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Fees in an Imperfect World

An Application to Motor Vehicle Emissions

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RESOURCES FOR THE FUTURE

Fees in an Imperfect World: An Application to Motor Vehicle Emissions

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Abstract

This paper compares an emissions fee on measured vehicle emissions rates to a mandatory regulation that requires all vehicles to maintain emissions below a minimum standard. We model the motorist's decision under the fee policy and simulate the fee and regulatory policies using data from an emissions inspection program that includes test and repair information for more than 50,000 vehicles. Under ideal conditions with perfect information and no subsidies, the fee on emissions rates performs substantially better than the regulatory policy. When more realistic modeling of available information and market conditions are included, there is little difference in the cost and effectiveness of the fee and regulatory programs. In particular, we find that the ability of the polluter to assess the emissions and cost outcomes of is critical importance for the performance of the fee policy.

Key Words: pollution fees, emissions control, vehicle pollution, inspection and maintenance

JEL Classification Numbers: Q52, Q53, Q58

Contents

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I. Introduction

Environmental economists long have championed economic-incentive policies, such as taxes and tradable permits, as cost-effective alternatives to traditional command-and-control (CAC) regimes. Attempts to put theory into practice may be complicated, however, when the polluters in question are myriad individual agents facing high transaction costs and possessing imperfect information about pollution-reduction technology and costs.

Such problems are likely to plague efforts to use incentives to increase carbon sequestration and to reduce nitrate and chemical runoff from U.S. farms (e.g., Khanna, Isik and Zilberman 2002). Similar difficulties could reduce the cost-effectiveness of incentive policies aimed at reducing toxic emissions from small sources, such as dry cleaners. This paper examines ways that a fee policy may fail to live up to its potential for cost savings over a uniform regulatory approach in the particular case of reducing emissions of air pollutants from aging cars.

U.S. air quality legislation and regulation has sought for several decades to reduce air pollution from motor vehicles. The most effective and important policy to this end has been a series of increasingly stringent emissions certification standards for new cars. However, the equipment responsible for controlling pollution in certified engines can degrade with time and use, and air quality management authorities have struggled for years to develop effective and politically acceptable policies to improve emissions performance over the life of each vehicle.

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The success of such policies in controlling emissions "in-use" has been decidedly mixed. On the one hand, there is evidence that emissions of constant-aged vehicles have declined steadily in recent years (Stedman et al. 1994.) The main reason for this improvement has been rapid technological change in emissions-control equipment, which was encouraged by the more demanding warranty requirements of the Clean Air Act of 1990. On the other hand, no similar successes have been experienced in inspection and maintenance (I/M) programs. Early state and local I/M programs have been shown to be relatively ineffective (see e.g., Lawson 1993), although their costs also were low. Accordingly, the 1990 Amendments to the Clean Air Act directed the U.S. Environmental Protection Agency (EPA) to develop an "Enhanced I/M" program to deal with perceived inadequacies in the state programs (EPA 1992.) However, it is clear that Enhanced I/M is not nearly as cost-effective as the EPA had expected. For example, Harrington, McConnell and Ando (2000) found the costs of the Arizona program to be about what the EPA had predicted,[1] but the emissions reductions were only about a third of what the EPA predicted.

Economic theory predicts that if there are large differences in the costs of control and in the resulting emissions from different sources, the cost savings from economic incentive policies, such as fees, should be large (Newell and Stavins 2003). This argument, for the most part, has assumed asymmetric information on the part of governments and polluters. Polluters are believed to have good information about their own costs of pollution control, but these costs are not known to the regulators. Hence, cost savings should be large for a fee policy compared to regulation. Because there are great differences among vehicles in the costs of repair and changes in emissions, this sector may be a case where fees would be relatively cost-effective. However, the cost savings from fees will not be as great if vehicle owners are uncertain about the outcome of their attempts to reduce pollution. Other studies have looked at different types of uncertainty, particularly those that have to do with enforcement. For example, Segerson (1988) and Cabe and Herriges (1992) explore the problems associated with developing a pollution-reduction incentive policy when there is asymmetric information about abatement effort and the link between effort and ambient pollution levels is stochastic. Our paper models the situation in which polluters have ex ante uncertainty about the

[1] The Enhanced I/M rule was a "major regulation" requiring a regulatory impact analysis that, among other things, estimated the costs and emissions reductions expected to be achieved (see EPA 1992.)

outcome of their attempts to reduce pollution. This issue has not been addressed in the literature, but it is likely to arise in a number of contexts and may result in a serious loss in efficiency for economic-incentive policies. We explore the likely effect of such uncertainty on the cost-effectiveness of a vehicle-fee policy relative to regulatory policies.

We model other possible impediments to effective use of fees as well. One of these is the presence of transaction costs. Polinsky and Shavell (1982) examine the importance of transaction costs in affecting the efficiency of Pigovian taxes. However, most of the U.S. literature has focused on transaction costs associated with permit programs. Stavins (1995) and Cason and Gangadharan (2003) highlight the role that transaction costs can play in causing the outcome of a tradable permit program to deviate from the least-cost outcome.

Despite potential limitations, there is ongoing interest among economists in using economic incentives to deal with motor-vehicle pollution (West and Fullerton 2002.) Economic theory and earlier simulations (Sevigny 1998; Harrington, McConnell and Alberini 1998) suggest that there may be gains to be achieved if economic incentive policies are substituted for the more rigid regulatory approach in use under current I/M programs. The simulation model in this paper advances the literature by using a detailed representation of the multistage decision problem facing the motorist under an emissions-rate fee policy and takes particular care to specify the information available to the motorist at the time each decision is made. In addition, the model explicitly includes detailed representation of transaction costs, including the time and travel costs associated with visiting a repair shop or test facility and the cost of diagnosing emissions test failures. Variation in the value of time across motorists also is accounted for in the simulations.

With this more detailed and realistic representation of decisionmaking behavior, we find that while a fee policy theoretically can improve the cost-effectiveness of motor-vehicle regulation, the advantages of economic incentives are not as clear in the imperfect, real world. We examine which factors have the greatest effect on the performance of a fee policy relative to the mandatory program and find that ex ante information about the effectiveness of potential repairs and, therefore, future costs, is by far the most important. Our results suggest that making the fee-rate policy efficient requires more than establishing appropriate fee rates and applying them to measured emissions; it also requires that households have sufficient information about the costs and benefits of alternatives to paying the fee to make the right economic decisions.

We first provide information and background on the emissions problem for vehicles and the unique data to be used in the simulations. We then lay out the model of motorists' decisionmaking in the context of the policies to be examined, we describe the simulation methods and assumptions, and we then define the various scenarios to be studied. Finally, we describe the results of the simulations and draw conclusions.

II. Background and Data

In this paper, the regulatory program that provides the basis of comparison of the CAC policy to a fee alternative is an emissions inspection program in Arizona. The data are from the program in Maricopa County, which includes the Phoenix metropolitan area. Maricopa County has had a biennial, centralized Enhanced I/M program in place since 1995. Each vehicle registered in the county must be subjected to an Enhanced I/M test at test-only stations every two years. The test consists of a four-minute tailpipe emissions test designed by the EPA (the IM240 test) an examination of certain components of the evaporative emissions system, and a check to ensure that the vehicle has not been tampered with.[2] Although the Arizona program does require some evaporative emissions repair, our analysis focuses entirely on tailpipe emissions.[3] Any motor vehicle with emissions rates of hydrocarbons (HC), carbon monoxide (CO), or oxides of nitrogen (NOx) that exceed a set of emissions standards, or "cutpoints," must be repaired to meet the standards to remain registered.

This paper utilizes data on vehicle tests and repairs from the Arizona program for January 1995 through May 1996 for a sample of 56,706 of the vehicles that failed the test over this 17-month period.[4] When a vehicle fails, it is required to be repaired and retested until it passes. Each time it comes back for a retest, the owner must submit a repair

[2] Many of the "tampering" violations also appear to involve evaporative emissions. In Arizona, the most common "tampering" repair is the replacement of a damaged or missing gas cap.

[3] Evaporative emissions are those that are emitted from other parts of the vehicle besides the tailpipe. Because it is impossible to measure evaporative emissions cheaply, they provide no base for determining the kinds of emissions fees we examine.

[4] There were initially 135,734 failing vehicles out of a total of 995,904 tested vehicles during the entire 17-month period. We cleaned the data extensively, dropping vehicles that were plagued by data problems (e.g., bogus license numbers.) We also dropped failing vehicles that had no retests at all because we had no repair information for them. Finally, for the purposes of the simulations in this paper, we dropped vehicles that had rounds of repair that were not recorded to have any costs or repairs, since it is impossible to tell whether those records represent missing data or merely the presence of car owners that retest their vehicles without having repaired vehicles in hope of a more favorable test outcome.

summary showing repairs made and their costs. There are in total 68,404 rounds of repair in our data.

Two data constructions are necessary to quantify repair cost-effectiveness. First, it is convenient to have a single measure of the “output” of vehicle repair in the form of reduced pollution to develop a simple, if crude, notion of cost-effectiveness. Thus, we create a measure of “pollution” that is a weighted sum of emissions of the three pollutants that are the targets of the program. In grams, pollution = HC + .1CO + 2.5NOx. The weights are based on estimates of the ratios of marginal benefits that result from reducing the emissions rates of the pollutants as calculated by Small and Kazimi (1996) for the Los Angeles region. Second, the repair-cost data from the Arizona program contain many rounds of repair with costs recorded as zero even though repairs are reported as having been performed. This phenomenon simply may reflect missing data. However, there are other legitimate explanations. Repairs done under warranty may be reported as free, and zero costs may be reported for repairs done at home by do-it-yourself mechanics. Regardless of the explanation for the zero reported costs, it is important to have an idea of the costs of all repairs performed (regardless of who is performing them and paying the bill) to determine the total costs to society of I/M-induced repair. Thus, we use the data with non-missing costs to generate an equation that is, in turn, used to impute costs for rounds of repair that report costs to be zero.[5] This gives us an estimate of costs for each vehicle that is repaired. We refer to these as the full social costs of repair.

The data reveal much repair heterogeneity. On average, repairs do seem to reduce emissions rates[6] and improve fuel economy. However, there is great variation in those changes; it is not uncommon for some emissions rates to appear higher after a round of repair or for recorded fuel economy to worsen. Costs, too, are variable. Regardless of which set of cost figures is used, average repair costs are in the neighborhood of $100 per round of repair, but while some vehicle owners dealt with emissions-rate problems with essentially no expenditure, others spent more than $1,000 on a single round of repairs.

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[5] For more information on the methodology for imputing repair costs, see Ando, McConnell, and Harrington (2000).

[6] The raw emissions-rate data reported from the Arizona program are not consistent across tested vehicles. This is because the test protocol allows vehicles to “fast pass” or “fast fail” in less than the full 240 seconds of the test if early readings indicate that they are particularly clean or dirty. To have emissions-rate test results that are consistent across vehicles, we forecast full 240 second readings from fast-pass or fast-fail results; for a detailed discussion of the method involved, see Ando, Harrington, and McConnell (1999).

Variation in repair costs and outcomes translates into large differences in the cost-effectiveness of repairs across vehicles. The reduction in aggregate "pollution" rates a car owner can expect to get for a dollar of repair has a standard deviation (around 0.3) that far outstrips its mean of only 0.05 to 0.06 g/m per dollar.

Thus, emissions reductions from motor vehicles might be accomplished much more cost-effectively than the current I/M system, which requires repair of all vehicles with emissions above the I/M standard. Figure 1 illustrates this point. The figure shows the relationship between costs and emissions reduction from repairs. The dark line traces repair costs and emissions reduction from vehicles in our sample as they occurred in real time in the Arizona I/M program from January 1996 to May 1997. The lower line shows costs and emissions reductions taking the most cost-effectively repaired vehicles first and then moving up to successively less cost-effective repairs. The backward bending part of that curve reflects the fact that some repairs actually increase emissions. The potential for more cost-effective repair is striking—about 99 percent of the emissions reduction of the full I/M program could be obtained at only about 57 percent of the cost if only those vehicles with the potential for the most cost-effective repair were fixed.

Whether economic-incentive policies such as emissions fees are able to capture all of these efficiency improvements depends on many real world conditions.[7] We compare a world in which there are no impediments to the efficient outcome under fees to one that includes realistic constraints and costs that motorists are likely to face. We explore which conditions have the have the greatest effect on reducing the efficiency of fees relative to the CAC regulatory outcome.

III. Design of the Policies and Simulations

IIIA. Modeling Decisions under CAC and Emissions-Fee Policies

To explore the difference between the mandatory regulatory program and emissions fees for reducing vehicle emissions, we start by defining two polar cases. One

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[7] It is important to note that the emissions fee we examine here is an emissions fee rate (in grams/mile) that is comparable to what is required under the CAC regulation. A pure emissions fee (on total grams, for example) would allow for all possible adjustments, including reductions in driving and choice about type of vehicle in addition to the repair choices examined here. Due to the limitations of the data and our interest in comparison to the CAC policy, we consider only a range of possible efficiency; however, the extent of these possible efficiency gains is large and is shown in Figure 1.

represents a world in which car owners make decisions based on full information and full knowledge of costs, and they experience no transaction costs as a result of their decisions. We refer to this as the "perfect world." The other, which we call the "real world," reflects more realistic conditions under which motorists must operate. For example, they may not have full information about the emissions reductions or fuel economy benefits or there may be subsidies that cause motorists to ignore the true social costs of repairs. Finally, there can be sizable transaction costs associated with each decision, and these can vary under different policies. We describe first the perfect world cases and then the real world cases and the reasons for the differences in the two.

Perfect world. In the perfect world, motorists have full information about their vehicles' emissions and about the costs and outcome of repairs and any resulting improvements in fuel economy. In addition, there are no transaction costs, such as costs of getting vehicles tested or costs of getting to and from repair sites.

Under the CAC policy, owners must find out their vehicles' emissions and get vehicles repaired so that the emissions are less than or equal to the maximum allowed emissions levels, or cutpoints, which we designate E_c. There are three pollutants (HC,CO and NOx) and each vehicle must comply with all three cutpoints. All repairs must be done, even those that may have high costs and very little emissions reductions. Total emissions reductions and costs can be determined by summing over all vehicles that fail the test in the region.

Under the fee policy, motorists must make decisions about whether to pay a fee based on their vehicles' current emissions rates or repair their vehicles and pay either no fees (if the vehicle complies with the cutpoints E_c) or smaller fees after repairs have reduced emissions. The fee after j rounds of repair is fee_j and is defined as

$$fee_j = \max\left\{ \sum_{k=HC,CO,NOx} \left(t_k \left(E_{jk} - E_{ck}\right)\right), 0 \right\} ,$$

where t_k is the fee rate, per gram-per-mile of emissions of pollutant k, per year; E_{jk} is the emission rate of pollutant k after j rounds of repair; E_{ck} is the cutpoint for pollutant k.

The net costs of repair include the full repair expenditures (C^R) and the monetary value of any fuel economy changes that result from repair (F). Motorists may undertake several rounds of repair, j, to reduce their vehicles' emissions, at which point they pay a fee equal to fee_j for any emissions that still exceed the cutpoint limits. Total costs are defined as

$$C = \sum_j \left(C_j^R - F_j \right) + fee_j .$$

In the perfect world where motorists have full information about the costs and emissions reductions from repair, they simply choose that number of repair rounds, j, that minimize the costs of repair (there are zero repair rounds if the lowest cost option is to pay the fee up front).

The fee policy clearly will be better than the CAC alternative for any target level of emissions reductions, since only the most cost-effective reductions will be made.

Real world. The real world in which motorists actually have to make decisions is likely to differ from the perfect world modeled above in a number of ways. In both the CAC regulatory policy and the fee policy, there are likely to be transaction costs. These costs include getting a vehicle's emissions tested and the time and money costs of getting to and from repair facilities. These costs can vary with the situation faced by the individual motorist. In addition, as discussed above, motorists do not have complete information about costs, emissions reductions, and fuel savings from repair and they may have subsidy options.

Under the CAC policy, motorists in the real world will have to repair vehicles and pay any transaction and other costs associated with repair of their vehicles. In certain cases, such as when a vehicle is still under warranty, they may be able to avoid paying the costs of repair. But the warranty does not affect motorists' decisions under the CAC policy because the repair is required regardless of who pays the cost. The absence of a warranty could affect willingness to comply with the regulatory policy, but we do not model compliance in this analysis—we assume all motorists comply with the rule.[8]

Under the fee policy in the real world, motorists' decisions are much more complex. Because motorists do not know ex ante the costs or emissions reductions from undertaking repairs, the decision process becomes sequential. If their emissions exceed the emissions limits, they must first decide whether to pay the fee or get an initial diagnosis of the problem and potential repair solution. They may know the cost of the

[8] See Hubbard (1998), for example, for an analysis of the incentive for repair shops to comply with I/M program requirements.

initial diagnosis but they have very little information at that point about the problem or the cost of fixing it. If they decide to get the diagnosis, they will then have more information on which to base a decision about whether to undertake repairs. Once the decision has been made to undertake the first round of repairs, motorists will then know the resulting emissions, and, if the vehicle is still in violation of the cutpoints, they can decide whether to pay a fee or consider another round of repair. Thus, imperfect information at each stage results in this sequential decision process, with decisions made at each stage that may or may not be cost-effective.

The fuel economy benefits are related to the repairs motorists elect to have done under the fee policy. However, because motorists do not know with certainty the outcome of repairs, they also do not know the fuel economy benefits of repair with certainty. The sequential decision process also is dependent on the expectations about fuel economy. We model the initial real world case as one in which motorists are not aware at all of the fuel economy benefits and do not take them into account in the decision process.

Finally, in the real world scenario, we allow for the fact that some vehicles are going to be under warranty. Emissions equipment is warranteed for between two and five years. Therefore, owners of relatively new vehicles will not account for the costs of repair in making decisions and their decisions will be inefficient from a social perspective.

We explore the importance of each of these assumptions in the comparison of the CAC and fee policy by simulating the vehicle testing and repair process. The next section describes the method we use to conduct those simulations.

IIIB. Simulation Methods

We simulate the CAC program and a fee policy under both the stylized and more realistic assumptions described above. The vehicles in our simulations are those vehicles that failed the I/M test in Arizona, as described in Section II. Many vehicles have more than one round of repair because in the Arizona I/M program more than a third of those that failed initially failed again after the first repair attempt. Therefore, the unit of analysis in our simulations is the repair round. The simulations replicate each motorist’s action or decision at each round under the different policies. Use of the Arizona dataset constrains us to a maximum emissions reduction for each vehicle of the amount occurring under that program, since we have no evidence about additional reductions. Also excluded is the possibility of repair on any vehicle that passes the Arizona test. Both these limitations will tend to reduce the cost-effectiveness of fee policy in the simulations relative to what they might be in a real setting, so the evidence here can be considered a lower-bound estimate of the relative cost-effectiveness of the fee policy.

There are a number of vehicles that passed the tailpipe tests in the Arizona program but that are still recorded as failing the I/M test. Without better information, we treated these vehicles as having emissions-related tampering or evaporative system repairs. In both the CAC and fee policy simulations, we treat these repairs as mandatory and the emissions reductions and associated costs are carried along in the reporting of the results of both simulations.

For each simulation, we track the total costs to motorists of repair; the full opportunity costs of repairs, including costs imputed to repairs that appear to be home or warranty repairs; the monetized value of fuel efficiency changes resulting from repair;[9] the various measures of transaction costs; the changes in emissions of all three pollutants resulting from repair; and, finally, in the case of fees, the total amount of fees paid by motorists.

Transaction costs assumptions. There are several points in the emissions testing and control process at which motorists face transaction costs in this model. One component of transaction costs includes the expenses associated with seeking diagnosis and repair. Based on evidence from the Arizona program, the diagnostic cost itself is assumed to be one-half of the reported repair cost, or $65, whichever is lower.[10] Another transaction cost is the cost of testing or retesting the vehicle to determine the extent of the emissions reductions from repair. This cost we assume to be the cost of an emissions inspection at a centralized station.[11]

The time it takes to get to a testing station or a repair facility is also an important part of the transaction costs. It takes on average 27 minutes to get a vehicle tested, and a diagnosis of the emissions problems takes on average 18 minutes. To value time, we

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[9] We calculate that value assuming that repairs are effective for two years. We assign a number of miles driven per year to each vehicle depending on its model year. We assume that the price of gasoline is $1 per gallon (that was approximately the price during the time period when the data were collected). The value of fuel savings in the second year is discounted at rate of .05.

[10] For rounds assumed to have such diagnostic costs, the repair cost used in the simulation is equal to the reported repair cost minus the calculated diagnostic cost.

[11] These estimates are based on data from the Arizona I/M program. See Harrington, McConnell and Ando (2000) for more detail.

draw on the recent study by Small, Winston, and Yan (2003), which generates estimates of the median and the interquartile range of motorists' willingness to pay to reduce time spent driving. Based on these estimates, we assume that the value of time (VOT) is distributed normally, with mean equal to $20.36 and standard deviation equal to $15.09. Each motorist in our data set is randomly assigned a VOT according to this distribution (the few negative values drawn from the normal distribution were replaced by zeroes). We then calculate the transaction costs associated with the travel required to diagnose, repair, and retest a car as time spent in such travel multiplied by the motorist's VOT.

Simulation of CAC policies. There are two CAC simulation policies. One reflects the perfect world and the other the real world scenario, as described above. The effective difference in the two is that the real world case includes transaction costs. As described above, transaction costs do not affect behavior in the CAC scenario because motorists are required to repair vehicles—they have no discretion over how they comply with a CAC policy. They must repair the vehicle up to the point where it no longer fails the emissions test or the repair rounds observed in the data set are exhausted. The real world CAC policy employed here is almost identical in structure to the actual policy in place in Arizona.

To achieve different levels of emissions control in either CAC policy, we simply make the cutpoints less stringent. We then skip vehicles that pass the test and stop the repair process of cars that fail the initial test as soon as the new cutpoints are reached. To simplify the options considered, we examine only scalar multiples of the actual cutpoints in place in Arizona.

Simulation of the fee policies. There are a number of simulations of the fee policy. In the perfect world, with no transaction costs and subsidies, and where motorists have perfect information about repair and fuel economy, they make only one decision about the extent of repairs and the payment of fees. They minimize the costs of complying and they make only the most cost-effective repair or set of repairs given the established fee.

The real world case for the fee is much more complex. We explain the sequential process of the motorist's decisionmaking in some detail here. We assume motorists are risk neutral and somewhat forward looking, in that they recognize at the beginning of the process that a single round of repair may not succeed in reducing the fee to zero. We simplify the analysis by constraining car owners to consider only two rounds of repair. This simplification is justified by the fact that 93 percent of all failing cars have two or fewer rounds of repair in our data set (78 percent have only one round). Consumers stuck thinking about the ex ante (rather than conditional) probabilities of the need for further rounds of repair might be inclined not to think about supernumerary rounds.

A given motorist begins by submitting his car to the mandatory initial test. If he learns that the vehicle has failed the test, he is faced with a choice between investigating a round of repair and simply paying the fee required to register the car with its current emissions rate, fee_0. There are two transaction costs associated with simply going to a mechanic to get the car diagnosed: C_d^T, the diagnostic fee (which is only charged for the first round of repair) and the time cost of obtaining the diagnosis, C_m^T.

The motorist must form an opinion about the expected net cost that is likely to arise if he proceeds with the diagnosis and possible subsequent repair of the vehicle. This opinion necessarily must be based on very limited information, since there is no mechanic input at this stage of the process. We assume that the motorist has some expectations ex ante about what the costs and effectiveness of repair will be, both for the first repair and any subsequent repairs he might decide to make. We represent these expectations with predicted values obtained from the results of regression equations estimated for the following dependent variables: emissions reductions for each pollutant, repair costs, and fuel economy. The independent variables in the regression equations represent the information the motorist actually has at that node about factors that might influence the effectiveness or cost of repair. Thus, the explanatory variables include only the amount by which each of the three pollutants is above the corresponding cutpoint, the vehicle model year, and other vehicle characteristics, such as number of cylinders and the type of vehicle.[12] We refer to this information set as I_{1A}. The Appendix has details of these and the other regressions used for determining information for the motorists decisions as described below.

The first round decision can be summarized by equation (1A) below. If the motorist gets the diagnostic test and the first round of repair, he will have to pay the diagnostic transaction costs and the actual repair costs (C_1^R), although the latter may be mitigated by benefits stemming from repair-induced fuel-economy improvements (F_1). After that repair is done, he will have to bear another transaction cost (C_t^T) in the form of

[12] The R^2s for these equations were .36 for the change in HC, .37 for the change in CO, .28 for the change in NOx, .80 for the change in mpg, and .07 for repair cost. Equations for predicting the change in emissions and mpg from more distant repair rounds have slightly lower R^2s (see the Appendix for more detail on all of the equations).

time lost getting a retest. The motorist expects to respond to the results of that retest by paying the resulting new fee (*fee_1*), or, if he expects it to be cheaper, by performing a second round of repair, getting another retest, and paying the fee associated with those results (*fee_2*). Given all these considerations, the decision rule that determines the car owner's course of action is to get a first-round diagnosis if and only if:

$$fee_0 > C_1^T + E\left((C_1^R - F_1)\middle|I_{IA}\right) + \min\left\{E\left(fee_1\middle|I_{IA}\right), \left[C_2^T + E\left((C_2^R - F_2)\middle|I_{IA}\right) + E\left(fee_2\middle|I_{IA}\right)\right]\right\}$$

where transaction costs are defined as $C_1^T = C_d^T + C_m^T + C_t^T$ and $C_2^T = C_m^T + C_t^T$. (1A)

If the owner decides to get the diagnosis, he obtains more information about the repair and must decide whether or not to have it done. This improved information set is identified as I_{1B}. The cost of the repair is now known with certainty and is denoted C_1^R . The motorist also learns what parts the mechanic proposes to replace, adjust, or fix and what the mechanic expects the emissions rate and fuel economy to be if the repair is done. We calculate representations of the mechanic's predictions of repair effectiveness and fuel efficiency by using parameter estimates from four additional equations: one for the post-repair change in each of the three pollutants and one for repair-induced changes in fuel efficiency.[13] We regress these variables on vehicle characteristics, the amount by which each pollutant is above its cutpoint, and dummy variables for all the parts that are going to be repaired. These estimates of repair effectiveness and fuel economy based on information set I_{1B} are used to allow the motorist to decide whether to make the repairs or pay the fee. The motorist will perform first-round repair if and only if:

$$fee_0 > C_1^R - E\left(F_1\middle|I_{1B}\right) + C_t^T + \min\left\{E\left(fee_1\middle|I_{1B}\right), \left[C_2^T + E\left((C_2^R - F_2)\middle|I_{1B}\right) + E\left(fee_2\middle|I_{1B}\right)\right]\right\}$$

where $C_2^T = C_m^T + C_t^T$. (1B)

If the repair is successful in reducing the fee faced by the motorist (*fee_1*) to the expected level, the car owner does the first round of repair and pays the fee, *fee_1*, and the process stops. If, however, the car still fails the test, then the motorist faces another decision about whether to pursue repair. The first part of that decision is still whether to go to the mechanic and get an estimate on the new repairs proposed by the mechanic (though we assume that the mechanic no longer charges for the diagnosis itself.) We use another set of equations similar to those described above to represent the motorist's

[13] The R^2s for these equations were .37 for the change in HC, .38 for the change in CO, .30 for the change in NOx, and .80 for the change in mpg.

assessment of expected costs, emissions reductions, and fuel-economy savings in making the decision about whether to get the second round diagnosis. These equations use as explanatory variables the amount by which each of the three pollutants is still above the cutpoint, vehicle model year, and other vehicle characteristics, such as number of cylinders and the type of vehicle, and we include a set of dummy variables that identify which pollutant or combination of pollutants failed the test in previous rounds (this information set is I_{2A}).[14] One additional assumption here is that the motorist now becomes myopic, in that he effectively assumes that if he does the repair, he will then pay whatever fee results (fee_2) rather than pursue yet another round of repair. Thus, the motorist will get a second-round diagnosis if and only if:

$$fee_1 > C_m^T + E\left((C_2^R - F_2)\middle|I_{2A}\right) + C_t^T + E\left(fee_2\middle|I_{2A}\right). \tag{2A}$$

Once the mechanic has conveyed the new cost quote and described the parts to be fixed and the likely effects of the new repairs (yielding information set I_{2B}), the motorist will choose to do the second round repair instead of paying the fee if and only if:

$$fee_0 > C_2^R - E\left(F_2\middle|I_{2B}\right) + C_t^T + E\left(fee_2\middle|I_{2B}\right). \tag{2B}$$

Again, for repair rounds after the first round, costs are known with certainty and separate equations are estimated to represent the expected emissions reductions and fuel economy from additional repair. In these second round equations, in addition to explanatory variables such as vehicle characteristics, the amount by which each of the three pollutants are above the cutpoints, and dummy variables on parts that can be repaired, we include dummy variables for the combination of pollutants that failed the earlier test.[15] The equations used to estimate the expectations used in the different decisions are summarized in more detail in the Appendix.

To obtain different possible levels of emissions control under the fee policy we let the fee rates on HC, CO, and NOx emissions rates vary in absolute size but the magnitudes of CO and NOx fee rates, relative to HC, are fixed at 0.1 and 2.5, respectively. As with the weights used to generate a measure of aggregate "pollution,"

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[14] The R^2s for these equations were .79 for the mpg equation, .33 for the HC equation, .36 for CO, .27 for NOx, and .04 for costs.

[15] The R^2s for the equations for current round repairs are roughly .8 for mpg, .37 for HC, .37 for CO, and .30 for NOx. The equations for predicting the change in emissions and mpg from more distant repair rounds have slightly lower R^2s.

these ratios approximate the ratios of marginal damages calculated by Small and Kazimi (1995). These would be the ratios of the optimal fee rates to one another if emissions reductions were produced independently.[16]

IIIC. Simulation Scenarios

We explore a range of different scenarios. First, we examine both the CAC and fee policies under stylized assumptions of a perfect world. In the scenario we refer to as "perfect world CAC," motorists are required to fix all vehicles that exceed the emissions cutpoint for one or more pollutants, and we assume that transaction costs do not exist. The corresponding "perfect world fee" policy scenario assumes that motorists are making repair decisions in a world with no transaction costs and with perfect information about repair costs, repair effectiveness, and fuel economy improvements. In addition, all costs are fully considered, with no subsidy due to warranties or other such policies.

The next cases are the opposite of those above. They are called the "real world CAC" and "real world fee" scenarios. In both of these scenarios, we assume that transaction costs are non-zero and considered by motorists in their decisions. In the real world fee, we also assume that motorists do not have much information about potential repair effectiveness when they make decisions, that they make repair decisions on the basis of "private" repair costs (which exclude any costs of repairs done under warranty), and that they neglect the benefits of potential fuel-economy improvements in their decisions.[17]

We then examine a range of intermediate cases for the fee policy to see which have the greatest effect on the cost-effectiveness of the fee policy. The first is the "no-hassle" fee simulation, which is just like the real world fee except that transaction costs are assumed to be zero. The second case, referred to as the "consider mpg" scenario, is identical to the real world fee simulation except that motorists fully consider estimates of changes in mpg that could result from repair when they make decisions.

Another simulation represents the case of "perfect info" under the fee policy. Here, we artificially remove all uncertainty about the outcome of repairs; vehicle owners

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[16] However, as shown in Ando, Harrington, and McConnell (2000), emissions reductions for a given vehicle are very much jointly produced. Thus, the true optimal fees are unlikely to hold to that principle.

[17] There is some empirical evidence in other contexts to support the idea that consumers underinvest in energy efficiency. See Jaffe and Stavins (1994).

know exactly what the costs and results of all possible future rounds of repair will be ex ante. In all other ways, the real world assumptions hold. While no policy can eliminate all uncertainty, technical change or even policy changes might improve motorists' ability to forecast the outcome of repair; this simulation can place an upper bound on the gains to society of such change.

The final scenario, called "no subsidy," is like the "real world" except that motorists consider total (rather than private) repair costs when deciding whether to repair their vehicles or pay fees. In this case, motorists would not be exempt from repair costs, even when their vehicles are supposed to be under warranty. The results can be viewed as an indication of how much efficiency can be gained if repair decisions are made with the full costs of repair in mind.

IV. Simulation Results

We begin by comparing the fee policy to the CAC policy in the perfect world in which there are no transaction costs. Figure 2 shows total social costs of the two policies, which include all repair costs, and monetized fuel-economy benefits, as a function of total pollution reduced.[18] The CAC policy has much higher costs than the fee policy in the perfect world when motorists take fuel-economy effects into account, do not have warranteed or home repairs subsidized, and have perfect information about the costs and outcomes of any repairs they might undertake. The results show that under these conditions, a simple fee policy dramatically reduces the costs of accomplishing pollution reduction in an I/M program. For levels of pollution reduction as high as 4,200 tons, the cost of CAC is $6.4 million, while the cost of the fee policy is just over half that amount—$3.9 million. For lower levels of pollution reduction, the cost savings possible from the fee policy are even more dramatic. The cost of reducing pollution by about 2,770 tons is only $.38 million under the fee policy, while the cost of CAC is $3.8 million. Under the fee policy, costs are only a tenth as large.

However, as discussed above, the assumptions that underlie the simulations in Figure 2 are not realistic. Motorists do not, in fact, pay for repairs when their vehicles are under warranty, there are substantial transaction costs associated with I/M programs,

[18] Recall that "pollution" is a weighted sum of HC, CO, and NOx emissions. We assume that repairs are effective for two years. Thus, total pollution reduction given in these results is the sum of two years of reductions, with the second year's reductions discounted at a rate of .05.

motorists may not have good ex ante information about the likely costs and outcomes of vehicle repairs, and it is unlikely that most consumers are aware of the ancillary effects on fuel economy that are likely to result from I/M-motivated repairs. The graph in Figure 3 shows the CAC and fee policies under these realistic conditions. Costs are higher for both policy types than in Figure 2. Costs are higher for the CAC policy because transaction costs are higher and higher for the fee policy for all of the reasons listed above. More important, the proportionate cost savings generated by switching from CAC to the fee policy are much lower. The cost of reducing pollution by 4,200 tons is $9.3 million under CAC and $8.8 million under the fee policy (only a 5 percent reduction). The cost of 2,770 tons of pollution reduction are $5.8 million for CAC and $4.4 million for the fee policy. To reach even this moderate level of cleanup, the ratio of fee policy to CAC costs is still .76—hardly a dramatic improvement in cost-effectiveness. For very low levels of cleanup, there is essentially no cost reduction associated with using a fee policy instead of CAC.

We use a set of simulations to understand which elements of the real-world scenario are most responsible for reducing the cost-effectiveness of the fee program relative to CAC. Each of these simulations relaxes a single real-world assumption. This enables us to identify the extent to which policy and institutional changes might be able to improve the performance of a fee policy.

First, we investigate the role played by transaction costs in the performance of these policies. Figure 4 shows the outcomes of the two types of policies in the real-world scenario (as was also shown in Figure 3) and in a scenario much like the real world, except that we assume that transaction costs are eliminated. It certainly is true (indeed, almost tautological) that eliminating these costs from the system lowers the total social costs of reducing air pollution from motor vehicles under both CAC and fee policies. The cost savings are on the order of 35 percent if one looks at programs nearly as stringent as that currently found in Arizona (4,200 tons reduced, as shown by the points on the far right of the cost curves). It is also true that in the absence of transaction costs, even very low fees induce almost a third of the pollution reduction accomplished by the current Arizona program. However, the absence of transaction costs does not improve the performance of the fee policy relative to CAC.

The weakness of the improvement obtained by using fees may be, in part, because the real-world fee policy simulation specifies that decisionmakers ignore other important components of the costs and outcomes of repairs. In Figure 5, we present the results of three more fee simulations that analyze the relatively poor performance of the fee policy in the real-world scenario.

We first consider the case of motorists who attempt to take account of the monetized fuel economy changes when they are making the decision about whether to pay the fee or get a diagnosis and/or repair (the “consider mpg fee” case). It turns out that considering monetized fuel economy changes makes very little difference for the outcome of the fee policy. Total social costs are only slightly lower than the real-world scenario in which fuel economy changes are ignored. For the particular application at hand, this may not be surprising. Over two-thirds of all repairs in our sample yield a change in mileage that is less than or equal to 2 mpg in absolute value. Such minor changes yield very small ancillary costs or benefits. Furthermore, this scenario still assumes that motorists do not have perfect information when they must make decisions about paying the fee versus repair. They have only an estimate of the fuel economy benefits they will get. Their ability to forecast these benefits may not be sufficiently accurate to allow them to make more cost-effective decisions about repair.

Next, we consider a scenario in which repair subsidies are removed; motorists must consider the full costs of all repairs performed under warrantee or at home. This change from the real-world scenario produces even smaller improvements in cost-effectiveness than does requiring motorists to take account of ancillary fuel-economy changes. This is in spite of the fact that close to half of all rounds of repair has some warranty or home repairs. This finding may be understood if we recognize that the “subsidies” in question here are not targeted at repairs that are particularly cost effective (the correlation coefficient between a dummy for warranteed or home repair and cost-effectiveness of the repair is just -.05). For any given fee rate, the presence of subsidies will increase the amount of pollution reduction that results; this is clear from Figure 7, which shows that fee revenue is higher for a given level of pollution reduction when subsidies are taken away. However, these particular subsidies do not appear to alter repair decisions in a manner that has a big effect on cost-effectiveness.

Finally, we evaluate what is perhaps the most interesting of the assumptions, which is the importance of uncertainty under which motorists are forced to decide whether to pay the fee or seek a diagnosis or repair. Even with proper incentives, car owners may not have enough information about the likely costs and effects of repairs to succeed in consummating only cost-effective rounds of repair. The last simulation results presented in Figure 5 indicate that such uncertainty does play the biggest role of all of the issues examined in determining the cost-effectiveness of a fee policy in the I/M arena. If we allow the decisionmakers to have perfect information about the costs and emissions reductions associated with repairs, the total social costs associated with fee policy outcomes are between 40–50 percent lower than the costs associated with the CAC policy, particularly at relatively high levels of emissions reduction (more than 3,000 tons a year). This occurs even though motorists neglect fuel-economy changes and other social costs in their decisionmaking.

Information on the part of the polluter is one of the critical assumptions underlying the argument that fees will result in large cost-savings. But how much information is necessary? In this case, motorist uncertainty about repair effectiveness can never be completely eliminated because of the complexity of vehicle emissions systems and the variation in mechanic abilities. However, recent improvements in vehicle technology in the form of on-board devices that identify the source of emissions problems may allow for substantial improvement in mechanic diagnosis and repair. Our findings[19] indicate that moderate improvements in information can have a substantial effect on the performance of the fee policy. If motorist expectations for emissions-rate and fuel-economy changes are composed of 75 percent expected and 25 percent actual values, about half of the improvement associated with perfect information can be realized. By the time expectations are moved 75 percent of the way from the imperfect expectations toward the actual values, as much as 90 percent of that improvement is accomplished.

Economists tend to focus on efficiency when evaluating public policies, but other aspects of a policy's performance are of interest as well. In particular, it may be politically difficult to make changes to I/M policy that cause increases in the costs borne by motorists. Figure 6 compares net motorist expenditures associated with CAC to some of the fee-policy scenarios.

In the real-world scenario, for most emissions reduction levels, motorists would spend only slightly more money under a fee program than under the current CAC policy (not shown on Figure 6). However, it is interesting to note that the gap between the two is almost non-existent if the policy is either as strict as the current Arizona program or very weak. Not surprisingly, if warranties and free home repairs were to be eliminated (as in the "no subsidy" scenario), motorist expenditures are very high. At the other end of the

[19] These results are not graphed in this paper.

spectrum, if vehicle owners were to take ancillary fuel-economy changes into account during the decisionmaking process, they could accomplish emissions reductions with relatively low net expenditures by exploiting opportunities for such improvements. Finally, when consumers have perfect knowledge of the outcomes of repair rounds, there will be extremely high expenditure levels, as the simulations push emissions reductions up to the maximum observed in the data.

This latter pattern is best understood by looking at Figure 7, which shows the fee revenue associated with the fee simulations. Consumers with perfect information know about the rounds of repair that are going to be very expensive and yield little emissions reductions, and they will pay extremely large fees to avoid them. Hence, revenue increases rapidly in the perfect-information scenario as the simulation approaches the point where only highly cost-ineffective rounds of repair result in more pollution reduction.

In contrast, total revenue tends to rise and then fall with overall program stringency in the other simulations. At very low fee levels, many motorists pay the fee, but revenue is low because the fee rate is so small. As fee rates grow, revenue per car may rise, but more car owners repair their cars rather than pay the fee. Eventually, very high fees induce almost all motorists to repair their cars. In the absence of warrantee-type subsidies, revenue is relatively large because high fees are needed to induce car owners to actually reduce their vehicles' emissions rates.[20] Conversely, motorists who pay attention to fuel economy benefits need little inducement to accomplish a fairly large amount of initial pollution reduction; revenue there only catches up to that in the other scenarios once the rounds of repair that yield fuel-economy benefits largely are exhausted.

V. Conclusion

Basic environmental economics tells us that CAC policies, such as the enhanced I/M programs supported by the EPA, often are inefficient. Indeed, our research confirms that air-pollution reduction from mobile sources, in theory, could be accomplished in a more cost-effective fashion. However, the simulations presented here examine how some complications in the real world may prevent an economic-incentive policy from

[20] We expect that risk aversion also would push revenues (and consequently motorist expenditures) up, since higher fees are likely to be needed to induce risk-averse car owners to purchase repair with uncertain outcomes rather than pay fees of certain magnitudes.

achieving its cost-effectiveness potential. Such complications particularly are likely to occur when the relevant decisionmakers are acting with imperfect information.

We find that, given a set of realistic assumptions about consumer information and behavior, the emissions-fee policy considered here resulted only in slightly more cost-effective repair than the current I/M policy that requires all repairs to be done. This primarily is because of motorist uncertainty about the effectiveness of repairs. To be able to make the right decisions about which repairs to do, motorists need to have accurate expectations about how much repairs will cost and how much emissions will be reduced.

The argument in the literature on the efficiency of economic-incentive policies is based on the fact that there is asymmetric information on the part of polluters and the government—polluters know how to reduce emissions cost-effectively and the government does not have this information. But if polluters are uncertain about the costs and effectiveness of their possible actions, then the difference between incentive policies and regulatory policies will not be as great. This issue has not been addressed in the literature. We have explored the extent of the problem based on the likely amount of information available to motorists in deciding whether to pay a fee or seek repair and find that the cost-effectiveness of fees is substantially reduced compared to a traditional CAC regulatory program.

We also find that if individual motorists' incentives do not incorporate all elements of repair that affect social welfare, emissions fees likely will fail to outperform CAC. Motorists may not be aware of fuel-economy benefits when they are deciding whether to get a vehicle repaired. However, we find that considering fuel-economy benefits without good information about likely repairs and actual associated fuel-economy changes will not do much to improve the performance of the fee policy. Again, it is good information that is the key, this time about fuel economy, that allows motorists to make the most cost-effective repairs under the fee policy.

Not surprisingly, the simulations show that if transaction costs can be reduced, such as through the use of on-board diagnostics or remote sensing, then both CAC and fee policies are rendered more cost-effective. There is no evidence, however, that a reduction in transaction costs strengthens the case for using fees instead of CAC. Transaction costs might discourage consumers from acquiring as much information as they can about the likely cost-effectiveness of a repair before deciding whether to pay the fee, but that dynamic does not seem to be an important factor in the failure of fees to yield more efficient program outcomes than CAC.

It is important to point out that the results presented here give only a partial picture of the response to vehicle-emissions fees, due primarily to limits of the available data. First, the fee examined here is not a pure emissions fee on total emissions; rather, it is a fee on grams per mile. A pure emissions fee would allow motorists to make additional adjustments, including the number of miles traveled in different vehicles. Even for the emissions-rate fee, the analysis was constrained to only consider rounds of repair that had been done in the Arizona I/M program. In response to emissions fees, different and perhaps more effective repairs might have been performed. There would even be incentives to reduce emissions to very low levels under a pure fee without the zero-payment baseline assumed in this analysis. In addition, we were not able with this data set to consider the effect of fees or the CAC policy on vehicle scrappage rates. For example, under emissions fees, if the fees and the repair costs are both high enough, getting rid of an old car may provide an important opportunity for emissions reduction.

One other caveat to our finding that fees may not be much of an improvement over CAC is that we have not accounted for some of the underlying incentives for information collection with the two policies. Fees may have better potential to improve cost-effectiveness because they may induce better information collection and then better diagnosis and repair in the future. Under CAC, when vehicles have to be repaired, there is not as much incentive to predict the effectiveness of repairs or to find the most cost-effective method of repair. In addition, the extent of cheating or repair avoidance may be different under a fee policy. Finally, we have not exhausted the possible types of economic incentives; we have only examined one type of emissions fee. More radical departures from the current policy may yield improved results.

For vehicles, the fundamental problem with emissions fees is that motorists must be able to assess accurately not only the current fee they face but also to forecast repairs and fees into the future to make the most efficient current choices. This is a tall order, but recent improvements in vehicle technology in the form of on-board-devices that identify the source of emissions problems soon may allow for substantial improvement in mechanic diagnosis and repair. This, combined with other new techniques for reading emissions, may mean that emissions fees may be a viable policy tool to efficiently reduce emissions from the vehicle fleet in the future. Similar information improvements may be necessary to make fee policies useful for other cases of pollution reduction in which polluters are ill-equipped to predict the results of their own efforts to reduce pollution.

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Figures

Fig. 1. Total Repair Costs of Annual Emissions Reductions Depending on Choice of Rounds of Repair

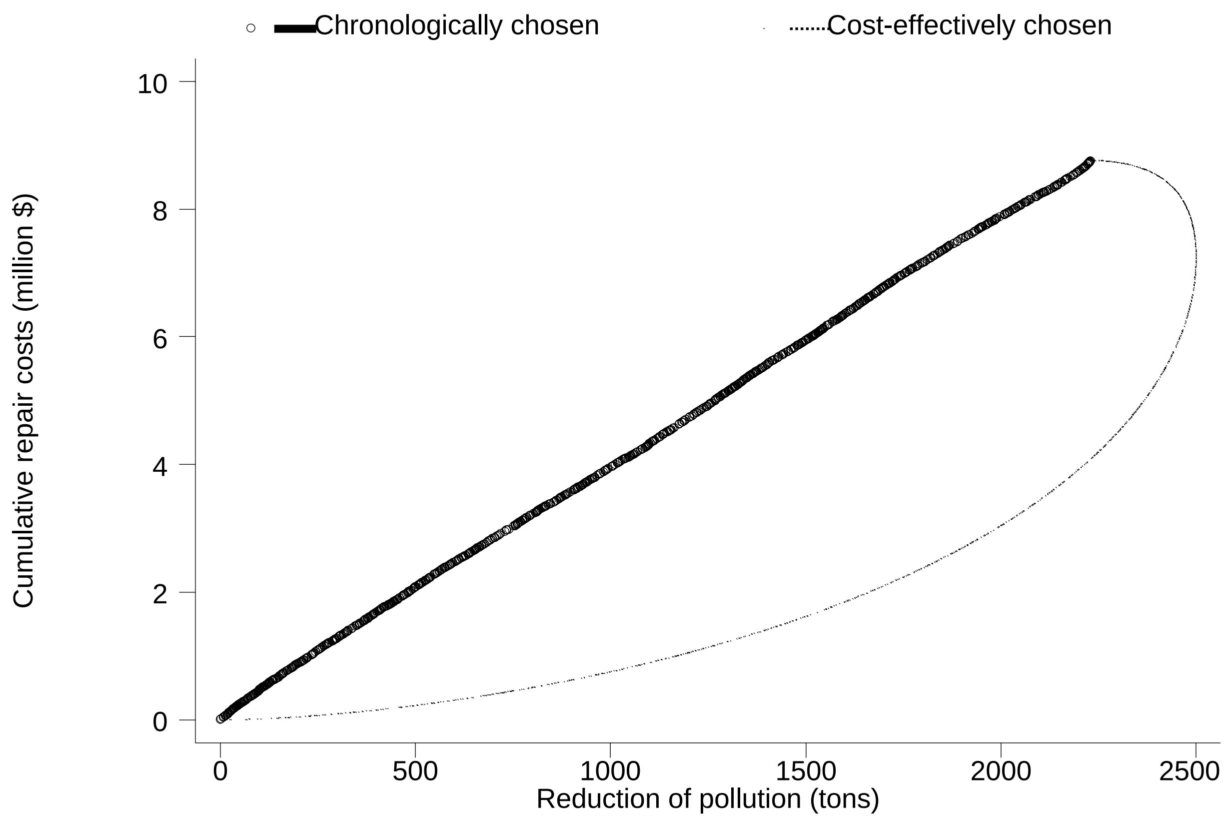


Fig. 2. Total Social Costs in a Perfect World: Command and Control v. Fee Policy

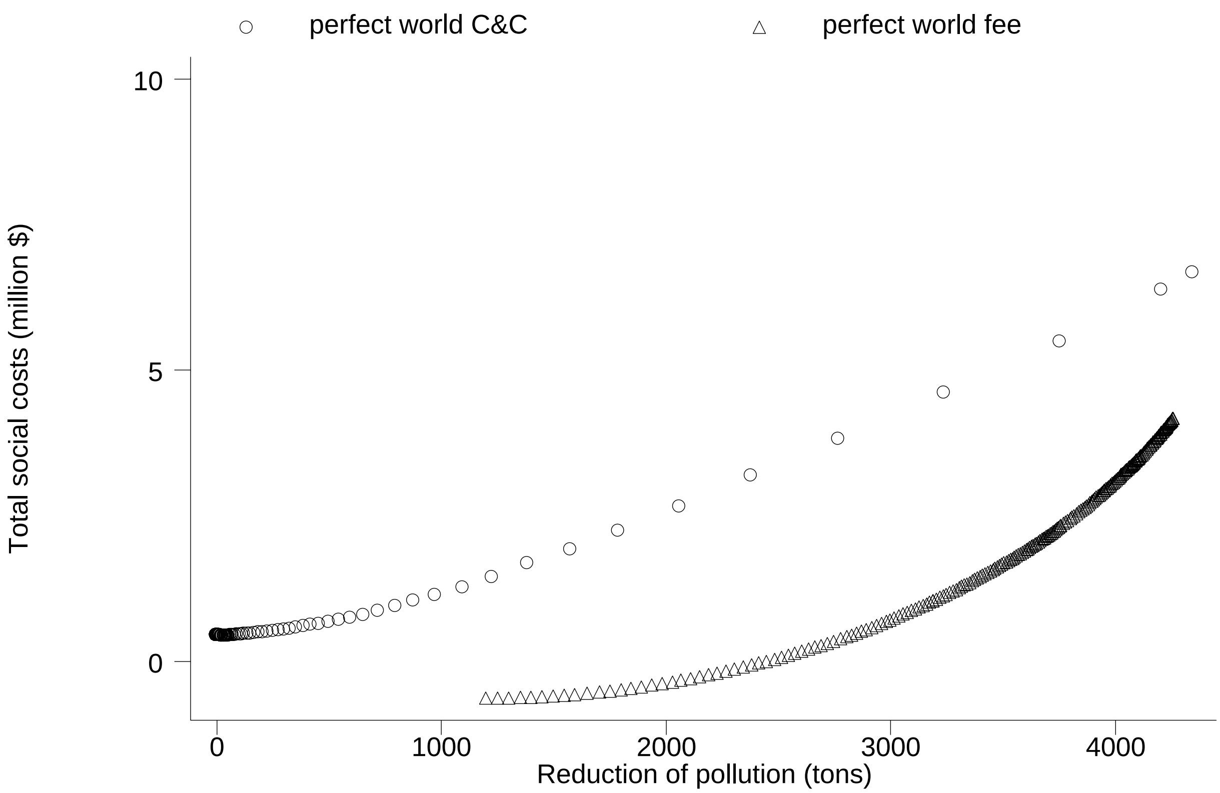


Fig. 3. Total Social Costs in the Real World: Command and Control v. Fee Policy

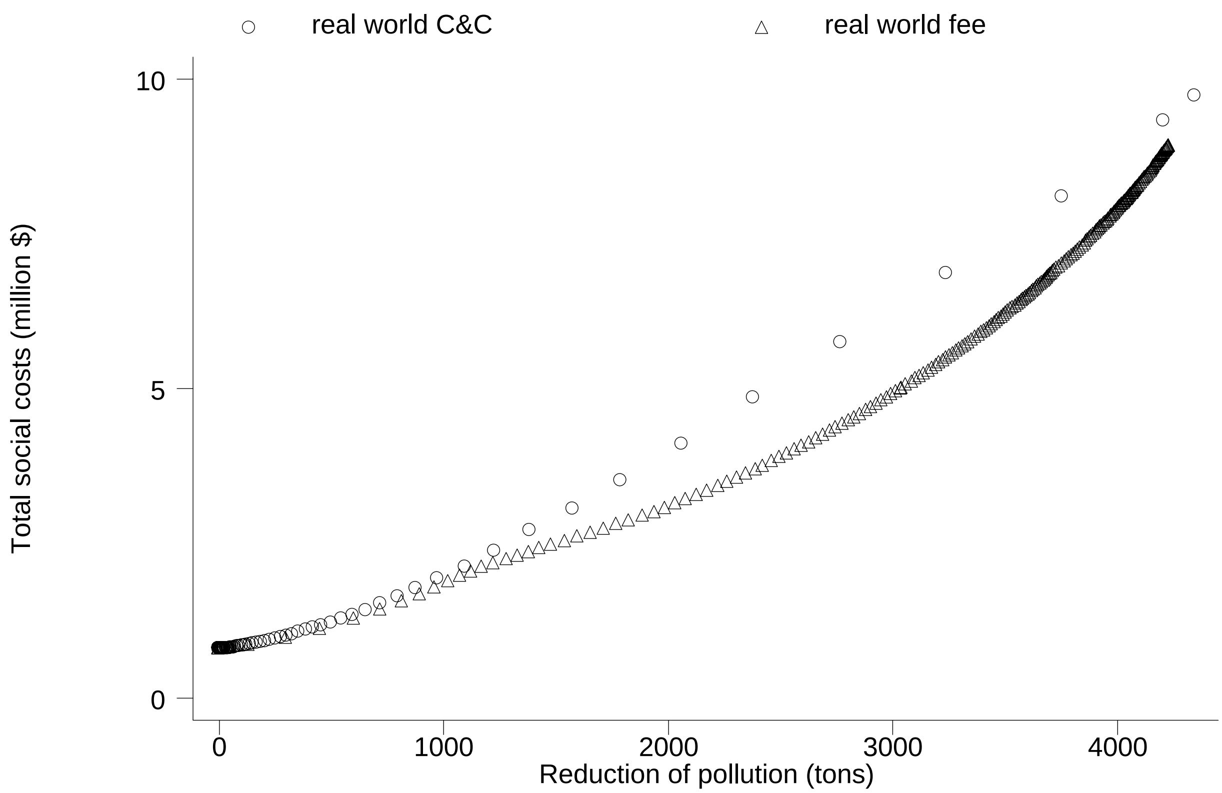


Fig. 4. Effect of Transaction Costs on Relative Cost-Effectiveness of Fee Policy v. Command and Control

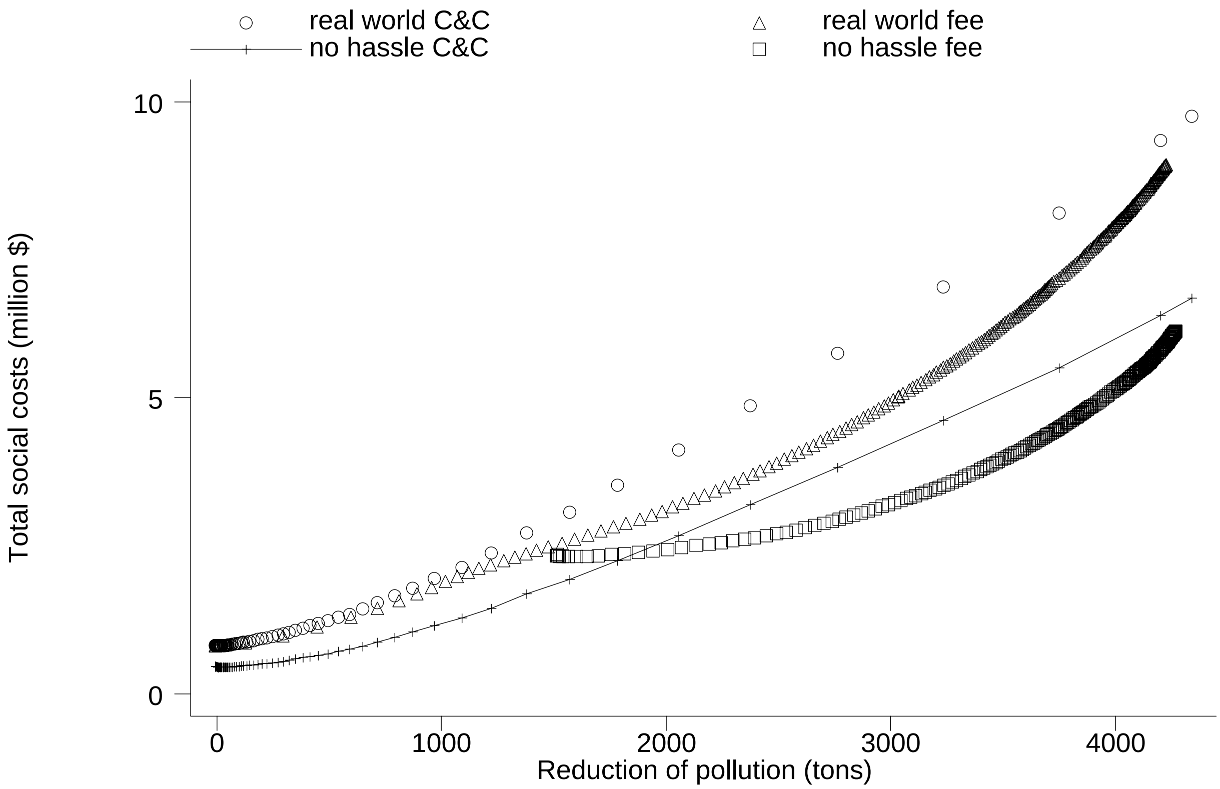


Fig. 5. Decrease in Total Costs from Fixing Problems with Real-World Scenario

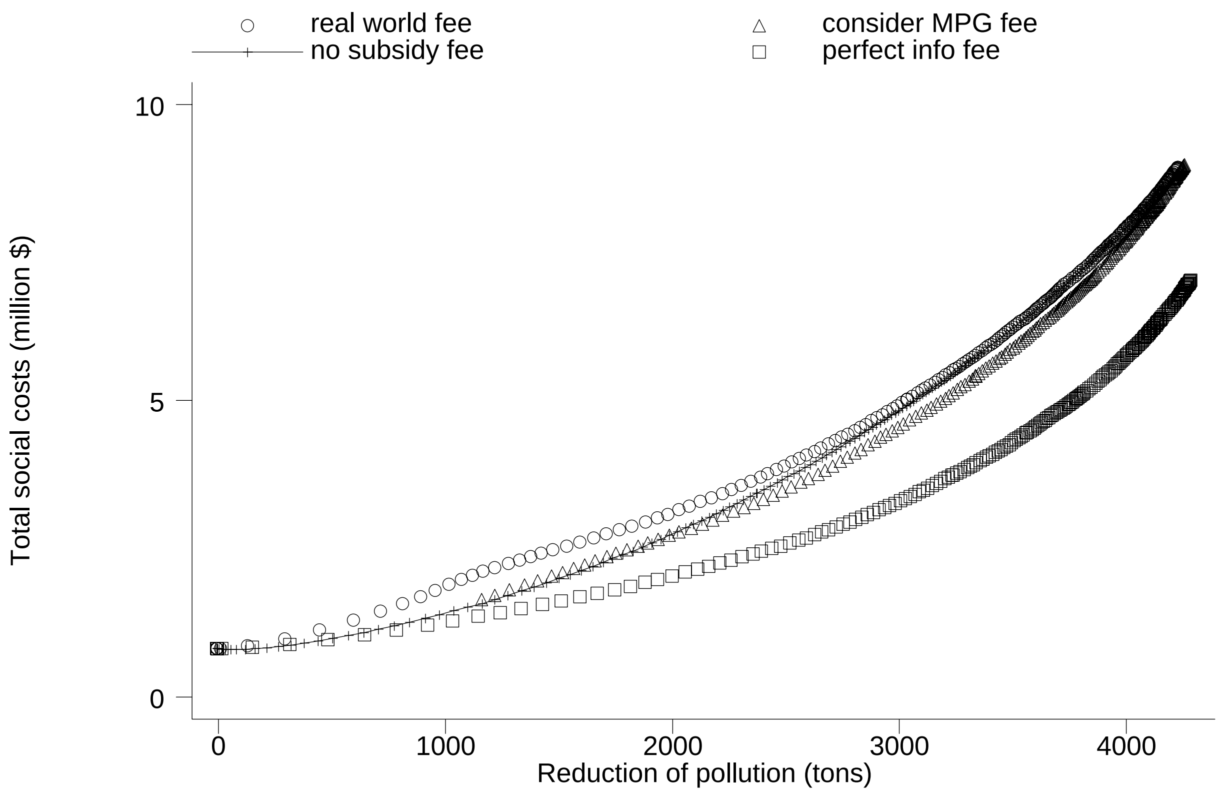
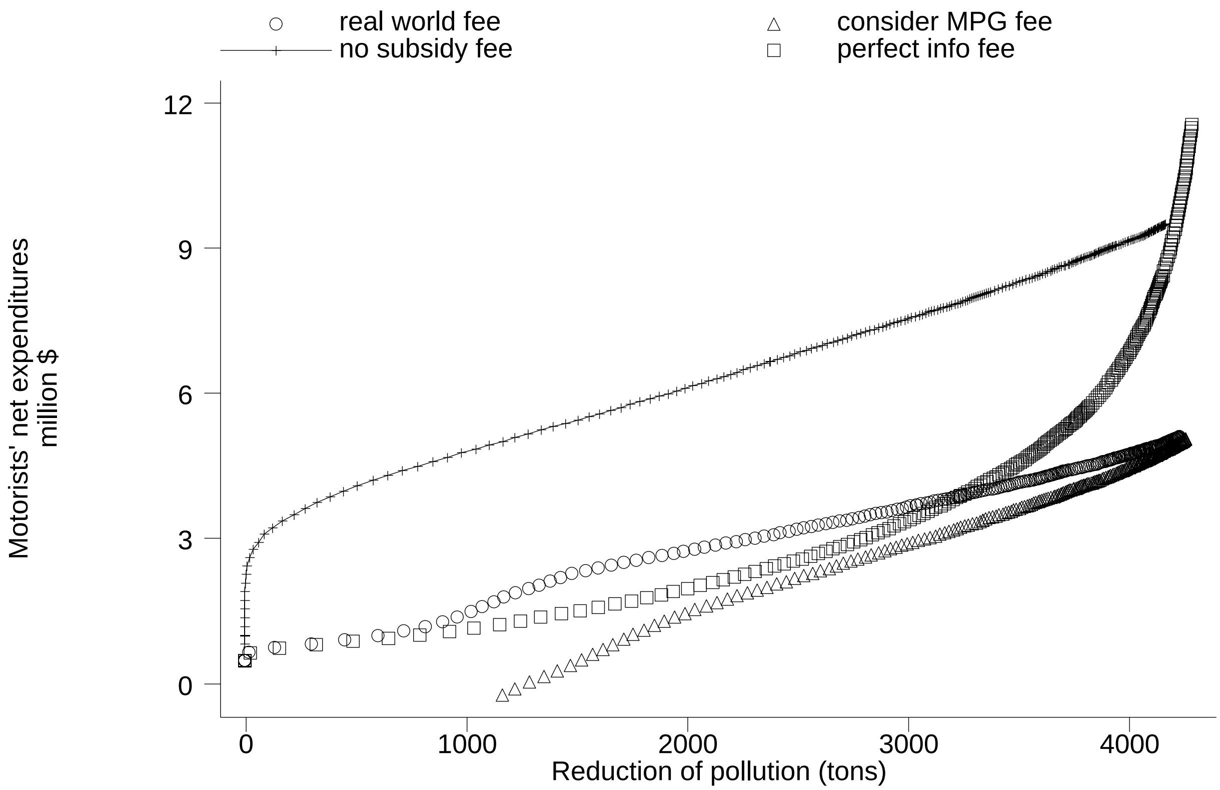
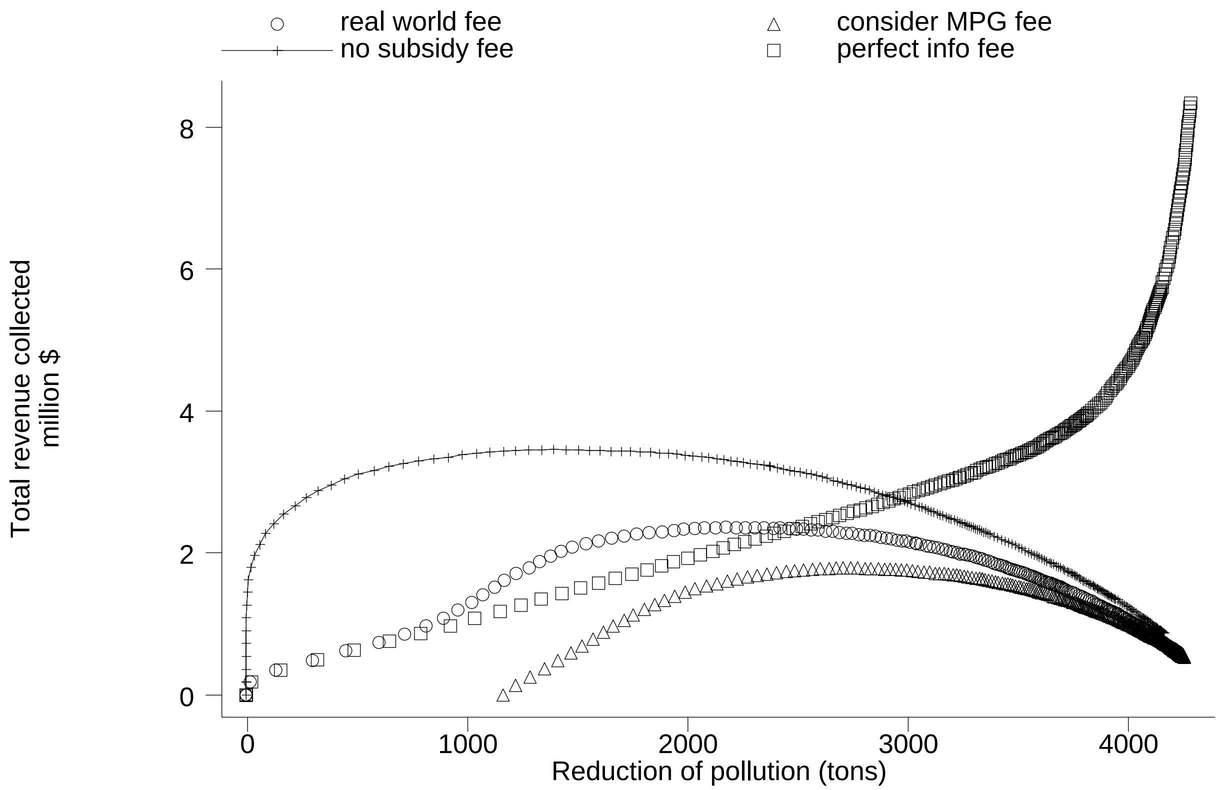


Fig. 6. Net Cost to Motorists of I/M Policy under Varied Scenarios



Note: Net expenditures include repair costs, transaction costs, and fees, and are net of monetized fuel-economy improvements. The repair costs counted are only those borne by the motorists in each scenario.

Fig. 7. Fee Revenue from Different Scenarios



Appendix

Table A1. Emissions Rate Reductions and Fuel Economy Improvements[a]

Test Result Change	Mean	Stand. Dev.	Min.	Max.
ΔHC (grams/mile)	.67	1.55	-10.31	13.25
ΔCO (grams/mile)	10.19	31.23	-259.30	327.27
ΔNOx (grams/mile)	.80	1.80	-12.58	13.80
ΔPollution[b] (grams/mile)	3.69	5.11	-27.67	51.15
-ΔMPG	.65	2.59	-21.86	24.70

[a] There are 68,404 rounds of repair summarized.

[b] "Pollution" is HC + .1CO + 2.5NOx.

Table A2. Cost and Cost-Effectiveness of Rounds of Repairs

Cost Statistic	#Observations	Mean	Stand. Dev.	Min.	Max.
Reported cost[a] ($ in 1995-6)	68,404	80.01	135.35	0.00	1400.00
Total cost[b] ($ in 1995-6)	68,404	128.19	126.02	0.00	1400.00
ΔPollution[c] (g/m) / reported cost	39,800[d]	.06	.33	-14.72	16.15
ΔPollution[c] (g/m) / total cost	68,377[d]	.05	.27	-14.72	16.15

[a] Reported cost is the raw repair cost data, which includes many zeros.

[b] Total cost includes potentially non-zero imputed values for costs reported as zero.

[c] "Pollution" is HC + .1CO + 2.5NOx in grams/mile.

[d] These statistics are not defined for observations that have costs equal to zero.

Table A3. Model Notation for Figure A1

Notation	Meaning
I_n	Information set at a given point in time *n*
E_j	Emission-rate test results after *j* rounds of repair
C_d^T	Transaction cost associated with getting diagnosis from mechanic: diagnosis fee
C_m^T	Transaction cost associated with getting diagnosis from mechanic: hassle involved in travel, leaving car, etc.
C_j^R	Cost of repairs for round *j*
P_j	Parts the mechanic proposes to fix in repair round *j*
F_j	Monetized benefits of repair-induced fuel-economy improvement actually yielded by repair round *j*
C_t^T	Transaction cost associated with getting another IM240 test

Table A4. Assumptions in Fee Simulation Scenarios

Scenario Name	Quality of information about costs and repair outcomes		Consider cost/benefit of repair-induced changes in MPG?		Transaction costs exist?		Pay the cost of warranteed repairs?	
	perfect foresight	use estimates	yes	no	no	yes	yes	no
perfect world	x		x		x		x	
real world		x		x		x		x
no hassle		x		x	x			x
consider mpg		x	x			x		x
perfect info	x			x		x		x
no subsidy		x		x		x	x	

Table A5. Total Social Costs[b] under Varied Simulation Scenarios

Assumptions	Policy Type	Total Social Cost (million $) of Reducing Pollution[a]:	
		2770 tons	4203 tons
perfect world	CAC	3.8	6.4
perfect world	Fee	.38	3.9
real world	CAC	5.8	9.3
real world	Fee	4.4	8.8
no hassle	Fee	2.9	5.8
consider mpg	Fee	4.0	8.7
perfect info	Fee	2.9	6.6
no subsidy	Fee	4.3	8.7

[a] “Pollution” is a weighted sum of three pollutants given by HC+.1*CO+2.5*NOx.

[b] Total social costs include transaction costs, all repair costs, and monetized fuel-economy changes. They are added up over all cars that failed the Arizona I/M test during a 17-month period.

Table A6. Features of Regressions Used to Generate Motorists' Estimates of Repair Costs and Outcomes

Variable predicted	Repair cost					MPG					
Time of prediction (node) [a]	1A	1A	1B	2A		1A	1A	1B	1B	2A	2B
Which round is prediction made for [a]	1	2	2	2		1	2	1	2	2	2
R^2	.066	.028	.047	.040		.798	.762	.799	.763	.792	.794
# observations	33,604	4,655	4,655	6,196		56,706	8,611	56,706	8,611	11,698	11,698
Dependent variable [a]	cost 1	cost 2	cost 2	cost 2		mpg 1	mpg 2	mpg 1	mpg 2	mpg 2	mpg 2
Car/truck dummy	x	x	x	x		x	x	x	x	x	x
Model-year dummies	x	x	x	x		x	x	x	x	x	x
Manual transmission dummy	x	x	x	x		x	x	x	x	x	x
Number of cylinders dummies	x	x	x	x		x	x	x	x	x	x
Body-type dummies [b]	x	x	x	x		x	x	x	x	x	x
Info about 1st test results[c]	x	x	x	x		x	x	x	x	x	x
Parts needing repair in 1st round [d]			x					x	x		
Info about 2nd test results				x						x	x
Did different pollutants fail 2nd round?				x						x	x
Parts needing repair in 2nd round [d]											x

Table A6 con't.

Variable predicted	HC g/m							CO g/m					
Time of prediction (node) [a]	1A	1A	1B	1B	2A	2B		1A	1A	1B	1B	2A	2B
Which round is prediction made for [a]	1	2	1	2	2	2		1	2	1	2	2	2
R^2	.362	.289	.373	.292	.333	.359		.370	.307	.376	.310	.358	.365
# observations	56,706	8,611	56,706	8,611	11,698	11,698		56,706	8,611	56,706	8,611	11,698	11,698
Dependent variable [a]	HC 1	HC 2	HC 1	HC 2	HC 2	HC 2		CO 1	CO 2	CO 1	CO 2	CO 2	CO 2
Car/truck dummy	x	x	X	x	x	x		x	x	x	x	x	x
Model-year dummies	x	x	X	x	x	x		x	x	x	x	x	x
Manual transmission dummy	x	x	X	x	x	x		x	x	x	x	x	x
Number of cylinders dummies	x	x	X	x	x	x		x	x	x	x	x	x
Body-type dummies [b]	x	x	X	x	x	x		x	x	x	x	x	x
Info about 1st test results[c]	x	x	X	x	x	x		x	x	x	x	x	x
Parts needing repair in 1st round [d]			X	x						x	x		
Info about 2nd test results					x	x						x	x
Did different pollutants fail 2nd round?					x	x						x	x
Parts needing repair in 2nd round [d]						x							x

Table A6 con't.

Variable predicted	NOx g/m					
Time of prediction (node) [a]	1A	1A	1B	1B	2A	2B
Which round is prediction made for [a]	1	2	1	2	2	2
R^2	.287	.211	.300	.216	.273	.290
# observations	56,706	8,611	56,706	8,611	11,698	11,698
Dependent variable [a]	NOx 1	NOx 2	NOx 1	NOx 2	NOx 2	NOx 2
Car/truck dummy	x	X	x	x	x	x
Model-year dummies	x	X	x	x	x	x
Manual transmission dummy	x	X	x	x	x	x
Number of cylinders dummies	x	X	x	x	x	x
Body-type dummies [b]	x	X	x	x	x	x
Info about 1st test results[c]	x	X	x	x	x	x
Parts needing repair in 1st round [d]			x	x		
Info about 2nd test results					x	x
Did different pollutants fail 2nd round?					x	x
Parts needing repair in 2nd round [d]						x

[a] "1" indicates round 1, "2" indicates round 2.
[b] There are 13 body-type dummies, including "sedan," "van," etc.
[c] Information about test results includes 7 dummies for which pollutants failed, 3 gaps between g/m readings and cutpoints, and mpg.
[d] There are 21 dummies for which parts need repair in a given round, including parts such as spark plugs, catalytic converters, oxygen sensors, etc.

Figure A1. Decision Tree

Go to mechanic for round 1 diagnosis? Decision based on equation (1A)
Information for estimating outcomes: $I_{1A} = \{E_0\}$

No: Pay *fee₀* Yes: Pay $C_m^T + C_d^T$

Actually do round 1 repairs, retest car? Decision based on equation (1B)
Information for estimating outcomes: $I_{1B} = \{E_0, C_1^R, P_1\}$

No: Pay *fee₀* Yes: Pay $C_1^R - F_1 + C_t^T$

Go to mechanic for round 2 diag? Decision based on equation (2A)
Information for estimating outcomes: $I_{1B} = \{E_0, C_1^R, F_1, E_1\}$

No: Pay *fee₁* Yes: Pay C_m^T

Actually do round 2 repairs, retest car?
Decision based on equation (2B)
Information for estimating outcomes: $I_{1B} = \{E_0, C_1^R, F_1, E_1, C_2^R, P_2\}$

No: Pay *fee₁* Yes: Pay $C_2^R - F_2 + C_t^T$

Note: All information sets contain information about fixed characteristics of the car (e.g., number of cylinders).