Uncertain Air Quality Impacts of Automobile Retirement Programs

SHI-LING HSU AND DANIEL SPERLING

The increasing cost of additional air pollution control has stimulated a search for less expensive market-based regulatory approaches. One market-based approach widely embraced by regulators and politicians is the accelerated retirement and scrappage of old automobiles. Businesses are granted emissions reductions credits by air quality regulators in exchange for removing old and presumably high-polluting automobiles from the road. In reviewing the data from recent programs and exploring assumptions made in evaluations of such programs, it was found that the air quality benefits are uncertain and may be small and that the costs may be higher than those for many other emission control strategies. In some regions and under some conditions, accelerated retirement programs may be much more effective than in other regions and under other conditions.

The growing cost of additional air pollution control has stimulated a search for more efficient market-oriented policy instruments. One approach is to create a market for emissions, whereby emissions credits can be traded among polluters. An example is the marketable permit program created under the 1990 Clean Air Act Amendments for power plants that emit sulfur oxides; power plant operators earn credits for exceeding pollution performance standards. They may sell these credits to other power plant operators that fall short of performance standards. However most of these programs have not been in existence long enough for meaningful evaluation of their success to be made.

This paper examines a specific marketable permit program for which there are some data and which is simple enough to be analytically tractable: accelerated automobile retirement programs, whereby tradeable credits are issued for the early retirement and scrappage of old automobiles, which are thought to account for an inordinately large portion of total vehicle emissions. Such programs, which currently have great conceptual and political appeal, are thought to be more cost-effective than other strategies and are relatively easy to implement, and it is thought that they will stimulate the economy by increasing the sales of new automobiles.

The benefits of accelerated automobile retirement may be illusory, however. A retired vehicle may have been junked soon afterward anyway or might have sat idle, in which case the emissions benefits of accelerated retirement would be minimal. The poor knowledge of the uses of old automobiles and of the in-use emissions of old automobiles creates so much uncertainty as to make it impossible to predict with confidence the amount of emissions reductions achieved by accelerated retirement programs.

HISTORY

The first accelerated automobile retirement program was carried out in 1990 by the Los Angeles-based Unocal Corporation. The Unocal South Coast Recycled Auto Project (SCRAP) program solicited automobile owners in the South Coast Basin to turn in their old (pre-1971) automobiles for $700 cash. Over a 4-month period Unocal purchased and scrapped 8,376 automobiles. Subsequently other pilot programs have also been carried out, such as the Cash for Clunkers program conducted in 1992 in the Chicago area by the Illinois Environmental Protection Agency (IEPA) and the 1992 Delaware Vehicle Retirement Program conducted jointly by the U.S. Generating Company of Maryland and Resources for the Future. Each of the latter two programs scrapped and studied over 200 automobiles.

ANALYTICAL FRAMEWORK

It is difficult to determine the amount of emissions reduction attributable to such programs. Accurate quantification of the emissions reduction is difficult, given the poor understanding of key economic and social variables involved. Moreover some air quality plans already contemplate some mobile source emissions reductions, so to avoid double-counting emissions reductions, the air quality benefits accruing from accelerated retirement programs must be distinguished from those already assumed to occur under air quality plans (*1*).

To quantify the emissions reductions resulting from an accelerated retirement program, determinations need to be made with a reasonable degree of certainty. (a) How much earlier were the old automobiles retired than they otherwise would have been without the program? (b) How much would the automobiles have been driven if they had not been retired? (c) What were the emissions levels of the retired automobiles? (d) How were the vehicle miles traveled (VMT) of the retired automobiles replaced? (e) How many VMT will occur on the replacement automobiles, when there is one? (f) What will be the emissions levels of the replacement automobiles?

Unocal retained a marketing research firm, Fairbank, Bregman and Maullin (FB&M), to conduct a follow-up survey of SCRAP program participants to investigate these questions. Although the survey provides valuable insight into the answers to some of these questions, it does not answer them conclusively and moreover raises many other questions. The FB&M survey illustrates how difficult it is to make these determinations with certainty. What follows is an analysis of these areas of uncertainty.

How Much Earlier Were Old Automobiles Retired Than They Otherwise Would Have Been Without a Retirement Program?

Quantification of the amount of emissions benefit resulting from an accelerated retirement program requires a determination of the

Institute of Transportation Studies, University of California, Davis, Davis, Calif. 95616.

average remaining life of the retired automobiles at the time they are turned in for early retirement and scrappage. The problem encountered when attempting to make this determination is the lack of knowledge regarding the behaviors of owners of old automobiles. Of the approximately 12 million pre-1974 model year automobiles in the United States, which of them would be turned in under an accelerated retirement program? What conditions make it favorable for automobile owners to scrap their automobiles? A substantial danger exists that accelerated retirement programs will only attract automobiles that were nearing the ends of their natural lives anyway, especially given the modest offer prices of such programs. Predicting which automobiles will be turned in for retirement is thus of paramount importance.

Models of automobile scrappage behavior have been proposed by Parks (*2*) and Manski and Goldman (*3*), but these models are not general enough to serve as the analytical basis for projecting the average remaining lives of old automobiles turned in for early retirement. Alberini et al. (*4*) have carefully studied the Delaware Vehicle Retirement Program and have proposed a model of the determinants of participation in accelerated automobile retirement programs, but their model does not predict the average remaining lives of the automobiles.

Several different approaches have been adopted to deal with this uncertainty, but none of the approaches is satisfactory. The California Air Resources Board (CARB) estimates, using vehicle registration data, that the average remaining life of California automobiles 15 years or older is 6 years (*5*). CARB guesses that the average remaining life of an automobile turned in for accelerated retirement would be roughly half that figure, or 3 years. Although this guess may seem like a fairly sensible assumption, it is not, as CARB admits, supported by data.

Another approach is to use nationwide scrappage rates to calculate the average remaining life of an automobile. The first three columns of Table 1 contain data compiled by Oak Ridge National Laboratory (ORNL) on nationwide automobile scrappage rates for 1978 to 1989 for each automobile age up to 25 years (*6*). The last two columns of Table 1 are calculations of the average remaining life of an automobile at each year of its life and the standard deviation for each year, as derived from ONRL's scrappage and survival data, which are given in columns 2 and 3 of Table 1. Note that the scrappage rate for year 26 is 1.0; this reflects an assumption that all automobiles still in operation after 25 years will thereafter be scrapped.

Note that the standard deviations of the average remaining lives of automobiles are very large in comparison with the averages themselves. For example the average remaining life of a 15-year-old automobile is 4.41 years, but the standard deviation is 3.17 years. This means that roughly two-thirds of all 15-year-old automobiles will be retired between 1.24 years and 7.58 years and that one-third will be retired at times outside that range. Note also that the scrappage rate for year 16 indicates that more than 20 percent of the 15-year-old automobiles were scrapped before the next full year elapsed. Much of this deviation might be explained by variations in the average remaining lives of automobiles across regions of the country. Colder climates tend to shorten the lives of automobiles. However reliable quantitative estimates or means

TABLE 1 Scrappage Rates and Calculated Average Remaining Lives and Standard Deviations for Automobiles, 1979–1989 (*6*)

(1) Age	(2) Scrappage Rate	(3) Survival Rate	(4) Average Remaining Life	(5) Standard Deviation
0	0.00000	1.00000	12.750984	5.048669
1	0.00441	0.99559	11.803035	4.998760
2	0.00674	0.98888	10.876342	4.935570
3	0.01025	0.97874	9.978622	4.857109
4	0.01546	0.96361	9.119612	4.761952
5	0.02303	0.94142	8.311014	4.649729
6	0.03368	0.90971	7.565832	4.521683
7	0.04803	0.86602	6.897099	4.380911
8	0.06629	0.80861	6.315722	4.232107
9	0.08790	0.73753	5.828058	4.080584
10	0.11137	0.65540	5.433148	3.930710
11	0.13460	0.56718	5.122657	3.784369
12	0.15557	0.47894	4.882178	3.640301
13	0.17300	0.39609	4.694290	3.494516
14	0.18650	0.32222	4.541229	3.341420
15	0.19641	0.25893	4.406761	3.174873
16	0.20339	0.20627	4.276573	2.988909
17	0.20818	0.16333	4.138028	2.778059
18	0.21140	0.12880	3.979239	2.537536
19	0.21353	0.10130	3.788115	2.263452
20	0.21493	0.07952	3.551422	1.953197
21	0.21585	0.06236	3.253743	1.606221
22	0.21644	0.04886	2.876286	1.225554
23	0.21683	0.03827	2.395758	0.820545
24	0.21708	0.02996	1.782760	0.412367
25	0.21724	0.02345	1.000000	0.000000
26	1.00000	0.00000	0.000000	0.000000

of estimation of the average remaining lives of automobiles are still necessary and still lacking.

The SCRAP program attempted to eliminate this uncertainty by asking the automobile owners directly. FB&M, in the SCRAP program follow-up survey, asked 800 SCRAP participants how long they believed their automobile would have lasted had they not turned it in for retirement under the SCRAP program (*7*). Nine percent reported that they were planning to scrap their automobiles anyway. Retirement of this 9 percent achieved no emissions reduction. The estimates of the remaining 91 percent of the respondents ranged from "less than 1 year" (11 percent) to "more than 6 years" (26 percent), with a median estimate of approximately 4 years (*7*). FB&M characterized these estimates of the remaining lives of their old automobiles as "optimistic," noting that respondents' estimates were higher than scrappage data would suggest (*7*).

Another method to reduce the uncertainty regarding the remaining life of an automobile is to require a mechanic's assessment of the condition of the automobile and of its expected remaining life (*8*). Although this method adds some objectivity, it has not been validated empirically.

The large standard deviations and uncertainty might not be an insurmountable problem if the sample of retired automobiles were a representative random sample of old automobiles. However retired automobiles will not be a random sample; because the remaining life of an automobile can be expected to vary inversely with the willingness of the owner to give up his or her automobile, there will exist a bias toward automobiles that have a lower-than-average remaining life. This finds support in the study by Alberini et al. (*4*), which found a strong correlation between the expected remaining life and the offer price that would be required to induce owners to give up their automobiles.

Without the statistical convenience of a random sample and given the large variance of the average remaining lives of old automobiles, the ability to predict the kinds of automobiles that will be turned in for early retirement is very poor. More data are needed before an accurate sample mean for the remaining lives of retired automobiles can be determined. Mobile source trading advocates may argue that it is still possible to ascertain an average that represents scrapped cars in the aggregate, but in light of the large uncertainties associated with old automobiles, it is doubtful that even this is possible.

How Much Would Automobiles Have Been Driven If They Had Not Been Retired?

Although the average mileage of automobiles by age is fairly well known, it is not known how much a retired automobile would have been used without the retirement program. Once again the problem is that such programs may attract the wrong automobiles—ones that are driven infrequently.

IEPA, in its 1992 Cash for Clunkers accelerated retirement program, relied upon odometer readings from the state's Division of Vehicle Inspection and Maintenance to ascertain the annual mileages of retired automobiles (*8*). Of the 207 automobiles of model years 1968 to 1979 retired by the Cash for Clunkers program, IEPA was able to obtain reliable manual mileage data for only 122 automobiles; many of the remaining automobiles were used very infrequently or not at all. These 122 automobiles had been driven an average of 7,908 mi during the last year, but the standard deviation was 5,776 mi (*9*). The distribution of VMT for these 122 automobiles is shown in Figure 1. Far from approximating a normal distribution, the irregular distribution shown in Figure 1 suggests that there is little predictability with respect to the VMT of retired automobiles. This irregular distribution, the large standard deviation, and the fact that IEPA was unable to obtain mileage data on almost half of the retired automobiles cast doubt on the usefulness of annual mileage data in predicting the results of future programs.

One way of establishing some reliability in the average annual mileage estimate is to obtain data from multiple sources. The Unocal SCRAP program obtained data on the average annual mileage of scrapped automobiles from three sources: (a) California Bureau of Automotive Repair records of smog inspections, (b) estimates from the CARB EMFAC-7E vehicle activity model, and (c) the FB&M telephone survey of SCRAP program participants (*10*). The smog records yielded an average annual mileage estimate of 5,689 mi, whereas the EMFAC-7E model projected the average annual mileage to be 5,368 mi. Telephone survey results varied significantly from those two projections, estimating an average annual mileage of 6,940 mi. The SCRAP program used an average of the first two estimates, yielding an average of 5,528 mi/year. Obtaining data from multiple sources, however, may not always be possible or practicable.

The South Coast Air Quality Management District (SCAQMD) is using a different approach in its Rule 1610 on vehicle scrapping (*11*). On the basis of CARB's BURDEN 7C vehicle activity model it simply assigns an annual mileage figure for each scrapped automobile on the basis of its model year, as follows:

Model Year	*Assumed Annual Mileage*
Pre-1972	4,600
1972–1974	4,700
1975–1981	6,500

To guard against the problem of scrapping already immobile automobiles, Rule 1610 also sets forth some selection requirements that must be satisfied before emissions reductions credits may be granted for an automobile: it requires that the automobile have been registered in the South Coast district as operable for 2 continuous years before scrapping, that it had been continuously insured for at least 1 year before scrapping or have been trans-

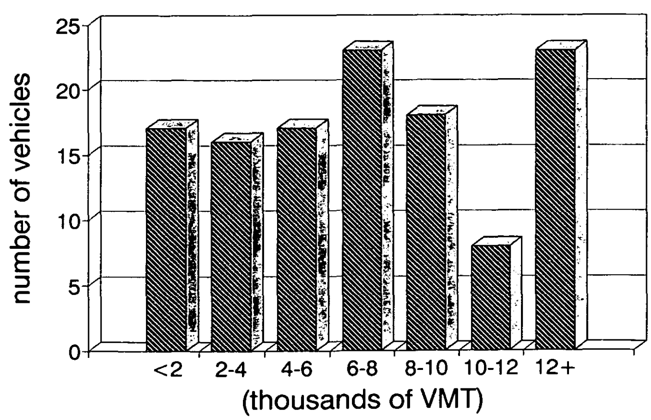

FIGURE 1 Distribution of VMT (IEPA Cash for Clunkers program).

ferred to ownership by a South Coast district resident before 1991, and that it have a functional exhaust system, bumpers, doors, fenders, side panels, hood, trunk, windshield, windows, seats, and instrumentation. These requirements will screen some of the most extreme cases of automobile owners rehabilitating their old and immobile automobiles to make one last push to the scrappage site. However making sure that an automobile "works" still does not indicate the extent of use before retirement.

In summary variability and uncertainty of use among older vehicles are large; reliable estimates are not available or easily obtainable. Because there is reason to believe that retired automobiles are not a representative sample of all automobiles in their age groups, simply taking the average mileage of all automobiles that are the same age as the retired automobile is not realistic. A great need thus exists for a reliable method of quantifying the amount of use of retired automobiles. This uncertainty is critical; consider that a vehicle driven 6,000 mi/year generates three times the pollution of a vehicle driven 2,000 mi/year.

What Were Emissions Levels of Retired Automobiles?

Emissions of automobiles scrapped under a retirement program may be estimated either by directly measuring the emissions of each retired automobile or by relying on computer models to predict the emissions of the retired automobiles. The former is expensive; the latter, as indicated below, is inaccurate.

In its 1990 SCRAP program, Unocal, in conjunction with CARB, tested 74 randomly selected automobiles by using the standard federal test procedure (FTP) (*12*). A consulting firm retained by Unocal performed a comparison of the test results with estimated results from California's EMFAC-7E emissions model (*10*). A comparison of hot stabilized tailpipe emissions is given in Table 2.

The EMFAC-7E model made a reasonably accurate prediction of CO and NO_x emissions, erring by 10 and 5 percent, respectively. However EMFAC-7E underestimated HC emissions by 44 percent. Moreover the ranges and the standard deviations for the data were very large relative to the averages. Tested emissions of scrapped automobiles were highly variable, as indicated by the last two columns of Table 2. For example the average HC emission rate for model year 1966 to 1970 automobiles was 16.62 g/mi, which is less than the standard deviation of 18.5 g/mi. Also EMFAC-7E did a fairly poor job of predicting cold-start and hot-start emissions; estimates differed from the FTP results by 25 to 63 percent. Furthermore these figures reflect only tailpipe emissions; nontailpipe emissions, which account for a substantial portion of automobile emissions, must also be predicted with some certainty.

One might also expect large differences across programs and regions. The tested emissions for scrapped automobiles in the EPA Cash for Clunkers program, which tested the retired automobiles by using an I&M 240 test (instead of an FTP test) were quite different from those of Unocal's program. Tested HC emissions averaged 10.6 g/mi versus 16.62 g/mi for the SCRAP program, CO emissions averaged 62.1 versus 84.64 g/mi, and NO_x emissions averaged 4.79 versus 2.39 g/mi. The standard deviations of tested emissions of the Cash for Clunkers program were also large: 13.1 g/mi for HC, 65.0 g/mi for CO, and 7.1 g/mi for NO_x. Whether the differences in tested emissions between the two programs are attributable to regional variations or to differences in test procedures, the need for some predictive power is apparent.

As further illustrated by Figure 2, the distributions of emissions of retired automobiles were abnormal. Note that the distribution of HC emissions for the IEPA program [Figure 2(*b*)] shows the same U-shaped pattern as the tested HC levels for automobiles tested in the Unocal SCRAP program [Figure 2(*a*)]. This suggests that the large variances in emissions levels found to exist for these two pilot programs may be an inherent characteristic of accelerated retirement programs.

The abnormal distributions, large variances, and large discrepancies between modeled and tested emissions of retired automobiles are dramatic and underscore the inability to accurately model the emissions characteristics of old automobiles. The alternative to using models such as California's EMFAC or the Environmental Protection Agency's (EPA's) MOBILE to project the emissions of old automobiles is to test each automobile as it is turned in for retirement. However the FTP procedure that was used by Unocal and CARB to test automobiles is expensive and is known to be inaccurate (*13,14*). The I&M 240 test, which produced vastly different results in the IEPA program, is as yet unproven. Thus assigning an appropriate value to the emissions of a scrapped automobile is not straightforward.

How Will VMT of the Retired Automobile Be Replaced?

As poor as the understanding of the use and characteristics of retired automobiles is, even less is known about the ways in which people would replace their retired automobiles and the air quality impacts of their decisions. CARB assumes that automobile owners who retire their automobile will replace the VMT of the retired automobile by driving a newer, cleaner automobile that has "av-

TABLE 2 Tested and Modeled Hot Stabilized Tailpipe Emissions for Scrapped Cars, SCRAP Program, 1990, grams/mile (*10,12*)

Pollutant	EMFAC-7E	Average Tested Emissions	Range*	Standard Deviation*
HC	9.16	16.62	1.9 - 85.4	18.5
CO	76.16	84.64	11.9 - 248.5	50.0
NOx	2.26	2.39	0.4 - 9.0	2.1

*a small speed correction factor was applied to these figures.

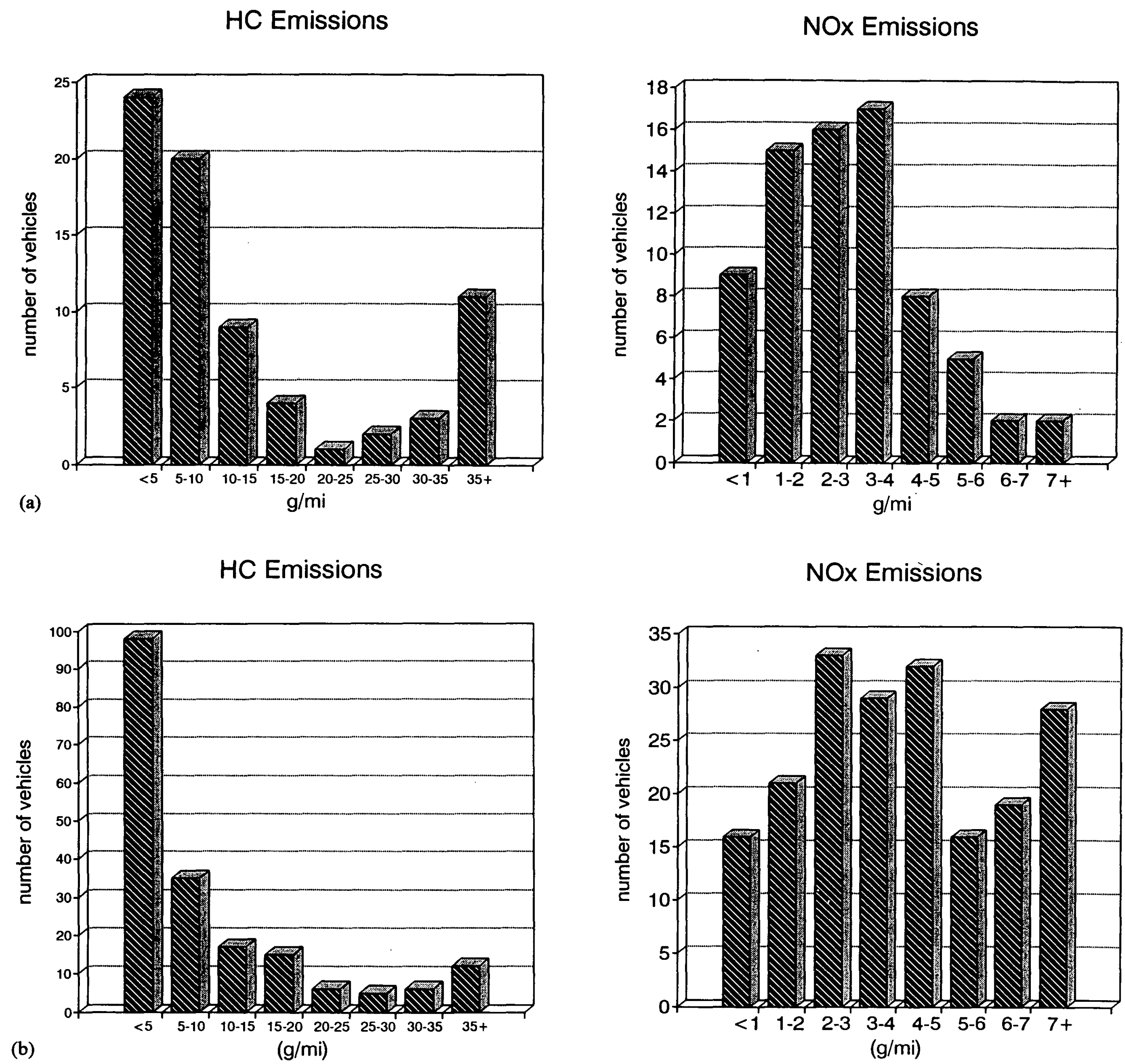

FIGURE 2 Distribution of emissions levels (*a*) of retired automobiles for Unocal SCRAP program and (*b*) IEPA Cash for Clunkers program.

erage'' emissions levels. This seems a sensible assumption, yet like virtually all other assumptions that need to be made to justify mobile source emissions reductions programs, it has no empirical basis. Some of the following questions in this regard need to be answered: How many participants will replace their old automobiles with brand new automobiles? How many will replace them with used automobiles? How many will replace their old automobiles with increased use of other, older automobiles that they already own? Will the participant drive the replacement automobile more frequently than he or she did the old automobile? Would an active accelerated retirement program in one region suck in old automobiles from neighboring regions and negate the emissions reductions achieved by retirement?

In its follow-up survey of the SCRAP program, FB&M polled SCRAP program participants as to how they had replaced the miles driven on their old automobile. About 46 percent were driving a newly bought automobile, 42 percent were driving another automobile that they already owned, 8 percent were either getting rides or using public transportation, and 3 percent reported that they did not drive much anymore (*7*). Will this pattern persist in other programs? Would the amount of payment for the old automobiles affect this figure? Will the timing and repeated offerings of the program affect this figure? Again these are questions that need to be examined before instituting accelerated retirement programs.

When There Is a Replacement Automobile, How Extensively Would It Be Used and What Would Emissions Levels Be?

Of the 86 percent of the respondents in the FB&M survey that reported that they had already purchased another automobile or were driving an automobile that was already available, 35 percent reported that they were driving the same amount as before, 38 percent reported that they were driving more, and 13 percent reported that they were driving less (*7*). FB&M did not, however, ask the respondents to quantify the differences.

As mentioned above CARB assumes that after an automobile owner turns in the old automobile for scrappage the owner will replace it with an "average" vehicle and will drive the replacement vehicle more frequently than the old automobile because of greater reliability and comfort. Similarly SCAQMD, in its Rule 1610, assumes that for every automobile scrapped under an accelerated retirement program there will be a replacement automobile that will emit, on average, 1.5 g of reactive organic gases per mi and 0.9 g of NO_x per mi and that will be driven an average of 9,800 mi/year (*11*). Although these assumptions may seem sensible and conservative, the lack of research data makes it as difficult to disprove them as it does to support them.

The uncertainty with respect to quantification of the emissions levels of replacement automobiles and the extent of use of replacement automobiles is large. This is not surprising because rarely does an automobile owner know how he or she will replace a retired automobile; it is presumptuous of policy makers to attempt to predict the behaviors of these automobile owners.

SENSITIVITY ANALYSIS

Uncertainty in the variables discussed will have a profound effect on the magnitude of emissions reductions resulting from an accelerated retirement program not only because the variabilities are large but also because of the multiplicative relationship between the independent variables (the number of automobiles retired under the program and the average remaining life, annual mileage, and emissions levels of the retired automobiles). A sensitivity analysis, presented in Table 3, illustrates this point.

The HC emissions reduction resulting from an accelerated retirement program is quantified as follows. First, the quantities of HC emissions that are avoided by retirement of the old automobiles are calculated by multiplying together the number of automobiles retired (column A in Table 3), the average emissions of the retired automobiles (column B), the average annual mileage of the retired automobiles (column C), and the average remaining life of the retired automobiles (column D). Second, the increase in emissions attributable to use of a replacement automobile is calculated by multiplying together the number of automobiles retired and the average remaining life of the retired automobiles (columns A and D) with the average emissions rates and the average annual mileages of the replacement automobiles (columns F and G).

For the baseline case assume the following:

1. Automobiles turned in for retirement are driven only an average of 4,600 mi, as SCAQMD attributes to pre-1972 automobiles;

TABLE 3 Sensitivity Analysis for Emissions Reductions Achieved by Accelerated Retirement Programs

	(A) No. Autos to be Retired	(B) HC Emissions of Retired Autos (g/mi)	(C) Average Annual Mileage of Retired Autos	(D) Average Remaining Life of Retired Autos (yrs)	(E) tons of HC emissions avoided from retired autos	(F) HC Emissions of Replacement Autos (g/mi)	(G) Average Annual Mileage of Replacement Autos	(H) tons of HC from Replacement Autos	(I) tons of HC reduced (over life of retired auto)	(J) % over Baseline HC Emissions Reductions
a) Baseline Estimate:	10,000	16.62	4,600	3.00	2,528	1.50	9,800	486	2,042	(baseline)
b) Sensitivity of (B):	10,000	10.0 to 20.0	4,600	3.00	1,521 to 3,042	1.50	9,800	486	1,035 to 2,556	-49 to 25
c) Sensitivity of (C):	10,000	16.62	2,500 to 6,500	3.00	1,374 to 3,571	1.50	9,800	486	790 to 2,832	-57 to 51
d) Sensitivity of (D):	10,000	16.62	4,600	1.00 to 5.00	843 to 4,213	1.50	9,800	162 to 810	621 to 3,103	-67 to 67
e) Sensitivity of (F):	10,000	16.62	4,600	3.00	2,528	0.50 to 2.50	9,800	162 to 810	2,186 to 1,538	16 to -16
f) Sensitivity of (G):	10,000	16.62	4,600	3.00	2,528	1.50	4,600 to 9,800	228 to 486	2,299 to 2,042	13 to 0
g) Extreme Estimates:	10,000	10.0 to 20.0	2,500 to 6,500	1.00 to 5.00	276 to 7,163	0.50 to 2.50	9,800	270 to 270	6 to 6,893	-100 to 238
h) High Scenario:	10,000	19.00	5,000	4.00	4,188	1.50	9,800	648	3,540	73
i) Low Scenario:	10,000	14.00	3,000	2.00	926	1.50	9,800	324	602	-71

(E) = (A)x(B)x(C)x(D)x0.000001 metric tons x 1.102 short tons/metric ton

(H) = (A)x(F)x(G)x(D)x0.000001 metric tons x 1.102 short tons/metric ton

(I) = (E) - (H)

(J) = 100 x [(I) - 1862] / (I)

2. The average remaining life of an automobile turned in for retirement is 3 years;
3. The emissions rates of the retired automobiles conform to those measured in conjunction with the SCRAP program (Table 2);
4. Automobiles driven to replace the retired automobiles are driven an average of 9,800 mi/year, as SCAQMD assumes in Rule 1610; and
5. The average HC emissions rates of such replacement automobiles are 1.50 g/mi, as SCAQMD assumes in Rule 1610.

The calculation of the HC emissions reductions achieved under this baseline scenario is contained in line a of Table 3. A hypothetical program that retires 10,000 automobiles would reduce HC emissions from 2,528 tons (column E) to 486 tons (column H), a reduction of 2,042 tons (column I). Lines b through d of Table 3 contain the results of this same calculation when the baseline assumptions regarding the retired automobile are varied. For example, line b contains a range of possible values for the HC emissions of the retired autos (10 to 20 g/mi) and the resulting amounts of emissions reductions are set forth in column E. Lines e and f test the sensitivity of the calculation when the baseline assumptions regarding the replacement automobile are varied. Line g contains the extreme high and low estimates of HC emissions reductions, which are obtained by taking the most favorable and least favorable values of all independent variables; the low extreme is a mere 6 tons, and the high extreme is 6,893 tons, a nearly threefold increase over the emissions reductions from the baseline estimate. Lines h and i of Table 3 contain some more realistic high and low scenarios of HC emissions reductions, taking the most favorable reasonable values of all independent variables for the high scenario and the least favorable reasonable low values for the low scenario. These scenarios indicate that a reasonable range of high and low estimates of emissions reduction would be from 602 to 3,540 tons.

It is obvious that calculations of the amount of emissions reductions from an accelerated retirement program are highly sensitive to assumptions made regarding the characteristics and use of the retired automobiles, whereas they are less so for the assumptions regarding the replacement automobiles. These simple examples show that the risk and magnitude of error in the quantification of emissions reductions are large. They also suggest that the estimation problem is intractable: for any accelerated retirement program, the numbers that need to be calculated to quantify emissions reductions will invariably be small (and will get smaller as emissions standards are tightened in the future) and will have large variances. Worse still, any error associated with these small numbers will be magnified in an accelerated retirement program, because each error pertains to one of many automobiles scrapped in a retirement program.

COSTS OF EMISSIONS REDUCTIONS

Because of the large uncertainties inherent in estimates of emissions reductions, estimates of the cost-effectiveness of accelerated retirement programs are uncertain as well. Adding to the uncertainty problem is the lack of a widely accepted methodology for calculating the cost-effectiveness of emissions control strategies.

Several cost-effectiveness studies on accelerated retirement programs are reviewed in Table 4. The cost-effectiveness of a program is obtained by dividing the total program costs by the number of tons of pollutants reduced by the program. However there is no widely accepted methodology that determines which pollutants should be included in the calculation or that apportions the program costs among the different pollutants included. The CARB estimate simply adds together the tons of HC with the tons of NO_x to obtain the number of tons of pollutants reduced; this implicitly equates the value of a ton of HC reduced with a ton of NO_x reduced, a debatable assumption because the ozone-producing effects of HC and NO_x are not only unequal but inverse in some instances because of the unusual shape of ozone isopleths (*15*). The Sierra estimate (*16*) also adds into the calculation one-seventh of the tons of CO reduced. This assumption may or may not be appropriate, depending on whether there is a CO problem in the proposed area. The Sierra Research calculation also differs in that it assumes that the benefits of emissions control strategies are positive only in areas and at times when there are violations of clean air standards; this assumption has not been made in other cost-effectiveness estimates.

Calculation of the costs of accelerated retirement programs is also problematic. The governmental costs of administering such a program are uncertain. Although CARB simply assumes a flat cost of $100 per vehicle, it seems unlikely that this simple linear re-

TABLE 4 Cost-Effectiveness Estimates of Accelerated Retirement Programs

Study	Geographic Area	Cost-Effectiveness ($/ton)	Pollutants Considered
CARB (1993)	California	2,800	HC, NOx
IEPA (1993)	Chicago	2,989	HC, NOx
		3,461	HC
		21,951	NOx
Washington (1993)	Sacramento	1,303	HC
		5,619	NOx
		187	CO
Sierra Research (1994)	California	7,600	HC, NOx, CO
	U.S.	13,900	HC, NOx, CO

lationship is realistic. The assumed offer price for purchase of the automobiles is by far the largest expense of such a program, yet there is no agreement on what such a figure should be. The IEPA study cited in Table 4 assumed an offer price of $750 per car; a reduction in the offer price to $550 per car lowered the cost-effectiveness figures by about one-fourth (*8*). The Sierra Research study assumed an offer price of $700 (*16*). Simply lowering the offer price is clearly not a solution, because the findings of Alberini et al. (*4*) show that the success of such programs is highly correlated to the offer price.

Consider the emissions reduction uncertainties analyzed earlier. A range of cost-effectiveness can be calculated by using the high and low scenarios discussed earlier and given in Table 3 (lines h and i). Assume the following:

1. An offer price of $700;
2. Overhead and administrative costs of $100 per automobile;
3. For retired automobiles a range of average HC emissions of 14 to 19 g/mi, average annual mileages of 3,000 to 5,000 mi, and average remaining life of 2 to 4 years; and
4. For the replacement automobiles, 1.5 g of HC emissions per mi and average annual mileage of 9,800 mi/year.

These assumptions and ranges of uncertainty translate into a range of cost-effectiveness of $2,260 to $13,289/ton of HC. This range is reasonably consistent with the comparable estimates made by IEPA ($3,461) (*8*) and Washington ($1,303) (*17*), although it is somewhat less optimistic.

Comparison of these figures with the cost-effectiveness of alternative emissions reduction strategies is problematic. Calculations of emissions reductions from alternative strategies suffer from the same methodological problems of determining which pollutants to include in the calculation and how to apportion program costs among the different pollutants. EPA has nevertheless used a rough rule of thumb that the marginal control costs of alternative emissions reduction measures are $3,050/ton of HC, $2,750/ton of NO_x, and $300/ton of CO (*18*). The congressional Office of Technology Assessment (OTA) has estimated the marginal control costs for various emissions reduction strategies to be $2,200 to $6,600/ton of HC for reasonably available control technology (RACT); $120 to $770/ton of HC for higher standards of gasoline volatility; and $2,100 to $5,800/ton of HC, NO_x, and CO for enhanced inspection and maintenance programs (with one-third of program costs being attributed to HC, one-half to NO_x, and one-sixth to CO) (*19*). The Sierra Research study included cost-effectiveness estimates for a number of emissions reduction strategies, including on-board refueling vapor recovery ($6,870/ton of HC) and evaporative emissions controls ($6,347/ton of HC) (*16*).

Thus when compared with the cost-effectiveness of alternative emissions control strategies, the range of cost-effectiveness estimates shows that there is some modest hope that accelerated retirement programs might be a more efficient means of reducing air pollution. The optimistic assumptions yield a cost-effectiveness of $2,260/ton of HC, which compares reasonably favorably with the EPA's rule-of-thumb estimates and OTA's low-end estimates for RACT and enhanced inspection and maintenance. The pessimistic assumptions on the other hand yield a cost-effectiveness of $13,289/ton, higher than those of most other strategies currently being considered. It should be remembered, however, that marginal control costs for alternative pollution control strategies vary greatly from region to region. SCAQMD, for example, has already implemented the least expensive emissions control strategies and is forced to consider more costly strategies to further reduce emissions. Moreover the effectiveness of accelerated retirement programs can be expected to vary greatly from region to region; the retirement of long-lasting Southern Californian automobiles can be expected to have a larger air quality impact than the retirement of those in snowy midwestern states.

CONCLUSION

The uncertainties of the air quality benefits that would accrue from accelerated automobile retirement programs cast doubt on the present usefulness of such programs. Although the range of emissions reduction cost figures for accelerated retirement programs leave some room for optimism, no definitive statements can be made about their cost-effectiveness until better estimates of air quality benefits can be made. Similar problems arise for other proposed types of mobile source emissions trading programs as well. Accurate predictions of the emissions levels of buses and fleet vehicles are necessary before regulators become too enamored with the idea of trading credits for the purchase of or conversion to low-emission buses or fleet vehicles. The inherent estimation problems of accelerated retirement programs caused by the small numbers representing emissions levels and the relatively large degrees of uncertainty associated with such numbers are common to all mobile sources. With respect to any mobile source trading program, it appears safe to say that the level of uncertainty and estimation error will inevitably be great. Furthermore regional variation must be taken into account; differences in marginal control costs and automobile characteristics require that evaluations of accelerated retirement programs be done at a regional level.

Mobile source trading advocates may dismiss the concerns regarding uncertainty raised in this paper, arguing that as long as one knows roughly the characteristics of old and replacement automobiles in the aggregate there is no need to bother with the characteristics of individual automobiles. However accurate predictions of such factors, even in the aggregate, are not feasible at this time. The irregular distributions of emissions and VMT of retired automobiles presented in this paper are evidence that statistical averages are unreliable in predicting emissions reductions accruing from accelerated retirement programs. Current estimates of the air quality impacts of accelerated retirement programs are merely guesses.

Better predictive power will not come easily; more pilot programs such as the SCRAP program and IEPA's Cash for Clunkers program are necessary before accurate predictions can be made about the characteristics and uses of both retired automobiles and the newer automobiles that replace them. Research is needed to improve understanding of the behaviors and motivations of automobile owners who might be candidates for participation in such programs and the kinds of automobiles that these people will turn in for accelerated retirement programs. The study of Alberini et al. (*4*) represents a large step in this regard, but for accelerated retirement programs to be effectual, a model of participation that is able to predict the key variables discussed in this paper is needed. In the meantime continuing research into technologies such as remote sensing devices is also very important, because such tools may not only improve the predictability of automobile emissions but may themselves also prove to be a tool for reducing mobile source emissions (*20*).

How successfully and honestly the inherent uncertainties of mobile source trading programs are dealt with will determine the success of such programs. It is too early to pass judgment on mobile source trading programs, but it is not too early to scrutinize the implementation of such programs and examine ways to improve their design to ensure that their adoption will truly result in air quality improvement.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the valuable assistance of Mary Brazell, Mark Simons, Barry Ellman, Glenn Passavant, Will Schroeer, Michael Riehle, David Coel, Steve Plotkin, Tom Evershenk, Roger Kanerva, Gale Newton, Randall Guensler, Michael Quanlu Wang, and the anonymous reviewers who enriched this paper with their comments and suggestions.

REFERENCES

1. Guensler, R. Reconciling Mobile Source Offset Programs with Air Quality Management Plans. *Proc., 85th Annual Meeting, 92-117.01.* Air and Waste Management Association, Pittsburgh, Pa., June 1992.
2. Parks, R. W. Determinants of Scrapping Rates for Postwar Vintage Automobiles. *Econometrica*, Vol. 45, No. 5, 1977, pp. 1099–1115.
3. Manski, C. F., and E. Goldman. An Econometric Analysis of Automobile Scrappage. *Transportation Science*, Vol. 17, No. 4, 1983, pp. 365–375.
4. Alberini, A., W. Harrington, and V. McConnell. *Determinants of Participation in Accelerated Vehicle Retirement Programs*. Discussion Paper QE93-18. Resources for the Future, Washington, D.C., 1993.
5. *Mobile Source Emission Reduction Credits: Guidelines for the Generation and Use of Mobile Source Emission Reduction Credits.* Air Resources Board, State of California Environmental Protection Agency, Sacramento, 1993.
6. *Transportation Energy Book*, Edition 13. Document ORNL-6743. Oak Ridge National Laboratories, Oak Ridge, Tenn., 1993.
7. *Final Summary Report on the Results of the Unocal SCRAP Program Post-Participation Survey*. Fairbank, Bregman & Maullin, San Francisco, Calif., 1991.
8. *Project Design for High-Emission Vehicle Scrappage*. Illinois Environmental Protection Agency, Springfield, 1992.
9. *Pilot Project for Vehicle Scrapping in Illinois*. Illinois Environmental Protection Agency, Springfield, 1993.
10. *Evaluation of Vehicle Emissions from the Unocal SCRAP Program.* Radian Corporation, Sacramento, Calif., 1991.
11. *Draft Staff Report for Proposed Rule 1610: Old-Vehicle Scrapping.* South Coast Air Quality Management District. Diamond Bar, Calif., 1993.
12. *Unocal SCRAP: A Clean-Air Initiative from Unocal.* Unocal Corporation, Los Angeles, Calif., 1991.
13. Guensler, R., S. Washington, and D. Sperling. *A Weighted Disaggregate Approach to Modeling Speed Correction Factors.* Report UCD-ITS-RR-93-6. Institute of Transportation Studies, University of California, Davis, 1993.
14. *Rethinking the Ozone Problem in Urban and Regional Air Pollution.* National Research Council, National Academy Press, Washington, D.C., 1991.
15. Tesche, T. W. Applications of Photochemical Models. In *Environmental Modelling* (P. Melli and P. Zannetti, eds.), Elsevier Applied Science, New York, 1992.
16. *The Cost-Effectiveness of Further Regulating Mobile Source Emissions.* Report No. SR94-0204. Sierra Research, Inc., Sacramento, Calif., 1994.
17. Washington, S. Benefit-Cost Analysis of a Vehicle Scrappage Program. *Proc. 35th Annual Transportation Forum,* Arlington, Va., 1993.
18. Shroeer, W. L. *A Cost-Effective Accelerated Scrappage Program for Urban Automobiles.* Environmental Protection Agency, Washington, D.C., 1992.
19. *Retiring Old Cars: Programs to Save Gasoline and Reduce Emissions.* U.S. Congress, Office of Technology Assessment. U.S. Government Printing Office, Washington, D.C., 1992.
20. Harrington, W., and V. McConnell. *Cost-Effectiveness of Remote Sensing of Vehicle Emissions.* Discussion Paper QE93-24. Resources for the Future, Washington, D.C, 1993.

Publication of this paper sponsored by Committee on Transportation and Air Quality.