Coase and Car Repair: Who Should Be Responsible for Emissions of Vehicles in Use?

Winston Harrington
Virginia D. McConnell

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RESOURCES FOR THE FUTURE
1616 P Street, NW
Washington, DC 20036
Telephone 202-328-5000
Fax 202-939-3460
Internet: `http://www.rff.org`

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Abstract

This paper examines the current assignment of liability for in-use vehicle emissions and suggests some alternative policies that may reduce the cost and increase the effectiveness. We first discuss the cost, performance and incentives under current Inspection and Maintenance (I/M) programs, using the recently implemented Arizona "Enhanced I/M" program as an example. These programs were designed to identify and repair vehicles with malfunctioning emission control systems. Since their inception, however, I/M programs have been plagued by transaction costs that have drastically raised the cost of I/M as well as limited its effectiveness. These transaction costs fall into three categories: emission monitoring, repair avoidance, and non-transferability of emission reductions. We argue that most of these transaction costs can be attributed to the current assignment of liability for I/M to motorists, and we examine the potential for other liability assignments to reduce transaction costs and improve program efficiency. Among the alternative institutional arrangements discussed are greater imposition of liability on manufacturers, emission repair subsidies, repair liability auctions, and vehicle leasing.

Key Words: mobile sources, emissions, Coase, liability, I/M

JEL Classification Numbers: Q25, Q28, R48

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Winston Harrington and Virginia D. McConnell*

Soon after the Federal emission standards for new motor vehicles went into effect in 1977,[1] it became clear that there was often a great difference between the expected performance of the new emission abatement equipment and the actual performance on the highway. Something else besides new vehicle standards was going to be needed to achieve the ambitious vehicle emission-reduction goals envisioned by Act. The Environmental Protection Agency (EPA)[2] therefore encouraged the states to establish vehicle "Inspection and Maintenance" (I/M) programs to conduct periodic emission tests on all vehicles and to require owners to repair failing vehicles. EPA predicted that these programs would produce major reductions in emissions of hydrocarbons (HC) and carbon monoxide (CO) at very modest cost. But although the *potential* of I/M programs to reduce emissions was--and remains--very high, the available evidence suggested that the actual emission reductions attributable to these early programs was very small.

In response, Congress established in the 1990 Clean Air Act much more stringent requirements for state I/M programs. After much delay and vociferous opposition in many states, these "Enhanced I/M" programs began to be implemented in 1995. Based on early evidence in five states, the Enhanced I/M programs are doing a marginally better job of repairing dirty cars, but emission reductions are still only a fraction of what had been expected from the new program.

Why are the results from these programs so disappointing? Can--and should--anything be done about it? In this paper we will examine alternative approaches to the problem of reducing emissions of vehicles in use. We take a Coasian perspective, drawing on that author's insight on the fundamental importance of transaction costs to efficient resource allocation (Coase, 1961). Each assignment of legal rights and duties entails transaction costs. If those transaction costs are high enough, then transfers of rights and responsibilities will be disrupted and the efficient outcome may not be achievable. In that case, the preferred initial assignment is the one that minimizes the overall costs, including both the additional transactions costs themselves as well as the added cost of the inefficient choices.

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* Senior Fellows, Quality of the Environment Division, Resources for the Future.

[1] The 1977 standards were the first to require catalytic converters. The first federal emission standards for motor vehicles went into effect with the 1974 model year.

[2] Since its inception the I/M program has been administered by EPA's Office of Mobile Sources. In the paper, whenever we mention EPA, we are almost always referring to OMS.

Certainly, the current assignment of liabilities in I/M programs--primarily to motorists for the emissions of individual vehicles[3]--causes very high transaction costs. Most of the efforts are devoted to finding dirty cars rather than repairing them. Our recent study (described briefly below) of the Enhanced I/M program in Arizona indicates that only 29 to 36 percent of the total costs of the I/M program is devoted to the repair of vehicle emission systems; the rest is used for vehicle emission testing. The Arizona experience is typical: failure rates in I/M programs are 5 to 15 percent, so that about ten vehicles need to be tested to find one in need of repair.

Transaction costs also arise because motorists have ample opportunities for evading the responsibilities that are imposed on them. Motorists can fail to take emission tests; they may opt for incomplete repair; they may register their vehicles outside the I/M jurisdiction while continuing to use it there, or sell to someone who does so; or they may fail to register their vehicles at all. Moreover, those with the biggest incentive to avoid I/M tend to be those with the dirtiest vehicles. Even when gross-emitting vehicles are found, many never pass a subsequent retest. In Arizona, for example, 22 percent of vehicles that fail the initial emission test never pass any retest. While some of these vehicles may have been removed from the area or scrapped--both satisfactory outcomes from the standpoint of air quality--it is likely that a large number are still in local use.

Finally, the current policy prevents the transfer of liability for emission reduction from one vehicle to another. All vehicles subject to I/M are required to meet emission tests appropriate to their age and vehicle class; those that don't must be repaired until they do. Repair costs are quite heterogeneous, and expenditures bear little relationship to emission reductions, so that costs could be substantially reduced by shifting resources towards vehicles that promise large emission reductions per dollar spent. This may sound like the economist's standard argument for economic incentive approaches over command and control. And so it is, but with a twist: Under the current liability assignment, the monitoring methods do not give results that are sufficiently precise and replicable for individual cars. However, such precision is unnecessary to meet the environmental objectives of I/M, for what is environmentally important is the sum of emissions of all vehicles in the program area. If liability were assigned elsewhere, it would be possible to judge performance on average or total emissions for groups of vehicles, which, thanks to the Law of Large Numbers, is much more replicable and precise.

The goals of this paper are to describe the current assignment of cost and liability for in-use emissions, explore alternative liability assignments, examine the kinds of policies that would be necessary to change those assignments, and inquire into whether the gains from these policies would justify those changes.

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[3] Except for warranty repairs, for which the manufacturers are responsible. This is discussed further below.

BACKGROUND

I/M programs were first introduced in the U.S. in the late 1970s, enabled by a provision in the 1977 Clean Air Amendments specifying that approval of State Implementation Plans would only be granted when "to the extent necessary and practicable" there will be "periodic inspection and testing of motor vehicles to enforce compliance with applicable emission standards."[4] Congress was reacting to accumulating evidence of discrepancies between new vehicle emission certification and actual in-use emissions.

The states responded by establishing programs that differed in detail but were similar in many important respects. Most importantly for present purposes, all the programs put the onus of bringing the vehicle in for testing, as well as the cost of any repairs that might be necessary, on the motorist (except for warranty repairs). This is certainly the simplest and most natural assignment, and apparently no alternative assignments of responsibility were discussed. After all, motorists were already responsible for the maintenance of their vehicles and they were responsible for repairs required to meet mandatory safety inspections. Emission repair does differ in one important respect from ordinary maintenance and safety repairs, in that the motorist receives no direct benefit from reduced emissions. Still, making the motorist responsible was sensible for at least two reasons. First, some repairs that reduced emissions had other effects that motorists actually cared about, including better driveability and better fuel economy. Second, making motorists responsible seemed to be consistent with the "polluter pay" principle, which by this time had been generally accepted as both an ethical principle and policy prescription.

In most I/M programs the emission test of choice was the "idle" test, performed under no-load conditions by inserting a probe in the tailpipe. Some programs also had visual tests to look for tampered vehicles. All programs put the onus of bringing the vehicle testing and repair primarily on the owners. Any vehicle failing the test was required to return within some period of time (usually about a month) for a retest. During that period, presumably, the owner would repair the vehicle himself or bear the cost of having it done at a repair shop. (If the vehicle was new enough, then the manufacturer's warranty would cover the repair cost.) To mitigate the financial impact of I/M on individual motorists, however, most programs also had "waiver" provisions that put an upper limit on what motorists had to spend on repair. Once this amount was exceeded, motorists were excused from further expense regardless of the final emissions of the vehicle.

These state programs fell into two classes: "centralized" ("test-only") programs, where inspections were conducted at a relatively small number of large specialized facilities operated by the state or by its franchisee; and "decentralized" ("test-and-repair") programs, in which motorists took their vehicles to any of a large number of privately-owned repair shops,

[4] 1977 Clean Air Act Amendments, Title 1, section 110, 2(g).

garages and auto dealerships certified to conduct emission inspections.[5] In decentralized programs the I/M tests were often simply added on to the existing safety inspection.

The apparent success of the safety inspection programs[6] caused federal policymakers to predict, indeed assume, similar success for I/M. Inventory models for mobile source emissions, using optimistic assumptions about high emitter identification rates and repair rates, predicted large emission reductions at relatively low costs from I/M programs. In fact, EPA SIP regulations assumed that simply having a program in place was sufficient for a State to get credit for reducing vehicle emissions by 25 percent. Furthermore, an early analysis by the EPA estimated the cost-effectiveness of I/M programs at less than $650 per ton of VOC emissions reduced (USEPA, 1981).

I/M and the 1990 Clean Air Amendments

By the late 1980s, it had become clear that many of the initial state programs, on which the EPA had placed such high expectations, were not very effective. EPA concluded that certain features of state programs were causing some state programs to fail and advised Congress to make it difficult for states to continue those features. When the Clean Air Act was amended in 1990, Congress drastically centralized the program, directing the EPA to determine where state programs had failed and to come up with stringent program guidelines for avoiding or overcoming those failures. The new "Enhanced I/M" regulations were to apply to areas designated as "serious" nonattainment areas and had to be in place within eighteen months.

Working under this tight deadline, EPA's Office of Mobile Sources promulgated new regulations in November 1992.[7] Like the old I/M program, the new regulation gave states with I/M programs emission "credits" toward the meeting of the SIPs. Instead of a blanket 25 percent credit, however, the new regulations gave out credits based on a much more detailed breakdown of program features. Thus states received reduction credits for implementing an annual rather than a biennial program, a program that discouraged tampering, etc. These credits made it difficult for the major metropolitan areas in most states to achieve the emission reductions required to meet SIP requirements without adopting most of the provisions of the Enhanced I/M rule. Despite the greater sensitivity of the emission credits to program design, they were still to be based on program features rather than on measured performance in reducing emissions.

The new Enhanced I/M regulation contained three important innovations designed to strengthen the program and make the state programs more effective at finding and repairing vehicles with excess emissions. These features were aimed at three problems that were

[5] In principle, one could have decentralized programs that are test-only and centralized programs that both test and repair, but in practice no such programs developed.

[6] However, more recent research on safety inspections has called into question the effectiveness of the safety program also. See Leigh, 1994.

[7] "Inspection /Maintenance Program Requirements: Final Rule." 57 F.R. no. 215, November 5, 1992.

thought to be the principal problems limiting the effectiveness of state programs. Listed here in order of increasing controversy, they were (i) excessive use of "waivers," (ii) the scope and accuracy of the emission tests used in the states, and (iii) the combination of test and repair in decentralized programs.

Waivers. The waiver limits in most state programs (typically $50-$75, but as low as $15) were below the cost of many repairs that were likely to be needed to achieve compliance. In response to a specific provision of the 1990 CAAA, the new regulations required this waiver limit to be at least $450.

Mandatory dynamometer tests. Research in the early 1980s suggested that the idle emission test in use in most programs was not very effective at identifying high-emitting vehicles, especially among vehicles equipped with the newly-developed electronic fuel injection. Emissions during idle were not well correlated to emissions when the vehicle was accelerating, and worse, a mechanic could often reduce a vehicle's high emissions during idle without materially affecting emissions when the vehicle was under load. The idle test was also unable to measure emissions of oxides of nitrogen (NOx), a pollutant growing in importance and concern. EPA developed a technically sophisticated emission test protocol that included use of expensive automatic analyzers and a dynamometer.[8] This dynamometer test, the "IM-240" test, simulated vehicle operation under a variety of speed and acceleration conditions.

Separation of test and repair. Finally, EPA concluded that decentralized test-and-repair programs were less effective than centralized, test-only programs. The new regulations therefore included a provision limiting the emission credits granted a decentralized, test-and-repair program to 50 percent of the credits available to a centralized program. The reasoning was that mechanics in test-and-repair stations may have incentives that differ from those of the motorist and those of the enforcement agency. On the one hand, they may have an incentive to fail clean vehicles to make repairs that are not really needed. Or, the mechanic may have incentives to pass vehicles that should fail, as a way of ingratiating themselves to customers and assuring repeat business. This was by far the most controversial aspect of the new regulations, because in the states with decentralized programs there were many in the auto repair industry who had become accustomed to and even dependent on the income from those programs and who became a strong and vocal constituency against EPA attempts at centralization.

The new regulation aroused a great deal of opposition, especially in the states with decentralized programs. At first the disputants consisted primarily of state politicians and members of the independent repair industry, for whom the emission tests and repairs were a revenue source and who had made investment decisions on the assumption that the existing program would continue. In California, for example, many garages banned together in an organization called "Clean Air Performance Professionals" in order to lobby the state

[8] A dynamometer is a device for simulating the operation of the vehicle under load.

legislature. The legislature formed an I/M Review Commission to study California's existing Smog Check program and to make the case that a (possibly revised) Smog Check program could achieve emission reductions comparable to those projected for the Enhanced I/M program.

The opposition spread to the public at large after a couple of states--Maine and Maryland--actually attempted to implement the Enhanced I/M program. Each was doomed by severe startup problems involving computer crashes and long queues, and amid claims of poorly trained operators causing false positives and damage to vehicles, both programs were suspended after a short time. As the news of these disasters spread to other states, opposition grew. Enhanced I/M became a prime example of "unfunded mandates" and unwarranted federal intrusion into matters better left to the states. After the 1994 election the new Republican-dominated Congress attached a rider to a highway bill[9] to prevent the EPA from automatically discounting I/M credits in a decentralized program by 50 percent. As a result of that and other concessions by the EPA, the states were given much wider flexibility in the design of I/M programs.

Early Results of Enhanced I/M

Notwithstanding the teething problems of the early Enhanced I/M programs, several states have decided to go forward with a program resembling EPA's Enhanced I/M program, including the use of the IM-240 test: Arizona, Colorado, Maryland, Ohio and Wisconsin.

Arizona was the first state to implement an Enhanced I/M, initiating the program in 1995. Data from this program has provided the first opportunity to examine how well the performance of an actual program compared to expectations (Harrington and McConnell, 1999). Table 1a compares the costs and emission reductions of the Arizona program to the results predicted of the "High Option" Enhanced I/M program described by EPA's Office of Mobile Sources in its 1992 Regulatory Impact Analysis (USEPA, 1992). Overall, EPA's total cost estimates are about 30 percent below our estimates for Arizona, and the main discrepancy is in the very large fuel economy improvements claimed by the EPA compared to our much more modest estimates based on the actual results in Arizona. EPA's estimates of the cost of other components, however, were much closer to the actual estimated outcomes. As shown, the per-vehicle tailpipe repair cost assumed by the RIA is very close to the average repair cost per vehicle in Arizona. (The Arizona program does not require evaporative emission tests; however, many of the so-called "tampering" failures in Arizona were due to missing or faulty gascaps, which tend to increase evaporative emissions.) The repair cost per registered vehicle is the product of the average cost of an emission repair and the fraction of vehicles that fail the test (i.e. that undergo repair). Compared to EPA estimates, repair costs in Arizona were

[9] The National Highway System Designation Act of 1995 (P.L. 104-59).

Table 1a. Enhanced IM Cost Comparison
$ per vehicle per year

	EPA estimate, 1992[h]	Arizona Enhanced I/M, 1995-96[c,d]
Test costs	$8.55[a]	$8.37[e]
Repair – tailpipe emissions	8.73[a]	8.30[f,g]
Repair – evaporative emissions	3.95[a]	
Fuel economy – tailpipe repair	-11.02[a]	-2.36[f,g]
Fuel economy – evaporative repair	-3.71[a]	
Motorist waiting and travel costs	7.50[b]	4.61[h]
Total	$14.00	$20.46

Source: Harrington and McConnell, 1998.
Notes:
[a] Taken from EPA (1992) Tables 6-9 and 6-7.
[b] EPA (1992) assumes 45 minutes elapsed time, at a leisure time value of $20.00/ hr.
[c] Costs are in 1992 dollars.
[d] Uses October 1996 actual value of 1.13 tests per passing vehicle per testing period.
[e] Uses cost to motorist – $16.75.
[f] Ando, Harrington and McConnell (1998) estimate repair costs of $123 and fuel economy benefits of $35 per failing vehicle per two-year testing cycle. For purposes of this table these costs are distributed over all vehicles.
[g] Includes both tailpipe and tampering repair.
[h] Mean test duration in Arizona is 8.7 minutes and average queue is 1.92 vehicles. Assumes value of waiting time equals the after-tax wage ($8.62 per hour in Arizona), average distance to test station is 4.5 miles, average speed 20 mph, and vehicle operating cost is $0.25 per mile.
[h] "High Option," Biennial Enhanced I/M (EPA, 1992).

Table 1b. Comparison of Emission Reductions
EPA Estimates vs. Arizona Experience
(Light-duty vehicles only)[b]

	Base case	After IM	Reductions
	g/mi		
EPA estimate (cutpoints)[a]			
All HC	1.96	1.27	35%
Exhaust HC (0.8 g/mi)	0.88	0.59	33%
CO (15 g/mi)	10.9	6.67	39%
NOx (none)	0.89	0.83	7%
Arizona Enhanced I/M, 1995-96			
HC (2.45 g/mi)[c]	0.75	0.66	12%
CO (48.2 g/mi)[c]	10.8	9.4	13%
NOx (2.45 g/mi)[c]	1.55	1.44	7%

Source: Harrington and McConnell, 1998
Notes:
[a] "High Option," Biennial Enhanced I/M, year 2000 (EPA, 1992, Appendix I). Cutpoints apply to 1984 and later vehicles.
[b] EPA emissions are weighted averages computed from tables in EPA 1992, Appendix I p. 7.
[c] Arizona cutpoints differ by model year for 1981+ model-year vehicles. Values given are fleet-weighted averages.

higher but failure rates were lower.[10] Our empirical estimates of motorist waiting and travel cost in Arizona actually turned out to be somewhat lower than the EPA assumptions.

The EPA originally forecast that this new generation of I/M programs would be substantially more effective at reducing emissions than the earlier I/M programs. Using the MOBILE inventory model to estimate vehicle emission reductions,[11] EPA predicted that Enhanced I/M would reduce exhaust HC emissions by 33 percent, and total HC emissions (exhaust plus evaporative) by 35 percent. Reductions in CO emissions of 39 percent and NOx of 7 percent were also predicted. All these predictions were based on assumptions that almost all eligible vehicles would be tested, and that, under relatively strict emissions standards, those that needed repair would be fully repaired to the standard. These predictions did not take account of potential implementation issues and, as a result, appear to have been too optimistic.

Table 1b compares the EPA forecasts with the actual emission reductions found for Arizona. The Arizona I/M data used are based on failed vehicles that received repair during all of 1995 and the first half of 1996.[12] The measured emissions reductions in Arizona are 12 percent for HC, 13 percent for CO and 7 percent for NOx. Although the percentage reduction in NOx emissions are similar in Arizona and the EPA forecast, the initial NOx emissions in Arizona are much higher than the EPA estimate. The HC and CO emissions are similar for the two cases, but the HC and CO reductions are much lower in Arizona. In addition, early designs of Enhanced I/M assumed that evaporative emissions tests for HC would be an important component of the test procedure, but none of the evaporative tests have proven to be workable and cost-effective, so no evaporative tests are currently being used in any I/M program. These data provide some evidence that the EPA projections greatly overstated the potential for emission reduction for HC and CO, and were optimistic about the NOx emissions level in fleet both before and after I/M testing and repair.

Not only did the Enhanced I/M regulation arouse much more opposition than EPA expected, it also has had a much smaller effect on emissions than anticipated. Evidently the changes made by EPA had some effect on vehicle emissions, but not enough to produce major improvements.

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[10] EPA assumed the average costs (1992 $) of "transient failures" to be $120 in 1992. NOx repairs were assumed to be $100, and pressure and purge tests were $38 and $70, respectively (EPA, 1992, p. 84). We found repair costs to be about $180 for vehicles that have emission test results that exceed cutpoints, and about $50 for vehicles that that have acceptable emission test results but fail the test anyway. We infer that these vehicles fail the tampering portion of the test.

[11] Emissions reductions that will occur from I/M programs are estimated from a computer model developed by the EPA's Office of Mobile Sources in Ann Arbor, Michigan. The results cited here are made using the most recent version of this model, Mobile 5B. For a description of the how the model was used to develop the effectiveness estimates of Enhanced I/M see USEPA (1992).

[12] The data used are the 2% random sample of vehicles that were given the full 240 second tailpipe test both before and after repair. Arizona has both a fast pass and a fast fail algorithm to shorten the test waiting time.

WHY IS I/M SO DIFFICULT TO IMPLEMENT? SOME ANSWERS FROM RECENT EMPIRICAL STUDIES

Since 1990 a large number of studies have been carried out that examine I/M performance and other aspects of on-road emissions, only some of which had been completed at the time the I/M regulation had been completed. Collectively these results have called into question important aspects of the current approach to in-use emission reductions as embodied in the I/M program. The data have come largely from three sources: remote sensing studies, repair/scrappage studies, and the newly-implemented I/M programs.

Before reviewing this evidence, we briefly describe remote sensing, an emission monitoring technology that allows large number of emission measurements of vehicles in use to be taken quite inexpensively. A remote sensor works by transmitting an infrared beam to a receptor on the other side of a roadway about a foot above the surface. When a vehicle passes the sensor and its exhaust plume cuts the beam, the device determines concentration of CO and of particular species of hydrocarbons relative to that of CO2. Through the use of stoichiometric principles and by making assumptions about the composition of the fuel, these ratios are then converted to grams of pollutant per gallon of fuel burned. If the vehicle's fuel economy is known, the emission reading can be further converted to grams per mile, which is the unit used in emission regulations. At the same time the sensor is making an emission measurement, a camera is taking a snapshot of the vehicle's license plate, so that the emission reading can be linked to other vehicle characteristics in the database maintained by the Department of Motor Vehicles.

Invented by Donald Stedman of the University of Denver, RSD has proven to be quite useful in the estimation of average emissions of vehicle populations and subpopulations. Below we consider some ways that RSD might play a more active role in policy implementation, but so far it has only been accepted for generating data to characterize fleets. For example, in 1991 Stedman and Gary Bishop of the University of Denver and their co-workers used remote sensors to collect emission data vehicles in use in Southern California (see Stedman et al., 1994, for a description). Stedman et al. (1994) were able to assemble a complete data base on over 90,000 vehicles and using the license plate identification, link to information in the California DMV data base. The DMV data base includes vehicle manufacturer, model year, and vehicle identification number (VIN), which encodes some technical information about the vehicle (such as engine and transmission type) as well as owner's address.

Compared to the scheduled lane tests of I/M programs, RSD has advantages and disadvantages. On the positive side, they are very inexpensive, with costs per measurement below 50 cents per test, compared to IM240 costs of $15-20 per test. In addition, RSD truly tests vehicles as they are used--on the road. Among the disadvantages, RSD is thought to be inaccurate, since the measurement is based on less than a second's worth of data, compared to several minutes in the IM240 test. RSD is also somewhat constrained by the number of suitable sites on the road, and does not measure NOx very well. Nonetheless, the low cost of remote sensing studies have enabled extensive data sets for fleet characterization to be performed, and RSD studies have now been completed in many states and foreign countries.

Now we turn to three areas where recent empirical studies have put I/M in a new and less favorable light: emission variability, cost and effectiveness of emission repair, and motorist and manufacturer compliance with I/M measures.

Sources of Emission Variability

As is well known, there is substantial emission variability, both *among* vehicles--variation in average emissions from one vehicle to another--and *within* vehicles--variation in instantaneous emissions of the same vehicle at different times. The former is of course why we have I/M programs in the first place; the object of I/M being to find the vehicles with the greatest excess emissions and get them repaired. This task is made more difficult by the variation in emissions within vehicles. In both cases a great deal of the variation is systematic and therefore can be explained by observable vehicle characteristics or operating conditions. However, a good deal has been learned recently about variation in emissions among vehicles in use that is at odds with the assumptions of I/M programs.

Variation among vehicles

It has long been known that emissions vary by the age and mileage of the vehicle, by model year and by vehicle type (i.e. whether car or light truck). The model-year variation is the product of the gradual tightening of emission standards between 1973 and the present, so that emissions from new vehicles in 1995 were less than five percent of the average emissions of uncontrolled vehicles from the early 1970s. Likewise, the differences between cars and trucks are at least in part attributable to the fact that cars are subject to more exacting emission standards. As vehicles are driven, emission rates increase, probably a consequence of the gradual deterioration of the emission control equipment and other systems on the vehicle that affect emissions. In the past EPA also distinguished between engine type; otherwise similar vehicles would have lower emissions if they used electronic fuel injection rather than carburetors. This factor is diminishing in importance as carburetor vehicles are gradually being retired.

Recently other systematic variations in emissions among vehicles in use have been observed. For one thing, emissions appear to vary by manufacturer (Ross, 1994; Ross et al., 1995; Bishop et al., 1996). This research has shown that as a rule, an imported vehicle from Europe have the lower emissions than either a domestic or Asian vehicle of the same age. Certain Asian manufacturers score better than domestic U.S. manufacturers, while others are worse. For some manufacturers, moreover, emission rates of certain (usually more expensive) models are higher on average than others. Variation in emission certification standards cannot explain these outcomes, since vehicles of the same age and class (i.e. whether car or truck) have to meet the same emission standards. Systematic differences in owners and owner behavior could explain part of the differences, at least of vehicles of different quality. One might expect, for example, that owners of more expensive vehicles might be more inclined to invest in vehicle maintenance. It is more likely, however, that these differences are due to the durability of the emission control equipment and other engine components that affect the performance of the emission control system.

While emissions of vehicles gradually increase from normal use, there can be great variation even in vehicles that were identical when new. The causes of these differences in emissions are largely unobserved. In part the observed differences are no doubt attributable to random variation in the quality of parts and assembly, but probably a greater portion are due to differences in vehicle operation, fueling and maintenance, especially maintenance (Beaton et al., 1995).

Differences in maintenance probably account for the apparent correlations between a vehicle's emissions and the owners socioeconomic status, even when correcting for vehicle age (Harrington, 1997).[13] Maybe this correlation arises because lower-income individuals tend to spend less on vehicle maintenance. Another possible explanation is the tendency of "lemons" and poorly maintained vehicles to enter the used car market to be bought by low-income purchasers. Some support for this idea has emerged from a recent in-use emission study finding that vehicles with transferred ownership had substantially higher emissions than vehicles still owned by the original owner (Slott, 1997). As shown in Table 2, higher-income households are far more likely to be the original owners of vehicles regardless of age.

Some of these findings call into question the invocation of the "polluter pay" principle to justify making motorists responsible for in use emissions. Is the polluter the current owner? Or perhaps the manufacturer whose emission control system failed to last? Or is it a previous owner who failed to maintain the vehicle properly and then unloaded it? In either case it is far from clear that inferiority of the emission control system was reflected in the price of the vehicle.

Variation in emissions of a single vehicle

Profiles of emissions of a single vehicle over time show enormous variation and depend on many variables, including vehicle speed, acceleration and whether the vehicle is in a "cold start" mode. To allow for this variation and to obtain emission estimates with some correspondence to real-world outcomes, EPA has developed the Federal Test Procedure (FTP), an emission test administered to new vehicles to certify compliance with new vehicle standards. The FTP has also come to be the "gold standard" against which all other emission tests are measured. In developing a new emission test for I/M programs, EPA strove to make the test correlate as closely as possible to the FTP, and in fact the IM240 test developed by EPA consists of the first four minutes of the FTP trace.[14]

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[13] This study used an RSD data set collected in California in 1991. The correlation observed was actually between emissions and average income in the owner's zip code, extracted from vehicle registration database. Zip code income is a far from perfect proxy for household income; it may in fact be a better proxy for education. But in either case it suggests that owners' socioeconomic status can strongly affect vehicle emissions.

[14] The test trace is the pattern of speed and acceleration that the vehicle must follow during the test. Aside from test length, the major difference between the two test is that the FTP is designed to measure both cold-start and hot-running emissions, but the IM240 is only designed to measure the latter. Regressions of the relevant portion of an FTP test against an IM240 test on the same vehicle have R-squares of about 0.7 for NOx, and 0.8 for HC and CO.

Table 2. Percentage of Vehicles Owned by Original Owner, by household income and vintage

Household income	1981-85	1986-89	1990-93	1994-98
0-$5000	11	16	41	59
$5000-10000	13	27	41	42
$10000-15000	15	29	46	58
$15000-20000	16	28	50	68
$20000-25000	20	30	52	68
$25000-30000	18	33	51	74
$30000-35000	21	35	53	73
$35000-40000	21	35	55	75
$40000-45000	26	40	57	77
$45000-50000	23	42	57	79
$50000-55000	26	39	57	78
$55000-$60000	29	44	61	82
$60000-65000	26	45	66	85
$65000-70000	32	48	65	82
$70000-75000	34	53	63	83
$75000-80000	31	51	66	85
$80000-100000	39	55	68	89
$100000 or greater	41	58	76	91

Source: 1995 Nationwide Personal Transportation Survey

To be useful for this purpose the FTP must be *representative* of the speeds and accelerations found in ordinary urban driving and *replicable* (i.e. successive tests on the same vehicle must give virtually identical results unless the vehicle has been altered). It may be neither. Today neither the FTP nor the IM240 test include the highest acceleration rates found in everyday driving. Emission inventories based on FTP and IM240 test results can therefore mis-estimate fleet emissions if emission rates are different during high-emission episodes.

While the EPA is aware that the FTP is not totally representative of modern urban driving and has done research on alternative test traces, it tacitly assumes the FTP is replicable. (Replicability is after all implied by the use of the FTP as a gold standard.) However, it is not clear that FTP results are replicable for all vehicles, or even that replicable results are possible. For emission test results to be replicable, all the variation in successive tests must be due to measurement error, or more precisely, that the emission test controls for all the variables capable of affecting vehicle emissions. The limited evidence provided by repeated tests on the same vehicle at approximately the same time shows that emission variation--on some cars, at any rate--cannot be explained by test variation alone. If emission test variation were attributable only to measurement error, then the error variance would be independent of mean emissions. However, when Bishop, Stedman and Ashbaugh (1996) examined emission test results from several sources, including FTP tests done as part of the Auto-Oil Program,[15] they found that successive FTP tests on the same vehicles can have drastically different results. In general, the greater the mean emission rate, the greater the variation as well. Clearly, vehicles with the greatest mean emissions are the ones it is most important to identify in an I/M program, and it is precisely these vehicles for which test replicability is in doubt.

If the test variation is large relative to the mean test result, i.e. a high signal-to-noise ratio, then motorists have a simple strategy for avoiding repair of high-emitting vehicles: Repeat the test until you pass. Given current practice in many states of not charging for a retest, motorists may repeat the test indefinitely; there is no way of determining at each visit to the testing station whether any serious repair attempts have been made. Obviously this strategy will not work for all vehicles, but in fact it is not known how often it will work. Examination of IM240 data for Arizona suggests that it is being employed on occasion, since there are vehicles that have appeared for testing more than five times. What is not known is the number of ordinarily high-emitting vehicles that got lucky and passed the emission test on, say, their third or fourth try. Again, more precise emission tests may reduce the instance of this phenomenon, but it cannot eliminate it as long as vehicle emissions are themselves inherently variable.

Inherent vehicle variability also has implications for how the emission reductions attributable to I/M are calculated. Emission improvements are determined by taking the difference in emissions between the vehicle's initial test result and its final result. Since the improvements are determined only by examining the emissions of the vehicles that fail, a bias is introduced. To see this most clearly, suppose that all vehicles have the same underlying emission distribution, so that any vehicle that fails the emission test does so only because of random error. Suppose also that vehicles receive no repair but are simply tested repeatedly until an emission test is passed. Clearly, measurement of emission reductions in the customary way would show positive emission reductions, even though no emission reductions have been achieved.

Few critics claim that all the emission reductions claimed by I/M are spurious in this fashion, but the fact is that no one knows how extensive this problem of "regression to the mean" is. As long as there is unexplained emission variability, it can only be determined by

[15] This was the popular name of the Air Quality Improvement Research Program, a research effort undertaken in 1990 by a consortium of automobile and oil companies to examine the emission implications of fuel modifications specified in the 1990 Clean Air Act Amendments.

repeated tests on the same vehicle. The EPA has largely ignored the issue, holding implicitly that intra-vehicle variation accounts for only a small part of the total.

Manufacturers' Response to Emission Test Protocols

But the fact that EPA uses a predetermined driving cycle for the FTP and, to a lesser extent, the IM240 test to preserve test replicability causes a more serious problem. Replicability is of course an important component of the scientific method, but there is a crucial difference between monitoring for enforcement purposes and measurement in a scientific experiment. In an experiment, Nature has no interest in how the experiment comes out. But when the object of the measurement is an actor--a motorist or a manufacturer, say--who has an interest in the outcome of the measurement, there is the possibility that the actor will change his behavior so as to affect the outcome.

Since emissions during high-acceleration are never tested, vehicle emissions during these events are subject to no emission standards. Thus, manufacturers have the opportunity and incentive to optimize their engines and emission control systems with respect to that particular driving cycle. Engines are now designed to burn an enriched fuel mixture when under high acceleration, which improves performance and is said to prevent engine damage. As a result, though, a great deal of unburned fuel is sent to the catalyst and only partially oxidized there , and the result is very high emissions, perhaps a hundred times the current standard for CO and ten times for HC (Ross, 1994). Certainly part of the reason that enrichment events are now such a major cause of high emissions in new vehicles is that manufactures knew that they could design vehicles to a particular test cycle, and that high-acceleration events were not part of that cycle.

Cost and Effectiveness of Repair

The EPA had originally forecast that the repair of emissions equipment would be relatively easy and inexpensive. However, the difficulty of repair for a relatively small number of vehicles is emerging as one of the biggest challenges facing current I/M programs. A comparison of EPA assumptions with empirical studies of repair is shown in Table 3.

The Enhanced I/M RIA assumed that repair costs for tailpipe emissions would be about $120 per repaired vehicle.[16] However, these costs were based on estimates of parts and labor costs from a small sample of vehicles, repaired not in actual repair shops but in EPA laboratories. The average emissions reductions for the vehicles repaired in these laboratories, upon which the EPA estimates of I/M program effectiveness are based are shown in Table 3. Emissions changes are substantial for HC and CO, but after repair emissions were often still above the standards the EPA wanted to use in I/M programs. The EPA went further then to assume that all vehicles would have to be brought into compliance in real world programs.

[16] Table 1a earlier in this paper reports repair costs per *vehicle in the inspection program* which includes those vehicles which fail and those that do not. The early EPA estimates of cost assumed a much higher failure rate because it was assumed that emissions tests would be much stricter than they been in practice.

Table 3. Comparison of EPA Repair Effectiveness Assumptions with Results of Non-EPA Empirical Studies				
			Average emissions[b]	
	N	Average Cost	Before repair	After repair
EPA Repair Dataset (FTP)[a]	266	-		
HC			3.13	1.24
CO			44.8	12.7
NOx			–	–
California I/M Review Committee (1993)	681*	$89.55		
HC			4.94	3.70
CO			48.4	41.4
NOx			2.12	1.89
Sun Company (Cebula 1994)	155	$338.55		
HC			4.83	1.55
CO			69.2	17.0
NOx			2.90	2.02
Total Petroleum (Lodder and Livo 1994)	103	$390.21		
HC			3.66	2.48
CO			45.64	33.38
NOx			–	–
California I/M Pilot Project FTP (Patel et al. 1996)	199	$305.50		
HC			3.34	1.65
CO			35.9	20.8
NOx			2.05	1.23
Arizona Enhanced I/M (Ando et al. 1999)	5909	$199		
HC			2.69	1.70
CO			40.4	25.7
NOx			3.14	2.24

Notes:

[a] Data set of vehicles repaired at EPA lab s and used to estimate changes in HC/CO emissions resulting from repairs in EPA (1992). Our thanks to David Brzezinski of EPA for providing us with the data.

[b] All emission measurements were made with FTP, except for Arizona I/M, which used the IM240 test.

These assumptions were not seriously challenged until a few studies reporting costs and effectiveness of repair in the real world emerged, including California I/M Review Committee (1993), Cebula (1994), Lodder and Livo (1994), and analysis of the Arizona I/M program. Emission reductions and costs from these programs are shown in Table 3. Until the advent of Enhanced I/M programs (such as Arizona's), studies of repair effectiveness were difficult to do largely because of sampling difficulties. By necessity recruitment in the other studies was voluntary, and there is a stronger-than-usual reason to suspect selection bias when those motorists who choose not to participate because they fear that previous tampering might be discovered or that efforts to avoid repair costs might be inhibited. In addition, the repair cost data were suspect, because they were reported by the owner and usually the specific repairs were not itemized.

The studies by Cebula (1994) and Lodder and Livo (1994) were not connected with I/M at all. They were evaluations of scrap-or-repair programs initiated by major oil companies in search of emission offsets. RSD was used in both studies to identify gross-emitting vehicles, whose owners were then offered an opportunity either to sell the vehicle for a fixed price or a free repair of the emission system. The results of these studies suggested that EPA's repair assumptions were optimistic, at least for the dirtiest vehicles in the fleet. While repairs did substantially reduce the emissions of these vehicles, the average repair cost was very high and regardless of cost some vehicles could not be brought into compliance with the emission standards assumed by the EPA for Enhanced I/M.

The repair study commissioned by the California I/M Review Committee was part of a larger project, an "undercover car" investigation that sent a sample[17] of nearly 5,000 vehicles to random inspection stations in various California cities in order to evaluate the Smog Check program in its entirety. The nearly 700 vehicles failing the initial test were then followed through the program until they received a Smog Check certificate. Improvements in these vehicles was compared against before-and-after FTP tests on each vehicle. The results showed that over half the vehicles actually had higher emissions after repair than before. For the most part these perverse results occurred in vehicles with borderline emissions. The sum of emission reductions in all vehicles was positive for all pollutants, but as shown in Table 3, those reductions were modest.

The Arizona program provides the first opportunity to examine the costs and emissions reductions from repair for a large number of vehicles in a setting where issues of selection bias are largely eliminated. Motorists with failing vehicles are required to complete a repair form before each retest. Compiling data from these reports, Ando, Harrington and McConnell (1998) find that the cost of a tailpipe repair in the Arizona program range from zero to over $1000, with an average of about $199. This includes only the cost of the repair

[17] Not random. In fact, the sampling methodology of the study was never made clear. One of the problems that bedevils research of I/M programs is at once the importance and impossibility of finding a random sample of in-use vehicles. Participation is necessarily voluntary, but the vehicles whose owners most fear the outcome of I/M would be the least willing to be in the sample.

itself, not the cost of driver inconvenience. This latter cost can be quite high for some vehicles, with 22 percent of failing vehicles having more than one retest, and some having over 10 retests. Also, emission reductions in Arizona are not as high as expected. Emission reduction of both HC and CO were modest compared to what the EPA data were predicting.

All of the studies shown in Table 3[18] find costs of repair to be higher than predicted by EPA, and the emissions after repair to be higher than EPA's estimates. It has turned out to be more difficult to find and repair vehicles than early proponents of I/M had hoped. Next we examine one way to reduce those costs.

Potential for reducing costs through economic incentive policies

Given that repair costs in Arizona are so much greater than expected relative to emission reductions, it is naturally of interest to consider the potential cost savings available from the use of economic incentives, which in effect allow the transfer of emission reductions from one vehicle to another. We used the Arizona IM240 test results and repair data to construct a simple simulation model to compare a simulated emission fee policy with simulated CAC policies (Ando et al., 1998).[19]

The results of the simulation showed that the EI program could achieve emission reductions comparable to those achieved in the simulated CAC program at only 60 to 70 percent of the repair cost. These results indicate the potential of a policy of economic incentives, in reducing repair costs, but it is also important to keep in mind the fact that repair cost in Arizona is only about 35 percent of the total cost, most of the rest consisting of the various costs associated with emission monitoring. This sort of EI policy, where motorists have to pay and where all monitoring is done by lane tests, will not do anything to reduce monitoring costs. Thus, the emission fee analyzed here only results in a reduction in total costs of around 14 percent.

The Distribution of Costs and Motorist Avoidance

The use of emission fees for motorists would not deal with one other unfortunate characteristic of I/M programs that emerged as researchers began to look closely at the IM240

[18] Except the California I/M Review Committee Study. However, the costs of about $90 per repaired vehicle include evaporative and tailpipe repairs. This is estimate is close to the average of EPA's tailpipe and evaporative repair cost estimates.

[19] The simulated CAC policies simply kept track of which repairs would have been done under less stringent cutpoints. The emission fee policy allowed each motorist failing the emission test a choice of repairing the vehicle or paying a fee proportional to the excess emissions for each pollutant. In making the choice the motorist compared the fee calculated on the known emission test results and the sum of the repair cost and the fee based on the predicted emission reductions from repair. The predictions derived from a statistical model of emission test results, in which the independent variables consisted only of those pieces of information available to the motorist after receiving a diagnosis of the cause of excess emissions. For various fee levels, we compared fee results to the cost and results of CAC programs less stringent than the existing program. For each vehicle the simulation used the actual repairs and emission reductions actually observed, It was impossible to examine more stringent EI and CAC policies, since they would involve repairs that we did not observe.

data from Arizona and Colorado. There are a large number of vehicles that fail their I/M test, but apparently are never repaired to pass. Estimates are that their share is as high as 25% of the failing vehicles (Ando et al., 1999). These vehicles may not complete the testing process for a number of reasons. They could simply be still in the process of being repaired, or, they could have received a waiver (about 4 percent of failed vehicles in Arizona).[20] The remaining non-passing vehicles are sometimes referred to as "disappearing vehicles" because it is not clear why they never show up as passing the test. They may have been scrapped, or sold outside of the region. Or, more troublesome to the I/M program, they may be improperly registered or registered outside the region but still driven in it.

Actually, there was considerable indirect and anecdotal evidence of motorist avoidance under the state programs prior to the 1990 Amendments. In California, for example, a study that relied on random roadside emission tests found that vehicles had very similar failure rates both ninety days before their I/M test and 90 days after the test (Lawson, 1993). This phenomenon became known as "Clean for a Day" (Glazer et al., 1993). Avoidance of I/M may have become more difficult with the implementation of Enhanced I/M, but there is little evidence that it has been eliminated.

To look more closely at the differences between failing vehicles that are eventually observed to pass and those that are not (the so-called disappearing vehicles), we estimated a probit equation, in which the dummy dependent variable equals 1 if and only if the vehicle passes the test.[21] Explanatory variables are those vehicle characteristics we can observe such as age, type of vehicle (car or truck), and initial emissions of the vehicle.

The results of estimation of this equation for the Arizona data from January 1, 1995 to June 1, 1996 are shown in Table 4. A positive coefficient for a variable indicates that a higher value of the variable is associated with a greater probability a vehicle will pass the test. If the initial test was too recent, an owner may be less likely to have had time to successfully repair and retest the vehicle during the data-collection period. Trucks are more likely to be passing than cars in Arizona, which fits with expectations since cars face tighter standards or test "cutpoints" than trucks. If some of the disappearing vehicle problem is that the I/M program causes some people to avoid the program by not repairing, then we would expect tighter cutpoints to induce more of this behavior. Table 4 also shows that for HC and NOx, vehicles failing by a wide margin are more likely to have final observed tests that are failures, either because the repairs are more time-consuming (and not complete by the end of our sampling period), or because the costs of bringing such a vehicle into compliance is high enough to

[20] Personal communication, Rick Day, Arizona Department of Environmental Quality, April 1, 1998. We have not yet learned which vehicles in our sample received waivers.

[21] The probit model posits a latent variable Z^{*}, which is a score representing the tendency of the vehicle to be repaired successfully. Z^{*} is specified as a linear combination of the effects of observable characteristics *W*, plus a disturbance term reflecting the influence of the unobserved variables:

$$Z^{*} = \gamma W + \mu$$

where μ is distributed standard normal. The variable Z is observed if and only if $Z^{*} > 0$.

induce the owner to drive illegally, scrap the car, or sell it out of the area. Finally, older cars are more likely to linger without being fixed; this may reflect the fact that older cars are better candidates for scrappage anyway, and thus are more commonly pushed into the junkyard by impending IM240 repairs.

Table 4: Results from Probit Analysis of Failing Vehicles

Explanatory Variable	Coefficient	Standard Error	Significance
Date of initial test	-.00010	.000043	*
Light truck	.036	.017	*
Medium-duty truck	.23	.027	*
FAIL HC ONLY	-.48	.028	*
Fail CO only	-.26	.035	*
Fail NOx only	-.11	.029	*
Fail HC and CO	-.54	.032	*
Fail CO and NOx	-.29	.11	*
Fail HC and NOx	-.51	.035	*
Fail HC, CO, and NOx	-.63	.056	*
(HC g/m, initial – standard)*(failed HC)	-.12	.0057	*
(CO g/m, initial – standard)*(failed CO)	-.00062	.00035	
(NOx g/m, initial – stand.)*(failed NOx)	-.15	.0073	*
Age at initial test	-.067	.0023	*
Length of initial test (seconds)	-.014	.00011	*
Constant	5.1	.56	*

Source: Ando, Harrington and McConnell (1999)
Notes:
The dependent variable = 1 if vehicle is observed to be repaired to pass, 0 otherwise.
There were 82,786 observations, and the log-likelihood value is 25,833.849
* indicates significantly different from zero at the 5% level.

There is additional evidence from Colorado that the I/M program may induce drivers to remove vehicles from the I/M region. Stedman, Bishop and Slott (1998) find, through remote sensing, that vehicle emissions in adjacent counties outside the I/M region rise for model year vehicles that are subject to testing in the I/M region, but not for untested vehicle model years. The implication is that high-emitting vehicles are moving outside the region to avoid the cost and inconvenience of repair.

Motorists incentives under the current liability assignment are also influenced by the manner in which the burden of compliance is distributed among income groups. Under current I/M programs, the distribution of compliance costs among motorists varies a great deal. As we mentioned above, the Arizona program results show that repair costs for a single vehicle can vary from a few dollars for a gas cap replacement to several thousand dollars for a variety of control system problems from the catalyst to the air injection system.[22] The Arizona results also show that the anticipated repair costs differ substantially by age of vehicle, primarily because the probability of failure increases as vehicles age. The first two columns of Table 5 show first the probability of failure by model year, and then the average cost of repair by model year. Combining these two, column (3) shows that the expected costs by model year are 10 times higher for a fifteen year old vehicle compared to a four or five year old vehicle.

Table 5. Expected Costs of Repair in Arizona I/M For an I/M Cycle

Model Year	(1) Probability that vehicle will fail initial test (percent)	(2) Average Costs of Repair for failing vehicles ($/vehicle)[a]	(3) Expected costs of repair, all vehicles ($/vehicle) (1)×(2)	(4) Probability that a failed vehicle will never pass (percent)	(5) Average income of owner (in national sample)
1981	45.4	132	60	43.7	$38,400
1982	41.2	140	58	38.1	35,500
1983	38.5	148	57	38.9	39,000
1984	35.9	153	55	37.2	40,800
1985	28.8	155	45	32.8	41,700
1986	19.8	145	29	27.6	44,100
1987	14.2	142	20	25.1	46,000
1988	12.2	150	18	22.9	47,300
1989	8.1	144	12	18.5	48,000
1990	5.6	134	7	15.8	51,200
1991	6.8	152	10	18.6	52,000
1992	4.4	138	6	13.1	53,600
1993	2.6	130	3	8.1	54,900
1994	1.2	80	1	1.8	57,400
1995	1.0	62	0.59	1.1	$61,000

Sources: Columns 1,2,3,4: Arizona Enhanced I/M Data Base, 1995-1996
Column 5. 1995 Nationwide Personal Transportation Survey
Notes:
a. Includes both the expenditures reported by motorists and our imputations of costs when repairs are made but costs are not reported. For late-model vehicles these imputations include warranty repairs and therefore overstate the burden on the motorist.

[22] Most of the vehicles with high repair costs in the Arizona I/M program

In addition, Table 5 provides further evidence that older vehicles are much less likely to eventually pass the emissions test than newer vehicles. Of fifteen year old vehicles that fail the test (1981 model year), almost half never show up as passing. We don't know exactly what is happening to these vehicles, but they clearly face relatively higher costs of complying with I/M requirements.

How do the costs of repair fall on different income groups in society? This is a difficult question to answer because there is no data linking income directly with vehicles in an I/M program. We can shed some light on this issue by looking at car ownership by vintage. The last column of Table 5 links model year holdings to average income of vehicle owners.[23] It is clear that older vehicles are owned by households with lower average income, and these are also the vehicles with the highest expected repair costs. Assigning motorists the liability for repairs means that those least able to pay are likely to be paying the highest costs. This represents both a political and economic dilemma for the current liability structure. Politically, it has been difficult to enforce a regulation with such a regressive incidence. States have responded by allowing waivers for vehicle owners who have paid up to some repair cost minimum. However, the economic literature has argued that those with "shallow pockets" should, for efficiency reasons, be required to demonstrate financial responsibility *ex ante* (Boyd, 1997). Applied to motor vehicles, this would require potentially large up-front payments from motorists and would no doubt arouse intense public opposition. We talk about this in more detail below.

There is evidence that motorists have found many other ways of avoiding I/M compliance. We have already discussed how the stochastic nature of emissions from a single vehicle can mean that motorists have an opportunity to subvert the test by retesting a failing vehicle without repair. Decentralized programs have come under particular scrutiny because, it is argued, they present many opportunities for avoidance. For example, Hubbard (1998) found evidence of moral hazard problems in California's decentralized I/M program. His study finds that consumers are able to provide incentives to station mechanics that allow them to pass, and therefore consumers will shop around to find stations most likely to respond to these incentives. Monitoring and enforcement costs are likely to be higher in a decentralized program with thousands of different test stations.

ALTERNATIVES TO CURRENT I/M PROGRAMS

The empirical evidence on the performance of I/M is disappointing, at best. The large number of vehicles, the emission characteristics of individual vehicles, and the behavior of drivers who have an incentive to avoid the regulation together conspire to make the current I/M program with its assignment of liability to individual motorists so difficult to implement effectively. In this section we consider policies that assign liability elsewhere.

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[23] The data used to estimate these averages are from the National Personal Transportation Survey. See U.S. Department of Transportation, NPTS (1995).

No I/M Program

Some observers now believe that the best I/M program is no program. They argue that nearly two decades of failure of I/M programs is itself a pretty good indication that an effective and economical I/M program simply cannot be devised. For example, Coninx (1998) concludes:

> I/M programs have never been proven to perform according to the optimistic predictions of their supporters. Even when only the direct costs are considered, I/M programs are much less cost-effective than alternative strategies. When all the other social, environmental, and financial costs of IM programs are taken into account, there are strong indications that the programs do more harm than good to both society and the environment. (p. 32)

Coninx's critique refers specifically to Canadian I/M programs in British Columbia and Ontario, but by implications includes all U.S. programs since the Canadian programs are largely modeled on U.S. efforts.

Besides, rapid improvement in new vehicle emission rates and emission durability have caused some to question whether I/M is even necessary. As noted above, vehicle emissions are gradually declining not only for vehicles when they are new, but throughout the product life cycle. In other words, the average emissions of, say, a 1993 vehicle today (in 1998) are much lower than the average emissions of a 1988 vehicle were in 1993. Thus, the absence of I/M programs does not necessarily mean that air quality goals in urban areas cannot be met. However, other factors are critically important for reducing overall fleet emissions such as growth in the vehicle fleet, the change in fleet composition toward trucks which have to meet less stringent emissions standards, and average vehicle age.

Maintain the Current Assignment of Liability

Inasmuch as they account for well over half the costs of the current I/M program, finding a way to reduce monitoring costs is the essential component of any program to reduce the transactions cost of in-use emission programs. Two recently-developed technologies offer promise in reducing those costs: remote sensing, which was mentioned earlier, and on-board diagnostic (OBD) equipment. To be effective, both OBD and RSD would have to be supported by electronic vehicle-identification, another technology that has been a product of the revolution in electronics and microprocessors.

<u>Use remote sensing to supplement or replace lane testing</u>

Ever since its commercial development in the late eighties remote sensing has been put forward by critics of I/M as an alternative to the expensive and inconvenient lane test that all programs now require. The great advantage of RSD is the very low cost of testing, made possible by the nearly unbelievable productivity of RSD. RSD only requires a second's headway between vehicles, which means in principle that thousands of vehicles per hour can be monitored. In most cases the practical limitation is imposed by the number of vehicles passing the sensor. Thus, the estimated cost to operate a two-man team of remote sensors is about $200,000 per year. If we make a conservative estimate of 5,000 vehicles per twelve-hour day (about three per minute) the cost of RSD is only about 15 cents per reading.

Although inexpensive, RSD also suffers from a number of limitations. The most important one is the mirror image of its productivity: the very short vehicle exposure to the sensor. Since RSD only senses emissions for an instant, it cannot possibly provide, in a single test, the performance of the vehicle over the full range of driving cycles in normal use. Also, the requirements of the technology can limit the number of suitable sites. Multiple lanes or two-way traffic is acceptable, but readings are invalid if the sensor beam is cut by more than one vehicle simultaneously. Slight acceleration is acceptable, but if the vehicle is decelerating or coasting, then the sensor gives no reading. The most common locations are freeway on-ramps or uphill off-ramps that require some acceleration. RSD is also limited by the nature of the measurement taken. What is reported is the ratio of the pollutant concentration in the exhaust plume to the concentration of carbon dioxide. To convert this ratio to a measure in grams of pollutant discharged per mile of travel, which is how the emission standards are written, one must know the fuel economy of the vehicle when the measurement is taken.

RSD also provides better results for some pollutants than others. It works best for CO. Estimates of HC are difficult because unlike CO, HC is not a chemical species but the sum of many hydrocarbons, the composition of which in exhaust can be affected by the composition of the gasoline. Typically an RSD unit is "tuned" to recognize the three or four chemical hydrocarbon compounds most likely to be found in vehicle exhaust, perhaps adjusted at the site to reflect the local fuel composition. Until recently RSD units did not measure NOx at all, and there is still some question about its accuracy for this purpose.

Ever since RSD was first developed, critics of the existing I/M policy have proposed ways to use it to replace all or part of the customary lane testing regime (see Spencer, 1992; Glazer et al., 1993).The most radical would have replaced lane tests altogether with remote sensors. Not only is remote sensing cheaper; it is so cheap that it is quite feasible to allow multiple tests of the same vehicle. A network of sensors would be used, which would allow the average vehicle to pass a sensor several times each year. As noted above, multiple tests on the same vehicle are necessary to separate emission test error from vehicle-specific emission variation. At each station both the emission estimates and the vehicle identification would be recorded and transmitted to some central location. After some number of excessively high emission readings, the owner of a vehicle would be notified by mail and ordered to take some action. For example, the vehicle could be ordered to appear at a certified repair shop within a certain time, and the repair shop could notify the authorities when the repair was complete. A variant of this proposal has the offending vehicle being directed to report to an I/M testing station for an IM240 test. Either would cut the cost of monitoring by using RSD as a screen. An economic examination of these proposals shows that these proposals can reduce the cost of finding high-emitting vehicles by about 30 percent, compared to the cost of Enhanced I/M (Harrington and McConnell, 1993).

However, using RSD for monitoring purposes to identify high-emitting vehicles poses some problems of its own, or at least there are some unknowns about how it would perform in an enforcement environment. Certainly RSD has proven itself capable of providing useful estimates of aggregate emissions. When it is used in this way, however, no motorist has an incentive to attempt to avoid the sensors or camouflage emissions. If the sensor network is fixed, then motorists would be able to avoid them with some ease. A mobile network would be more difficult to avoid, but probably more costly to administer. Also, limitations on where sensors can be placed might allow knowledgeable motorists to avoid sensors entirely (and any motorist with a gross-emitting vehicle that is difficult to repair would have the incentive to become knowledgeable). Motorists might also be able to practice avoidance even if they must pass a sensor. As noted above, taking the foot off the throttle essentially eliminates emissions from the tailpipe, so coasting past the sensor might be a way for a gross emitter to avoid detection. Under these circumstances the reading recorded for the vehicle is likely to be the emissions as the vehicle that preceded it through the sensor, which, for a gross emitter, almost always has lower emissions.[24]

Whether these problems would severely affect the performance of RSD based I/M programs is unknown. The fact is we know little of whether RSD can easily be avoidable by owners of gross-emitting vehicles.

There must also be an effective procedure for what to do after a noncompliant vehicle has been identified. Notifying motorists by letter, as suggested above, requires the linking of the emission testing system to the vehicle registration system maintained by the Department of Motor Vehicles. Even then, not all motorists can be identified in this way; people frequently move and fail to notify the DMV. Presumably motorists who are not contacted or who ignore notices to obtain emission test or repair could face registration denial, but that could be difficult to enforce.

Yet another problem is the public acceptance of a monitoring system based on RSD. While RSD can accurately characterize emissions in the aggregate, there are concerns about whether it would be able to estimate emissions of a single vehicle with enough accuracy to be legally enforceable. (TRC, 1994).[25]

On-Board Diagnostics

On-board devices that continuously check emissions systems and signal motorists if controls are not working properly have been touted as the best hope for the future of vehicle emissions control. Some have even argued that OBD will obviate the need for any formal I/M

[24] See TRC Environmental (1994) for further discussion of problems with RSD.

[25] Some observers have also questioned whether an extensive RSD network would also raise questions of Big Brother.

program: those motorists whose OBD lights are on, signaling problems with the emissions control equipment, will take steps to repair their vehicles. However, what OBD more realistically provides is the potential for improved diagnostic and repair information, and, at best, the potential to lower the cost of enforcing the liability for vehicle repair.

If current OBD systems are working properly, the light-on will convey to motorists that emissions systems need to be checked. But, if motorists continue to have primary liability for repair, at least after warranty periods are over, there must still be some way of ensuring that repairs are actually carried out. Most emissions control failures, especially on recent model year vehicles, are not evident to the driver. Some repairs to the emissions control systems do result in improved fuel economy,[26] but some do not, and motorists are unlikely to know about potential benefits. Under these circumstances, owners are unlikely to voluntarily undertake repairs that may involve high costs and minimal or unknown benefit.

OBD may still have the potential to yield lower costs than traditional I/M because they allow for the possibility of new methods for identifying high emitters. The use of drive-by monitors or transponders have been suggested for finding the vehicles that are likely to need emissions repair. Transponders on the vehicle would convey the information from the OBD system to another party, either at a service station or at roadside.

In addition, OBD systems have been touted for their ability to allow for easier diagnosis of emissions problems, and for improving chance of repair. To the extent this is true, it would lower the cost of repair to motorists and would therefore result in greater compliance in a system in which motorists have liability for emissions. In fact, whoever has liability for maintaining emissions control equipment, to the extent OBD lowers the cost of repair by providing better information, compliance is likely to be improved.

History of OBD. Initially, the car companies implemented simple OBD systems in the early 1990s as a way to identify and diagnose when there were failures in the newly evolving Electronic Control Units (ECUs) that controlled emissions. However, California began to use OBD to regulate emissions in the 1994 model year vehicles and the Federal government followed suit for all vehicles sold nationally beginning with the 1996 model year. Under this second generation of OBD, so-called OBDII, EPA required that the light come on if emissions exceeded 1.5 times the new car certification level.[27] This rule creates a new difficult regulatory issue for motorist liability. This trigger point is very tight, especially compared with cutpoints used in current I/M programs which are more like 3-4 times the new car standards.[28] After the warranty period has expired, motorists will have sole liability for repairing vehicles whose light has come on, and some of those repairs may be very cost-ineffective. For example, some of the repairs in Arizona that involved only the improvement of HC emissions cost more than $1million per ton removed.

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[26] Ando, Harrington, and McConnell (1999).

[27] OBD devices do not measure emissions directly, but only infer emissions from the general performance of the emissions control equipment.

[28] For example, the cutpoints for 1991 and later model year cars in Arizona's current I/M 240 program are as follows: 1.2 g/mi HC, 20 g/mi CO, 2.5 g/mi NOx. By comparison, "Tier 1" standards for new 1994-96 model year vehicles are 0.25 g/mi HC, 3.4 g/mi CO and 0.4 g/mi NOx.

So, although OBD systems have the potential to reduce monitoring costs when motorists are liable for repairs, they may actually increase the incentives for avoidance because of the stringency of the light-on cutpoints. In addition, only new vehicles are equipped with OBD systems; to the extent these systems can reduce monitoring costs and improve repair effectiveness, it will happen slowly as the fleet turns over. There are other liability assignments for reducing vehicle emissions that may have the promise to reduce costs and be more effective even in the near term.

Alternative Liability Assignments

Empirical studies of I/M programs provide plenty of room to doubt that Enhanced I/M programs are achieving anything more than modest results. An important part of the reason is that in the current institutional arrangements motorist have both the opportunities and the incentives to avoid compliance. The past strategy of reducing the motorist's opportunities to avoid I/M has not worked. These same empirical studies have also raised questions about the original ethical justification of assigning liability to motorists, since they provide evidence that is consistent with the possibilities that the relatively poor emission performance of some vehicles is attributable to defects of design or durability that originate with the manufacturers or to the poor maintenance by the vehicle's previous owner.

Perhaps, then, it is time to think about changing the incentives, and that means finding other ways to assign liability, and other parties to assign it to. Below we examine four new approaches to I/M, beginning with one that only involves a modest change from current practices and is in fact underway, and proceeding to a solution that involves a quite drastic change, namely the separation of vehicle possession and vehicle ownership.

<u>Extending liability to the manufacturer</u>

Because of the high costs and modest success of the current I/M system that assigns liability to the motorist, there is a movement already underway to shift the liability of maintaining emissions controls through the life of the vehicle more toward manufacturers. To some extent, there has always been a shared responsibility between motorists and manufacturers because of the warranty coverage requirements on emissions control equipment. Both the state of California and the Federal government are currently considering extension of these warranty requirements as a way of increasing manufacturer liability. In addition, motorist liability itself creates incentives for manufacturers to improve the lifetime performance of emissions control equipment. Manufacturers do not want to be swamped with warranty-covered repairs or with complaints by motorists whose vehicles have failed I/M.

And there is persuasive and growing evidence that the burden of cleaner in-use vehicles has been shifted toward the manufacturers as cars have become cleaner and emissions controls more durable. Vehicles produced after 1991 appear to have much lower emissions at 50,000 miles than did vehicles of earlier vintages. We outline briefly here why this has been happening.

Emissions equipment warranties. Warranties on emission control systems and parts place liability with the manufacturer through the period of the warranty. Table 6 shows the past and current warranty provisions by the EPA for U.S. vehicles (California has its own warranty requirements). Warranties cover defective parts and the performance of the equipment to meet I/M requirements. The performance requirement means that if a vehicle fails an I/M test and is under the warranty period, the manufacturer is liable for the repair even if there is no defect in the equipment.

Table 6. History of Emission Component Warranties For Light Duty Vehicles and Light Duty Trucks

Vehicle Model Year	Section 207 (a) of the Clean Air Act (Defects)	Section 207(b) of the Clean Air Act (Performance)
1994 and Earlier	5 years/50,000 miles	1) 2 years/24,000 miles on components 2) 5 years/50,000 miles on emission control devices or systems
1995 and Later	2 years/24,000 miles	2 years/24,000 miles
	Certain specified components (Catalyst, ECU, OBD) 8 years/80,000 miles	Certain specified components (Catalyst, ECU, OBD) 8 years/80,000 miles

Until the 1990 Amendments to the Clean Air Act, manufacturers were responsible for defects in all emission control equipment and for the performance in use of major emission control devices or systems for 5 years or 50,000 miles, whichever came first. Minor component problems had only a 2 year or 24,000 mile warranty. These warranty requirements continued through the 1994 model year, but the Amendments actually reduced the warranty period for most components and systems for 1995 and later model years. As Table 6 shows, the 1995 and more recent model year vehicles only have to meet the 2 years, 24,000 mile standards for almost all parts and components. It is only the major components such as the catalyst, the Electronic Control Unit and the OBD system that have the longer 8 years or 80,000 mile requirement.

It is unclear what impact warranty requirements have had on manufacturers. The presence of the 5 year/50,000 mile warranty through the early 1990s may have pushed manufacturers to build cleaner cars. The change in warranty requirements after 1994 provide a mixed message--some components face stricter warranty requirements, others more lenient. It is clear, however, that the EPA is moving in the direction of requiring stricter warranty requirements for federal "Tier 2" vehicles (those which have to meet the next round of stricter federal new car standards). It is likely that the warranty period on these cars will be 120,000 miles for major parts--California has already made this requirement and is extending this warranty period to trucks as well. Longer warranty period mean higher costs for manufacturers in repair and replacement costs and give them a clear incentive to improve the emissions performance of vehicles, at least through the warranty period.

Concern about customer satisfaction. Even after the warranty period is over, manufacturers do not want to deal with motorist complaints about I/M failures. There are reputation effects associated with vehicles makes that are known to have high failure rates. This provides some incentive to improve emissions control technology so that it is longer lasting. For example, the fuel injection technology implemented in the 1980s allowed controls to last longer. Currently, some manufacturers are trying to develop an air-fuel sensor instead of O2 sensor to improve the life time performance of vehicle emissions.

New car certification also extends liability to the manufacturer. Recent changes in the new car certification process have also begun to shift the responsibility for in use emissions more to the manufacturer. In the past, new car emissions certification had to be completed before cars were sold. Prototypes were driven for 100,000 simulated miles in the laboratory in order certify an engine family. Under the new rules, manufacturers with a good track record on emissions compliance can sell cars and certify that they meet the emissions standards by testing samples of in use vehicles. This regulatory change is likely to give manufacturers even more incentive to maintain performance of vehicles in use.

<u>Subsidize repair</u>

In California a vehicle subsidy program that would transfer a small part of the responsibility away from motorists has already been debated in the state legislature. Under the proposed program, vehicles facing high repair bills could qualify for a "co-pay" from the state to complete repairs. Motorists would have to qualify for the repair assistance, with eligibility determined by income at or below 175 percent of the federal poverty level (about $27,000 for a family of four). The eligible motorist would have to pay $250 and then could qualify for a subsidy of the remainder of the repair bill. The funds for the subsidy would come from a smog impact fee levied on vehicles brought into and registered in California from other states.[29] The California program would be grafted onto the existing I/M program, and therefore would not effectively address the main transactions costs problems identified here. Since periodic lane tests will still be required of all vehicles, monitoring costs will be very high. Likewise no discretion is allowed in choosing which vehicles to repair; that is determined entirely by the I/M test results.

It is possible, however, to use a more extensive repair subsidy program to reduce the high transactions costs of I/M programs by shifting the financial responsibility for vehicle repair and maintenance away from individual motorists.

One way such a program could work would be to use a RSD network to identify high emitters, who would be notified immediately by billboard of their emission status and advised to report to a repair facility. Most likely these facilities would consist of privately-owned

[29] These vehicles don't meet the stricter California emission standards, which are generally more strict than the Federal standards in effect in the other 49 states.

repair shops that have been certified by some authorizing body as being qualified to do emission repair. At the repair shop a diagnostician or mechanic would examine the vehicle and make a decision whether the repairs are cost-effective.

The revenues to support the program could come of out general tax funds or, more likely, from a tax or fee associated with vehicle ownership and use, such as a supplemental registration fee or an increment to the gasoline tax. Repair subsidies thus would shift some or all of the cost of I/M away from the drivers of dirty vehicles and onto motorists of all vehicles, or onto taxpayers in general.

Repair subsidies would thus reduce or eliminate avoidance incentives and would probably make it possible to use less costly monitoring methods to identify repair candidates. The greatest potential weakness of this sort of subsidy program is that it doesn't subject repair decisions to a market test. At the repair shop, that is, who decides whether repairs are cost-effective? It would be awkward and inefficient to assign this responsibility to government employees, who would be required to visit repair shops to approve each repair. But if the garage is to make the determination of which vehicles to repair, what contractual mechanism would guarantee that the most cost-effective vehicles would be repaired? If repair shops are reimbursed for all vehicles repaired, then they have an incentive to repair all vehicles and not necessarily in a least-cost manner.

One of the virtues of a subsidy program is that it allows a great deal of flexibility in designing mixed systems, in which the responsibility for I/M would be shared between the motorist and the government. For example, a subsidy program could be an insurance program that limits motorist responsibility to some upper limit. That is, it could accomplish the same objectives of the current waiver provisions without actually requiring the costly, often ineffective repairs that are part of the current waiver program. It could also be means-tested, giving preference to vehicles belonging to low-income motorists. However, as motorist responsibility grows, so does the incentive to avoid that responsibility.

Centralize liability for emissions

A more drastic approach would separate vehicle ownership from emission liability and remove the latter from motorists. Liability for emissions would be assigned to other parties, presumably firms with expertise in vehicle emission repair, each of whom would be responsible for the emissions of a large number of vehicles. As above, economic incentives would be applied to the sum of emissions from all vehicles in the firm's subfleet, and the firm would be responsible for bringing in vehicles in need of repair.

The trouble with the current emission warranty system--at least as a solution to the in-use emission problem--is that only affects new vehicles, which is not where the serious emission problems are. The current program is also potentially inefficient, since warranties are enforced against individual vehicles, which is less efficient than enforcing them against aggregate emissions. Moreover, most of the really gross-emitting vehicles are now out of warranty, and any plans to extend warranties of new vehicles would necessarily ignore these vehicles.

Suppose, however, that the responsibility for vehicle emissions were divided among a set of firms, each of whom were responsible for the emissions of a group of vehicles. The performance measure is no longer the emission rates of individual vehicles, but the *total* emissions of all vehicles controlled by each firm, as determined by a remote sensing network maintained by the air quality authorities. As noted above, RSD measurements of the total emissions of large numbers of vehicles can be quite accurate, especially if, as in this case, motorists no longer have any incentive to avoid the sensors. The conditions are ideal for the use of economic incentives; for example, the firm would pay emission fees if the total emissions of all its vehicles exceed some predetermined level.[30] This approach is especially attractive since it automatically takes into account not only the emission rates of the vehicles in the subfleet, but how much they are driven, since the more vehicles are driven the more likely they are to pass a sensor.

But how would a state or local metropolitan air quality agency arrange for other parties to take over responsibility for the emission control of all vehicles, and who would these parties be? One obvious candidate would be the vehicle manufacturers, especially since they already have some responsibility for in-use emissions under warranty provisions. However, I/M program implementation is now delegated to state and local authorities, who would not have much leverage over vehicle manufacturers except, perhaps, through their dealers. This suggests that either I/M should become a federal responsibility or that the policy should be directed at dealers rather than manufacturers. In any case, one can imagine practical and political difficulties if one were to require a group of firms to take over responsibility for I/M.

Suppose, instead, that these responsibilities were voluntary. For example, the vehicles in the fleet could be partitioned into subfleets, and then the responsibility for total emissions in each subfleet could be auctioned off to the lowest bidder, just as public works contracts are now. As in the case of subsidies, the necessary revenues to pay the contracts would come from a vehicle registration fee surcharge or new vehicle sales tax. A firm with a winning bid for a group of vehicles whose emissions were above a specified level would then pay an annual fee based on the amount by which the emissions of the subfleet exceeded the agreed upon limit.

This proposal would reduce monitoring costs and motorists' incentives for avoidance, and put the incentives for proper vehicle maintenance on the right party. What it would not do is to provide manufacturers with an incentive to design inherently reliable and easy-to-repair emission systems, because the party buying the vehicle is not necessarily the same as the party responsible for emission repair. To take care of this problem requires yet another step.

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[30] It would also be possible to devise a marketable permits scheme if desired, but we only discuss the fee approach here.

Vehicle leasing

In the past few years three- or four-year leases of new vehicles have become a popular alternative to installment purchase, especially at the high end of the market. A vastly expanded system of vehicle leasing could become the basis for a new system of in-use emission management. The responsibility for maintaining the vehicle, emission control system included, would rest not with the motorist but with the owner of the vehicle, whether the manufacturer or some other party. As in the preceding case, each leasing firm would pay fees based on the sum of emissions by its lessees, as determined by remote sensing. Since leasing companies are buying the vehicles, they would be able, in their purchase decisions, to give manufacturers the proper durability incentives.

Motorists could be encouraged to choose leasing arrangements over outright ownership by changes in income tax policy to favor leasing even more than now, and so as to encourage leasing even of older vehicles by low-income households. The vehicle emission control policy would now be directed at the lessor firm, who would presumably hold leases on a large subfleet of vehicles.[31]

The authorities would also regularly pass on to each firm, along with its bill for emissions, the readings for the individual vehicles. These individual readings may be too inaccurate and unrepresentative to use for regulatory purposes, but they would be valuable indicators to the firm of individual vehicles in need of repair. Each firm could adopt its own decision rules for how to use these individual RSD readings, as well as the additional conditions to be placed on lessees to ensure that malfunctioning vehicles are repaired in timely fashion.

Such a momentous change in vehicle ownership institutions would have many other consequences, the totality of which would be impossible to estimate before the fact. The additional control of vehicles and vehicle use would probably make it easier to deal with some other externalities and enforcement problems concerning vehicle use, including uninsured motorists, prevention of unlicensed or delicensed drivers, and possibly car theft. However, it would also be likely to make it more difficult for low-income households to obtain vehicles, reducing their mobility. It is questionable whether such vast changes in the current way of life can be justified solely on the basis of air quality improvements; other justifications would be needed.[32]

CONCLUSION

I/M has been a disappointment. Our review of the existing in-use emission reduction programs persuades us that I/M will continue to disappoint as long as motorists are held responsible for the emissions of their own vehicles. To a considerable degree this

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[31] Robert Slott has proposed vehicle leasing as one of a number of options that could be offered to motorists which would shift responsibility for emissions reductions to other parties (personal correspondence, December 15, 1998).

[32] See *Washington Post*, Sunday, December 13, 1998.

conclusion is shared by the EPA and other air quality authorities, who have responded by forcing manufacturers to extend warranty provisions on new vehicles, in effect pressuring manufacturers to reduce emission rates in new vehicles and make emission systems in new cars more durable and impervious to poor maintenance by the owners. This approach is piecemeal and inefficient. It requires manufacturers to ensure the emission integrity of each vehicle, even though all that is required for air quality purposes is to control the total emissions. It is not likely to be very effective, at least in the short run, because it does not do anything about the emissions of existing vehicles. Given the long life expectancy of vehicles now being manufactured, it will take a very long time for an extension of manufacturer warranty on new cars to have an appreciable effect on fleet emissions.

If more rapid reductions of in-use emissions are desired, we will have to rethink the allocation of responsibility for in-use emissions in a more fundamental way. We believe that alternative assignments of liability can reduce the cost of monitoring and enforcement of I/M, reduce the incentives of motorists to avoid maintenance and repair, and, by providing more flexibility about which vehicles to repair, increase the efficiency of I/M as well. We have discussed a variety of policy instruments for shifting liability from motorists, and in Table 7 we compare how they affect the transaction costs associated with existing I/M programs.

As shown, each of these instruments address at least some of the transactions cost categories characteristic of I/M. In particular, by shifting responsibility from motorists, all remove the motorists' incentive to avoid emission repair. However, they only remove a positive incentive; they do not put any incentive for motorists in its place. Under any of these approaches, the utility-maximizing motorist would be indifferent to emission repair. Therefore, motorist goodwill would very likely be a valuable, perhaps even essential, component of all these approaches. It would be useful to accompany the introduction of any such policy by a media campaign to inform motorists of the importance of clean cars. If motorists would embrace regular vehicle maintenance as beneficial to the environment, just as homeowners have largely embraced recycling, it could have a major effect on in-use emissions. That sort of motorist cooperation would seem to be impossible in the current coercive environment of I/M, but it might be quite feasible if the costs of voluntarism were limited to the occasional inconvenience of bring vehicles to a repair shop, and did not include emission repair costs.

Table 7. Alternative Approaches to Sharing Emission Liability: Summary of Characteristics

Policy	Transaction Cost Category: Motorist avoidance incentives	Transaction Cost Category: Monitoring costs	Transaction Cost Category: Transferability of emission reductions	Manufacturer Incentives to produce durable vehicles
Extended warranties[a]	Depends on length of warranty. Some effort required to ensure motorists bring in vehicles to be repaired.	No effect on existing vehicles; new vehicles could be identified with OBD.	Some within-manufacturer transferability possible if emission averaging is allowed. But potential savings are low.	Strong
Motorist subsidies or emission repair insurance[b]	Depends on subsidy levels. If high and broad, there will be little incentive to avoid repair.	Substantial cost reduction if gross emitters can be identified by remote sensing or OBD.	Difficult to overcome agency problems if private mechanics are given discretion over repair decisions.	Weak
Centralized repair liability[c]	Minimal incentive to avoid repair.	Public costs could be low, since average subfleet-specific emissions can be estimated by RSD. Private costs are uncertain and depend on the ease of winning motorists' cooperation.	Emission reductions are quite transferable. Well-adapted to emission fee or tradable permit regimes.	Weak, unless manufacturers are parties responsible for repair
Mandatory leasing[d]	Minimal incentive to avoid repair.	Lowest costs.	Emission reductions are quite transferable. Well-adapted to emission fee or tradable permit regimes.	Strong

Note: The baseline for the implied comparisons in the table is the Enhanced I/M program as promulgated by EPA in 1992.

Other comments:

[a] Only applies to new vehicles; therefore no immediate effect on emissions.

[b] Public funding source required.

[c] Political problems if liability for groups of vehicles is assigned by fiat. High administrative startup costs if liability is auctioned off.

[d] Possibly serious political opposition.

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