the program to analyze the cost effectiveness of scrapping 75,000 vehicles per year between 2001 and 2010. We also compare our estimates—conceptually and numerically—to previous cost-effectiveness estimates of the MI program and to estimates for other programs adopted to reduce ozone in the South Coast.

The resource costs of the VAVR program would include:

- administrative costs of the program including those associated with advertising, and inspecting, processing, and disposing of the vehicles,

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1For a discussion of these issues in the context of programs to reduce emissions of ozone precursors from light-duty vehicles, see Dixon and Garber (1996, pp. 27–31).

2Discounting environmental benefits is controversial, but standard economic reasoning implies that benefits that accrue further in the future are, in fact, less valuable than benefits that accrue sooner, other things equal.
the costs of monitoring and enforcing compliance with program rules, and
the economic value of the vehicles destroyed net of any salvage value.

The economic value of the vehicles destroyed is the most subtle, most misunderstood, and
perhaps the most important element of the calculation. Conceptually, what we want to measure
is the social value of the transportation services lost when a serviceable vehicle is destroyed.
Principles of economic-efficiency analysis suggest that this be measured by the value that the
owner places on the vehicle, or equivalently, the amount of money the owner requires to
surrender the vehicle, or the owner’s "willingness to accept." "Costs of the vehicles" in a VAVR
program are often misconceived in terms of financial costs, namely the purchase prices or
bounties paid for the vehicles. But since program participation is voluntary, purchase prices will
typically exceed the values of the vehicles to the owners who surrender them for scrapping. The
difference between the bounty received and the minimum amount that the owner would have
been willing to accept is a surplus benefit received by the seller. This surplus is not a component of
resource cost—it merely represents a transfer of value from the purchaser to the seller.

The social values of the scrapped vehicles cannot be predicted with precision. We attempt
to gauge them by using empirical information about purchase prices in VAVR programs and the
extent to which purchase prices may exceed willingness to accept.

Recent small-scale scrapping programs in the South Coast have purchased vehicles for
between $500 and $600. Alberini, Edelstein, Harrington, and McConnell (1994) report bounties of
$500 in a small-scale program in Delaware. However, purchase prices in the M1 program are
likely to be higher than these prices because of the somewhat stringent eligibility requirements,
the need to attract many more vehicles per year, and the fact that the program will tend to
increase used-LDV prices (by $66 according to our base-case estimates).

Kavalec and Setiawan (1997) provide evidence about bounty levels that is more pertinent
to the SIP M1 program. Using an econometric model of vehicle choice by California households,
they estimate required bounty levels of $785 in 1999 increasing to $965 in 2010 to attract 75,000
vehicles (at least 10 years old) per year in the South Coast. In its analysis of the cost effectiveness
of the VAVR program, CARB (1998a) considers purchase prices of $400, $600, and $800 per
vehicle. The basis for these values is not discussed, but presumably this is the range that CARB

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4 A CARB 1,000-vehicle pilot program in the South Coast paid $500 per vehicle (personal
communication with CARB staff, October 2000). Firms participating in the South Coast Air
Quality Management District's VAVR program have paid up to $600 per vehicle. (Satzman, 1997).
5 Sierra Research (1995) assumes a cost of $1,000 per vehicle, including administrative,
testing and disposal costs. In addition, BAR's Consumer Assistance Program (described in
Section 1) plans to purchase vehicles for $1,000 each (California Department of Consumer Affairs,
2000).
staff considered likely. Administrative costs are often assumed to be $100 per vehicle (see CARB, 1998a, p. 34; and Alberini, Edelstein, Harrington, and McConnell, 1994).

The surplus gained by each vehicle seller must be subtracted from the purchase price to estimate the social value lost by taking a vehicle out of service. Estimates of this surplus from a small pilot program and a large-scale, hypothetical program range from about 25 to 40 percent of the purchase price.\(^6\)

In the face of this uncertainty about program costs, we proceed by specifying a plausible range for the resource costs per vehicle purchased by the program. This range is $500 to $1500. We think it very unlikely that the resource cost per vehicle will be below $500. Current small-scale programs are already paying more that this, and the purchase prices are expected to be higher in the SIP M1 program. Surplus to the sellers may account for as much as $125 to $200 of a $500 purchase price, but it will be largely offset by $100 for administration, testing, and disposal. We also think it very unlikely that the resource costs will exceed $1,500 per vehicle. For example, for resource costs to exceed $1,500, purchase prices would have to exceed $2,000 if sellers’ surplus accounts on average for one-third of the purchase price, and administrative, testing, and disposal costs amount to $100 per vehicle. Purchase prices as high as $2,000 seem very doubtful in light of the estimates of Kavalec and Setiawan (1997) and our high-end estimate of price effects of $295 (see Table 7.3). Resource costs of $1,000 per vehicle appear to be a good ballpark estimate.

Table 8.1 combines three resource cost estimates with three estimates of the South Coast emissions effects of the program, namely, the estimates resulting from parameter values used in our base case and in our development of credible ranges.\(^7\) Because benefits of the program continue after 2010, emissions reductions through 2020 are included in the calculations. Both costs, which cease to accrue after 2010, and emissions reductions are discounted to present value in 1999 using an annual discount rate of 4 percent.\(^8\)

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\(^6\)Alberini, Harrington, and McConnell (1994) estimate willingness to accept from a survey of participants in a small-scale program in Delaware and estimate that the total surplus to program participants was about 23 percent of purchase payments. Hahn constructs a supply curve of vehicles to a hypothetical scrapping program and infers a range of 26 to 40 percent (Hahn, 1995). See Dixon and Garber (1996, p. 174) for discussion.

\(^7\)We do not include predicted emission reductions due to the program in the rest of California because the primary purpose of the VAVR program is to reduce emissions in the South Coast. The benefits outside the South Coast are an example of the kind of benefits that are relevant for policy but are often not incorporated in calculated cost-effectiveness ratios.

\(^8\)Discount rates of 3 to 5 percent have commonly been used in calculating the cost effectiveness of emissions-reduction programs for light-duty vehicles (see Dixon and Garber, 1996, p. 263).
Table 8.1
Cost Effectiveness of Scrapping 75,000 Older Vehicles
per Year from 2001 to 2010 in the South Coast
(dollars per ton of ROG plus NOx, 1999 dollars)a,b

<table>
<thead>
<tr>
<th>Effect of Program on Emissions</th>
<th>Resource Cost ($/vehicle)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Top of credible range</td>
<td>3,700</td>
</tr>
<tr>
<td>Base case</td>
<td>6,700</td>
</tr>
<tr>
<td>Bottom of credible range</td>
<td>11,100</td>
</tr>
</tbody>
</table>

a Costs and emissions reductions discounted using a real discount rate of 4 percent.
b Includes emissions effects through 2020.

Assuming resource costs of $1,000 per vehicle, costs for the entire 10-year VAVR program are estimated to range from $7,500 to $22,200 per ton. The cost-effectiveness ratios are proportional to the assumed cost per vehicle. For example, costs per ton fall by 50 percent when resource costs are assumed to equal $500 per vehicle and increase by 50 percent when resource costs are assumed to be $1,500 per vehicle.9 Thus, the figures in Table 8.1 can be easily adjusted to consider the consequences of other assumptions about resource costs per vehicle scrapped through the VAVR program.

The predicted emissions effects of the program increase and then decrease over time. Moreover, the LDV fleet is projected to become cleaner over time in terms of emissions per mile. How does the predicted cost effectiveness of the program change over time? Assuming base-case parameter values and resource costs of $1,000 per vehicle, cost effectiveness for the first year of the program (2001) is estimated at $10,200 per ton compared with $13,400 per ton for the 10-year program (Table 8.1).10 And, while a decision need not be made any time soon about extending the program beyond 2010, our estimates suggest that the cost per ton of extending the program by one year (namely, through 2011) would be $17,400 per ton.11

As detailed presently, our estimates of cost per ton are somewhat higher than those reported by others who have considered variants of the SIP M1 program. Numerical comparisons

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9 Cost-effectiveness results are not very sensitive to varying the discount rate from 3 to 5 percent. For example, using base-case emissions reductions and resource costs of $1000 per vehicle results in cost-effectiveness ratios of $13,328, $13,421, and $13,515 when discount rates of 3, 4, and 5 percent are used, respectively.
10 Cost effectiveness in the first year is calculated by simulating the emissions effects of a program that lasts only one year (2001).
11 Cost per ton of extending the program one year is calculated using the present values of the incremental costs and incremental emissions reductions of a program operated from 2001 through 2011 rather than from 2001 through 2010.
should be made cautiously, however, because of differences in the features of the programs being studied, what effects of the program are considered, and how cost effectiveness is defined. Reported estimates of cost effectiveness range from $4,200 to $6,700 per ton of ROG plus NOx in Kavalec and Setiawan (1997) for a program that scraps 75,000 vehicles (10 years old and older) from 1999 through 2010.\textsuperscript{12} Several factors reduce their cost-per-ton estimate relative to ours: administrative, testing, and disposal costs are not included; they do not allow for any increases in used-LDV prices because of the program; emissions benefits are not discounted; and emissions reductions are calculated assuming that the Smog Check program is wholly ineffective. They do not net out seller surplus, however, and this tends to increase their cost-per-ton estimate relative to ours. Sierra Research (1995) calculates a cost-effectiveness ratio of $8,200 per ton for a similar-sized program.\textsuperscript{13} CARB’s estimates range from $2,600 per ton to $7,600 per ton for a range of purchase prices plus administrative costs of $500 to $900 (CARB, 1998a).\textsuperscript{14} CARB, however, considers cost effectiveness only for vehicles purchased in 1999, which conceptually corresponds most closely to our estimate of cost effectiveness in the first year of the program ($10,200 per ton).

What do our estimates suggest about the attractiveness of implementing the SIP M1 program? First, our analysis suggests the cost effectiveness of the program will be similar to that of many already implemented elements of the ozone-reduction strategy for light-duty vehicles in California. More specifically, Table 8.2 reports cost-effectiveness ratios calculated for several other elements of California’s strategy as Garber and Dixon (1996) were best able to determine in 1996 from a review of existing studies, synthesis, and further modeling.\textsuperscript{15} As can be seen by comparing Tables 8.1 and 8.2, even our highest cost-per-ton estimate of $33,300 for the VAVR program (Table 8.1) is below the high end of the ranges for many of the existing programs in California’s strategy (Table 8.2).

Second, and much more important for policy purposes, the cost effectiveness of the VAVR program is likely to be quite good relative to other still-available options for reducing emissions of ozone precursors in the South Coast. In particular, the

\textsuperscript{12} This range is for estimates using discount rates of 3 and 6 percent. Kavalec and Setiawan (1997) also simulate effects of a program restricted to vehicles at least 20 years old, but this program involves scrapping fewer than 40,000 vehicles per year through 2006, making those results especially difficult to compare with ours. (See Kavalec and Setiawan, 1997, Table 10.)

\textsuperscript{13} This estimate does not discount costs or emissions, and does not net out seller surplus. It also assumes that the LDVs purchased by the program are “high emitters.”

\textsuperscript{14} CARB does not discount emissions and includes sellers’ surplus in its cost estimates.

\textsuperscript{15} The figures in Table 8.2 are expressed in 1995 dollars. To make them more comparable with the cost-effectiveness estimates in Table 8.1, which are expressed in 1999 dollars, they could be increased by about 9 percent. (This is the 1995 to 1999 increase in the Consumer Price Index—All Urban Consumers. Source: Bureau of Labor Statistics, data accessed from http://146.142.4.24/cgi-bin/surveymost on March 21, 2000.)
programs that have already been implemented are projected to leave California far short of meeting federal and state clean-air goals, and the SIP commits California to identifying and implementing additional measures to reduce LDV emissions in the South Coast.\textsuperscript{16} The key policy question is whether a VAVR program should be among the policy measures to be implemented in the future. Our estimates suggest that the answer is yes because options for the future are likely to be less cost effective than programs that have already been implemented and, thus, less cost effective than a VAVR program. Specifically, while it is hoped that new technologies and additional creative thinking will provide California with attractive new options for reducing emissions of ozone precursors, it is important to recognize that the programs that have already been implemented are by and large those politically feasible programs that have been identified and have appeared to be most cost effective to date.\textsuperscript{17} Thus, it seems unduly optimistic to base policy on a presumption that air-quality goals for 2010 can be met with programs that are more cost effective than the VAVR program appears to be.

Not only does it seem likely that a VAVR program would be more cost effective than other programs that may be required to achieve compliance with air-quality regulations, the program also looks reasonably attractive in terms of economic efficiency. Specifically, our cost-per-ton estimates in Table 8.1 are in the general range of estimates of the social benefits per ton of reducing ROG and NOx emissions in the South Coast. For example, Dixon and Garber (1996, pp.

\textsuperscript{16}For example, CARB's State Implementation Plan for Ozone contains a "Black Box" for mobile-source emissions reductions in the South Coast Air Basin from programs that are yet to be identified. After adoption of the LEV II program in 1998, CARB estimated that 43 tons per day remain in the Black Box (CARB, 1998b, pp. 1–2).

\textsuperscript{17}Many economists favor policies that discourage pollution through altered prices such as emission-based vehicle registration fees (Harrington, Walls, and McConnell, 1995), or taxes on gasoline, engine size, or vehicle age (Fullerton and West, 1999). No matter what the merits of such policies, it seems that they are not being seriously considered for implementation in California because they are anticipated to be very unpopular.
21–22, 364–370) concluded from a review of existing literature that benefits of reducing ROG and NOx emissions in the South Coast are likely to exceed $5,000 per ton, perhaps by a substantial amount, but are probably less than $25,000 per ton.\textsuperscript{18} Only under rather pessimistic assumptions do our estimates of cost-per-ton for the VAVR program in Table 8.1 exceed $20,000, and our base-case estimates of emissions effects combined with our best guess of resource costs of $1,000 per vehicle imply a cost per ton of $13,400.

In sum, our analysis suggests that the planned VAVR program—or an improved variant of it—is an attractive means for promoting air quality in the South Coast despite the fact that it may be somewhat optimistic to expect emissions benefits as large as the 25 tons per day in 2010 projected in California’s SIP for Ozone.

\textsuperscript{18} These figures are expressed in 1995 dollars. They should be increased by about 9 percent to make them comparable with figures in Table 8.1.
9. LESSONS FOR POLICYMAKERS

In this concluding section, we summarize our findings and discuss implications for policy choices that will be made in the near term. We begin by summarizing our quantitative conclusions and briefly recapping some more general lessons. Then we discuss implications of our analysis for the magnitude and distribution of economic burdens resulting from program-induced increases in used-LDV prices. We then comment on options for improving the design of the VAVR program before it is implemented. Finally, we discuss the fact that the program is not currently funded and could become a political casualty.

PREDICTED PROGRAM EFFECTS: SUMMARY

Two frequently mentioned concerns about the effects of the voluntary accelerated vehicle retirement (VAVR) program planned for California’s South Coast stem from uncertainty about how markets for light-duty vehicles (LDVs) will respond to implementation of the program. Specifically, it is difficult to anticipate the degrees to which

- prices of used vehicles will increase, and
- potential emissions benefits will be attenuated by migration of vehicles into the South Coast.

Developing reliable quantitative information about these issues requires an analytic framework that explicitly represents the determinants of market reactions to the program and rigorously develops empirically grounded predictions. Our study is the first to analyze the SIP M1 measure using such a framework. While our analysis has limitations, our quantitative predictions of price effects are the first to be developed from a market analysis, and our predictions of emissions effects are the first to take explicit account of in-migration.

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1 Besides the inherent limitations of analyzing such complex phenomena using market models that are aggregated over vehicles within vintages and over large geographic areas, several possibly important phenomena are not addressed in our analysis. For example, we have not analyzed the following: the extent to which increased prices of used vehicles might lead to increased maintenance and extended vehicle lives; how differences in emission credits by age of vehicle scrapped would affect the vintage-composition of participating vehicles; whether the program might lead owners to avoid scrapping LDVs that are almost old enough to qualify for the program, so that they can eventually be scrapped through the program; the sensitivity of our predictions to deviations from CARB’s estimates of emission rates for vehicles of various model years in various calendar years; or the extent to which total vehicle miles traveled by LDVs in the South Coast might decline due to decreases in vehicle stocks and higher implicit costs of operating vehicles when vehicle prices are higher.
We analyzed a VAVR program that, during each year from 2001 and 2010, retires 75,000 South Coast LDVs that are at least 15 years old. For the base case, we predict (see Table 6.1) that as a result of implementing the program, prices of used LDVs in 2010 will be $66 higher per vehicle and South Coast emissions of ozone precursors—reactive organic gases (ROG) and oxides of nitrogen (NOx)—will be lower by 13 tons per day. These predicted emissions reductions are substantial, but only about one-half as large as the target of 25 tons per day in 2010 incorporated in the State Implementation Plan (SIP) for Ozone. The emissions effects are likely to be larger than 13 tons per day in 2010, however, because (as enumerated at the end of Section 7), at least four of our assumptions tend to underpredict emissions effects.

We also analyzed the pattern of these program effects over time. (See Figures 6.1 and 6.4.) Predicted program effects on both used-LDV prices and emissions in the South Coast increase over time during the first five of the ten years during which the program operates (2001 through 2005), decrease gradually over the next five years, and decrease rapidly after the program is discontinued. In the base case, the largest predicted effect on used-LDV prices is $79 per LDV in 2005 and 2006, and the largest predicted effect on South Coast emissions is 18.8 tons of ROG plus NOx per day in 2005. Effects on used-LDV prices and emissions are largely eliminated by 2013 (Figures 6.1 and 6.4).

But any single set of estimated price and emissions effects, such as those just summarized, is subject to considerable uncertainty. Estimates of the ranges in which program effects can be confidently expected to fall are much more informative for policy purposes. To provide such information, we developed what we call “credible ranges” for effects of the program. (See Table 7.3.) While we cannot attach a precise quantitative probability statement to these ranges, we believe it highly likely that the true effects of the program will fall in these ranges. Our credible range for the effect of the program on used-LDV prices in 2010 is $22 to $271 dollars per vehicle. Our credible range for South Coast emissions reductions in 2010 is 8 to 28 tons per day, although we expect the actual emissions effects to be closer to 28.

Thus, our estimates indicate that—despite attenuation by vehicle migration into the South Coast—the planned VAVR program would result in substantial emissions benefits, albeit perhaps short of the SIP target of 25 tons per day in 2010. But would these emissions reductions be worth their cost to California? To examine this issue, we considered the cost per ton of emissions reductions of ROG plus NOx and developed a credible range for this cost-effectiveness ratio. These calculations include resource costs of the program over its entire history (2001 through 2010, after which time costs cease to accrue) and emissions reductions through 2020.

Our credible range for cost per ton of emissions reduction is $3,700 to $33,300. (Table 8.1.) These values compare favorably with cost-per-ton estimates for many elements of California’s
strategy for reducing emissions from LDVs that have already been implemented (Table 8.2). Much more important, they are likely to compare favorably with still-available options for further reducing emissions in the South Coast, some of which will have to be implemented for California to meet its air-quality goals for 2010. Moreover, comparing our credible range of cost per ton for the VAVR program with available dollars-per-ton estimates of the social (health and other) benefits of reducing South Coast emissions of ozone precursors suggests that the VAVR program may also be well worth the costs. Thus, the VAVR program for improving air quality in the South Coast appears attractive even on economic efficiency grounds.

In sum, our analysis leads us to conclude that the planned VAVR program is likely to be a very worthwhile part of California’s effort to improve air quality in the South Coast.

MORE GENERAL LESSONS ABOUT VAVR PROGRAMS

Our quantitative analysis focuses on the case of a particular VAVR program modeled on the one planned for the South Coast. For example, the program involves scrapping 75,000 South Coast LDVs per year for 10 years, with eligibility rules requiring vehicles to be at least 15 years old, in reasonably good condition, and not out of Smog Check compliance. Our quantitative estimates cannot be applied directly to programs that differ substantially in terms, for example, of size, duration, location, and vehicle-eligibility requirements. But our analysis provides several general, albeit non-numerical, lessons about the effects of large-scale VAVR programs that operate for several years.

These lessons include the following:

- Increases in prices of used vehicles will be spread across the spectrum of vintages.
- Migration of vehicles into the region where the program operates will also be spread across the spectrum of vintages.
- Price and emissions effects will increase during at least the early part of the period during which the program operates.
- Price and emissions effects will tend to stabilize over time and may even decrease during later years of program operation.
- Price and emissions effects will persist for some time after the program ceases operating.
- Increases in prices of used vehicles will tend to increase sales of new vehicles.
- Price and emissions effects will be felt outside the region in which the program operates.
DISTRIBUTION OF COSTS DUE TO PRICE INCREASES

Potential price effects of the program have received policy attention primarily because of concerns that price increases could be very large, and that the costs would fall primarily on low-income households. A key reason for concern about effects on low-income households is a somewhat widespread sense that price effects of the SIP M1 program will be largest for—or even isolated to—particularly old vehicles, for example, vehicles old enough to qualify for scrapping through the VAVR program.

Our analysis indicates that price effects will not be nearly as large as some have suggested\(^2\) and many seem to fear, and that they will not be isolated to particularly old vehicles. Concerns about low-income households bearing the brunt of price effects cannot be dismissed, however. While there is good reason to believe that the program will tend to increase the prices of used vehicles of all vintages by the same dollar amount, any such increase would represent a larger percentage of price for vehicles with lower market values. The high end of our credible range of price effects (in 2010) is $271, which is about 5 percent of our estimate of the average price of a used California LDV of $5,500. But a $300 increase in price could be substantial relative to the wealth or income of many households or individuals.

What households or individuals would actually be harmed if prices of all used LDVs were to increase by the same amount? A little bit of analysis suggests an answer that may be surprising. In particular, price increases will hurt individuals who

- do not own a vehicle, but want to buy a used one,
- want to increase the number of used LDVs they own, or
- own a vehicle and plan to drive it until it is ready to be scrapped and then replace it with a used vehicle.

What about individuals—no matter their income levels—who own vehicles that they will sell rather than scrap? They would not be hurt by across-the-board price increases because the extra amount they will have to pay as buyers should be similar to the extra amount they will receive as sellers.

Thus, the incidence of costs due to increases in used-LDV prices is a more subtle issue than many discussions suggest. The degree to which the price effects of the program are concentrated among low-income households depends on the degree to which individuals or households who want to buy a used vehicle without selling one are concentrated within low-income groups. Undoubtedly, many of the individuals or households who will be harmed have low incomes. But

\(^2\)For example, in this context, Moyer, Pera, and Wool (1995, p. 20) allude to the possibility that program costs of buying vehicles could rise from $1000 "to $2000 and may even reach $3000."
it also seems clear that some low-income households will not be harmed because they will own—and eventually resell—vehicles whose values will increase because of the program. Moreover, costs will also be borne by higher-income individuals who plan to drive their vehicles into the ground and people of all incomes who have yet to purchase their first vehicle, e.g., young people.

POTENTIAL FOR IMPROVING PROGRAM DESIGN

Our analysis has focused on a particular version of a VAVR program for the South Coast based on the rules adopted by CARB. (See CARB, 1998a.) We have concluded that this version looks promising. An improved version of the planned program would, of course, be even more attractive.

Some features of the program have yet to be determined, and there is still time to modify features that have already been adopted as regulations. Reconsideration of vehicle-eligibility rules could be worthwhile. Two aspects of the eligibility rules that appear problematic involve requirements regarding a vehicle’s physical condition and its Smog Check status.

Regarding a vehicle’s physical condition, the program has extensive functional and equipment requirements for eligibility.\(^3\) We have characterized these as requiring the vehicle to be in “reasonably good condition.” The apparent purpose of these requirements is to reject vehicles with quite short expected remaining lives. This is an important objective; however, the requirements can provide incentives for owners to repair vehicles or add equipment so that the vehicle can be promptly scrapped. While incentives for such responses are difficult to avoid, the responses would create pure economic waste. It may be worthwhile, then, to review the functional and equipment eligibility requirements with such potential waste in mind and, perhaps, to eliminate requirements that may be unimportant or redundant given the others for predicting expected remaining vehicle life. Another potentially attractive response would be to deduct estimated costs of repairs necessary to meet eligibility requirements from the bounties paid for vehicles; this would eliminate incentives to repair vehicles just before they are destroyed.

Perhaps more important are the current eligibility rules involving a vehicle’s status regarding the Smog Check program. As described in Section 1, current VAVR program criteria exclude from eligibility vehicles that are not in good Smog Check standing or whose next inspection is due within 90 days.\(^4\) The reasons for these requirements are discussed by CARB (1998a, pp. 5, 8-9). Appropriately, CARB seeks to avoid double-counting of benefits for SIP accounting purposes and not to attribute to the VAVR program emissions reductions that are actually attributable to the Smog Check II program. The Smog Check II program, which is

administered by the Bureau of Automotive Repair (BAR), has a scrapping option for some vehicles that fail inspection.\textsuperscript{5} As a result, it seems, CARB decided to design the M1 program to exclude vehicles that might be eligible for scrapping through the BAR program.

Although this exclusion of relatively dirty vehicles from the M1 program will undoubtedly simplify emissions accounting, it may also greatly compromise the fundamental policy goal: improving air quality. We fear that this is a case of the SIP-accounting tail wagging the air-quality dog. In particular, the M1 eligibility rule may prevent many dirty vehicles that would not be scrapped because of Smog Check II requirements from being removed through the M1 program.\textsuperscript{6} Moreover, relaxing this requirement could save resource costs attributable to inspecting and repairing vehicles that are about to be scrapped.

In fact, there can be major advantages to designing Smog Check and vehicle scrapping programs to work in concert. For example, Dixon and Garber (1996, pp. 193–194) argue that a desirable function of a VAVR program is to provide an outlet for vehicles whose market values are depressed by failure to pass Smog Check. The current VAVR program rules attempt to eliminate this outlet. While it is well-appreciated that there are major pitfalls to eliminating relatively clean vehicles from program eligibility,\textsuperscript{7} eliminating relatively dirty vehicles from program eligibility could be counterproductive.

**MOVING FORWARD**

We have concluded that the planned M1 VAVR program looks attractive as a policy option, and that modifying some features of the program could make it even more attractive.\textsuperscript{8} But funding for the program has not been established, and program implementation is very much in doubt. The amount required annually to buy emissions credits created by scrapping 75,000 LDVs is on the order of $100 million.

\textsuperscript{5}This is the vehicle-scrapping component of the Consumer Assistance Program described in Section 1.

\textsuperscript{6}The proposition that the Smog Check II program will eliminate from the fleet almost all especially dirty LDVs—by inducing vehicle repairs, by scrapping through the BAR program, or by Smog Check II enforcement and consequent inability of owners to register failed vehicles—seems optimistic given the disappointing history of vehicle inspection and maintenance programs in California and elsewhere.

\textsuperscript{7}The concern is the creation of incentives to tamper with vehicles to make them dirty enough to qualify for a bounty. See, for example, Alberini, Edelstein, Harrington, and McConnell (1994), and Dixon and Garber (1996, p. 193).

\textsuperscript{8}It is also important to remember that modifying program features in various ways could also make it less attractive.
Impediments to establishing funding for the program include lingering bad feelings from the history of the adoption of the VAVR program as an element of the 1994 SIP for Ozone\textsuperscript{9} and the fact that allocating tax dollars to the program could be politically costly. Regarding the latter, many other elements of California's strategy for reducing emissions of ozone precursors from LDVs do not require allocation of much public money.\textsuperscript{10} Such measures are implicitly, and much less visibly, financed through price increases for gasoline and new LDVs borne by consumers and through lost profits borne by stockholders. These are examples of so-called hidden taxes, which have the political advantage of not requiring explicit allocations of public monies that have obvious opportunity costs, namely, reductions in public spending on other programs or foregone tax cuts.\textsuperscript{11}

These difficulties suggest that the M1 program may suffer a political death. If the program is not implemented, the SIP will have to be revised to replace the VAVR program with one or more other policy measures projected to reduce emissions by 25 tons per day in 2010. Moreover, even if the VAVR program is implemented, additional measures will be required to achieve compliance with federal air-quality standards by 2010 or even several years later.\textsuperscript{12} It is very likely that measures less promising than the VAVR program will be implemented whether the VAVR program is implemented or not.

The air-quality problem in the South Coast is real, and important policy decisions will be made over the next few years to address this problem. The VAVR program is likely to be more cost effective than other alternatives for further improving air quality, and it may even be economically efficient. If the VAVR program is not implemented, the health and wealth of Californians may suffer.

\textsuperscript{9}The M1 VAVR program replaced a measure proposed by CARB staff to provide incentives "to purchase large numbers of vehicles meeting or exceeding ultra-low emission standards, zero-emission vehicles, and hybrid electric vehicles," which was opposed by "a broad-based coalition of businesses and industries lead [sic] by the Western States Petroleum Association (WSPA) and the California Chamber of Commerce" (CARB, 1998a, p. 4). CARB has maintained pressure on the coalition to solve the funding problem: "No new additional funding sources have been secured or even identified by the coalition of M1 program advocates. As a result, there is currently no funding to purchase emission reductions to meet M1 program goals during the 2000–2010 time frame" (CARB, 1998a, p. 7).

\textsuperscript{10}These include reformulated gasoline, tighter emission standards for new vehicles, and the zero-emission vehicle mandate. See, for example, Dixon and Garber (1996) or Dixon, Garber, and Vaiana (1996).

\textsuperscript{11}However, BAR's Consumer Assistance Program, described in Section 1, does involve spending state money to promote air quality by scrapping vehicles.

\textsuperscript{12}As described in Section 8, the SIP includes a "Black Box" projecting emissions reductions from programs that are yet to be identified. Compliance in the South Coast by 2010 is hardly assured, and any newly identified programs or technologies that could further reduce emissions at reasonable cost could be viewed as "already spoken for."
APPENDIX

ESTIMATING THE AVERAGE PRICE OF USED VEHICLES IN CALIFORNIA

Collecting price data for a vehicle model for several model years from the Kelley Blue Book (KBB) website is time consuming. It was not feasible to collect prices for all models for all model years because more than 350 different models of LDVs were sold in the U.S. during the relevant time period (late 1970s through 1997). Because we wanted to incorporate price information for as many California LDVs as possible—given the number of models for which price data were to be collected—we focused on LDV models with relatively high sales levels during any of the calendar years 1985, 1990, or 1995.2

The KBB database does not include prices for LDVs older than 20 years; we collected information for model years back to 1978. To extract a trade-in (or a retail) price quote from the website for a selected model and model year, one must supply several pieces of information in addition to model, model year, vehicle condition, and type of price—among these is the zip code of the location of the vehicle. We used a Los Angeles zip code. We had been told by KBB personnel that doing so would yield prices specific to California, but experimentation indicated that quoted prices did not differ across zip codes for the Rocky Mountain states and westward.

To extract a price, one also must specify accumulated mileage (odometer reading) and information about features of the vehicle, such as number of cylinders, number of doors, and the presence or absence of various types of optional equipment. For mileage, we specified the average accumulated mileage (rounded to the nearest 1,000 miles) for a California vehicle of the relevant age (given the model year) using data from CARB, which distinguishes cars and light-duty trucks.

1After exploring potential sources of data on used-LDV values, we identified Kelley Blue Book as the most appropriate source because their price data are distinguished on a geographic basis and include information for western states. We attempted to obtain price data in machine readable form, but personnel at Kelley Blue Book reported to us that no datasets (flat files) suitable for our purposes exist and that the best way to collect the data was one price at a time from their website.

2Historical data on California LDV sales by model are not available, so we used national sales figures from the annual Market Data Book published by Automotive News to identify models with high sales levels. (Sales figures by model are not available for imports for the early 1980s.) All of the 82 models for which we collected trade-in price data had at least 0.5 percent of national sales in one of the three years. (There are 122 models that meet this criterion; the 82 are those for which the procedures described below enabled us to collect consistent data over several model years.)
We developed rules for specifying features for a vehicle model, and for each model we collected prices for as many model years of the model as possible while consistently specifying the same values for the following major features: engine size (one in the middle of the range),\(^3\) transmission (always automatic); number of drive wheels;\(^4\) number of doors (always four for cars and two for trucks); air conditioning (always yes); and truck bed size (one in the middle of the range).\(^5\) For other features of the vehicle, we used default values supplied by the website software.

This procedure yielded data on western U.S. trade-in prices for vehicles in good condition for 82 models for various sets of model years as far back as 1978.\(^6\) First we averaged prices of different models for the same model year over models using national\(^7\) (calendar year) sales of each model as weights.\(^8\) We then averaged the model-year average prices\(^9\) over model years using as weights the proportions of LDVs in the South Coast of different model years. The result was $4,218, which represents the average \textit{trade-in} price of vehicles in good condition for model years 1997 and older as of December 1998 to January 1999.

To gauge how much higher than $4,218 the average price of used LDVs in California might be, we also collected KBB \textit{retail} price quotes for 20 models selected from among the 82 models for which we collected trade-in prices. The 20 models were selected to include cars, trucks, vans, and sport-utility vehicles. We compared the retail price series to the corresponding trade-in price series for the 20 models, computing ratios of retail to trade-in prices for each model and model year. The average ratio is about 1.5 for the 1997 model year. It increases almost linearly with age.

\(^3\)For models with only two engine-size choices, we alternated using the larger size if a smaller size had been chosen for the previous model for which such a choice had to be made, and vice versa.

\(^4\)When there was a choice between two- and four-wheel drive, we alternated; e.g., we chose four-wheel if we had chosen two-wheel for a model the last time such a choice was available.

\(^5\)When there were only two choices we alternated in a fashion similar to that used for engine sizes and number of drive wheels.

\(^6\)For 15 of the 20 model years we had between 30 and 50 prices to average (more than 40 in most cases); for four model years we had between 20 and 30 prices; and for model year 1978 we had data for only 10 models because data for the 1978 model year were not available after January 1, 1999.

\(^7\)National sales figures are from the annual \textit{Market Data Book} published by \textit{Automotive News}.

\(^8\)The model-year average trade-in prices fell almost exponentially with age. Regression of the logarithm of average trade-in price on a constant and age of vehicle has an \(R\)-square value of 0.97 and a coefficient of age of -0.19—i.e., average trade-in prices decrease with age by about 19 percent per year.

\(^9\)The average for the 1978 model year was $404, and the price-age curve was flattening by age 20, so we used $400 to represent the average trade-in price for all model years before 1978 (i.e., for which we could not collect price data from KBB).
back to model year 1983 to approximately 3.5 and finally stabilizes at about 3.5. To project average retail prices for each model year, we then multiplied average trade-in prices for the model year by the calculated ratio of retail to trade-in price for each of the model years 1984 through 1997 and by 3.5 for all earlier model years. We then averaged these retail prices over model years using as weights the proportions of LDVs in the South Coast of different model years. The result is $7,545, which represents the average retail price of vehicles in excellent condition for model years 1997 and older as of December 1998 to January 1999.
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Fighting Air Pollution in Southern California by Scrapping Old Vehicles
Lloyd Dixon, Steven Garber

This report analyzes the effects of an innovative and controversial program—voluntary accelerated vehicle retirement—that is part of California's plan for complying with federal clean-air standards by the required date of 2010. Under this program, whose implementation is in doubt, during each year from 2001 to 2010 as many as 75,000 light-duty vehicles (LDVs) that are at least 15 years old would be purchased in the greater Los Angeles area and then scrapped. The authors' analysis of program effects accounts for LDV-market responses including increases in used-LDV prices and consequent migration of vehicles into the region where LDVs are scrapped. The analysis predicts that program-induced increases in used-LDV prices will be between $22 and $271 in 2010; the best point estimate is $66 per LDV. While predicted emission reductions are largest for 2005, the program would almost certainly reduce emissions by between 8 and 28 tons per day in 2010, with actual reductions probably closer to the upper end. The authors analyze program cost effectiveness, conclude that a vehicle-scrapping program should be implemented, and suggest ways the program might be improved.