2003

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Don Fullerton, *University of Texas at Austin*
Sarah E. West, *Macalester College*

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December 2003

Don Fullerton* Sarah West†

*Department of Economics, University of Texas at Austin, Austin, TX 78712, dfullert@eco.utexas.edu

†Department of Economics, Macalester College, 1600 Grand Avenue, St. Paul, MN 55105, wests@macalester.edu

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Abstract

All urban centers in California violate the Federal standard for ozone. So far, the State has addressed vehicle emission problems with a variety of mandates. In contrast, economic theory suggests that costs of achieving air quality can be minimized by the use of incentive policies such as permits, taxes, or subsidies. The purpose of the research described in this monograph is to explore incentive programs that might be added to the State's repertoire of effective vehicle pollution reduction policies. The monograph is not very technical in nature, but it explains our theoretical approach, numerical simulation model, and statistical estimation.

We find that a single rate of tax on emissions is most efficient. A vehicle-specific gas tax or a miles-specific vehicle tax can attain the same efficient outcome. Uniform rates that incorporate heterogeneity are "second-best". A combination of three uniform rates can attain 71 percent of the gain from the emissions tax. A gas tax alone can attain 62 percent of the emissions tax gain. A subsidy to new vehicles would be regressive. A tax on gasoline is not regressive across the lowest incomes but is regressive from middle to high incomes.

*We are grateful for the support of our families, for helpful discussions of vehicle emission policies with many economists and other professionals, and for the financial support of the Public Policy Institute of California (PPIC). Special thanks go to Jon Caulkins, Dietrich Earnhart, Jim Gale, Dan Gaynor, Larry Goulder, Michael Greenstone, Winston Harrington, Robert Innes, David Kendrick, Suzi Kerr, Arik Levinson, Robert Pollack, Kevin Rask, Raymond Robertson, Hilary Sigman, Dan Slesnick, Ken Small, Richard Wall, Margaret Walls, Pete Wilcoxen, Rob Williams, Paul Wilson, Ann Wolverton, and anonymous referees. For help with data, we thank the California Air Resources Board, Satya Devesh, Mary Hostak, and Raphael Susnowitz. We are solely responsible for any remaining errors. The views expressed herein are those of the authors and not those of the PPIC.

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Summary

Over the last few decades, air quality in California has improved. Yet all urban centers and many other areas of the state still violate the Federal standard for ozone. Even more areas violate the stricter California State standard. The San Joaquin and South Central Coast Air Basins are considered to be in "serious" nonattainment of the standard, while Sacramento and the Southeast Desert Modified Air Quality Management Area are in "severe" nonattainment. As is well known, the Los Angles area is in "extreme" nonattainment of the national ozone standard.

So far, and with some success, the State of California has addressed vehicle emission problems with a variety of mandates and restrictions. These command and control (CAC) regulations can guarantee vehicle emission reductions, but they do not provide much flexibility. In contrast, economic theory suggests that costs of achieving any particular level of air quality can be minimized by the use of incentive policies such as permits, taxes, or subsidies. If an individual has to pay the price of a permit or pay a tax per unit of emissions, then that individual has the incentive to find all of the cheapest and most convenient ways to reduce emissions.

The purpose of the research described in this monograph is to explore incentive programs that might be added to the State's repertoire of effective vehicle pollution reduction policies. The monograph is not very technical in nature. Rather, it is meant to explain fully and intuitively some recent results in academic research, with full citations to technical working papers and publications in academic journals. After Chapter 1's introduction, Chapter 2 summarizes California's vehicle pollution trends over time, the attainment of standards, and the costs of doing so. Then Chapter 3 discusses actual vehicle pollution control policies in California, and Chapter 4 describes important criteria for the comparison of various CAC and incentive policies.

Methodology and Data

Our own framework of analysis begins with Chapter 5. Initially, we consider a world where an ideal emissions tax is available and perfectly enforceable, and we use it to calculate the theoretically-ideal set of driving behaviors that would minimize the costs of achieving a given air quality. We then suppose that the ideal emissions tax is *not* available, and we consider alternative instruments.

We take three approaches to this problem. First, in Chapter 5, we build a theoretical model to identify the circumstances under which a set of taxes and subsidies on market transactions is logically identical to the emissions tax. Second, in Chapter 6, we build a computer model to simulate the effects of alternative policy instruments that are not identical to the emissions tax. We use a large set of data that captures considerable heterogeneity among households, and we use specific assumptions about costs and tastes. Using this model, we then calculate the effects of each policy. Third, in Chapter 7, we develop statistical models to estimate demands for car characteristics and fuels. This estimation accounts for the simultaneity of these choices: the demand

for gasoline depends on the type of car, and the demand for each type of car depends on the price of gasoline.

To conduct our simulations and estimation, we use data from the 1994 Consumer Expenditure Survey (CEX) and the California Air Resources Board (CARB). The CEX includes each household's income, gasoline expenditures, other expenditures, and automobile characteristics including make, model, vintage, and number of cylinders. The CARB data contain information on the fuel efficiency and emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) from 345 cars tested in California between November 1995 and March 1997. We match cars from the CEX with information on identical cars in the CARB data.

Major Findings

A single rate of tax on emissions is most efficient.

In the model described in Chapter 5, we find that a single rate of tax on emissions of all different consumers will minimize the total cost of pollution abatement, even as it induces each consumer to change behavior to a different extent for each method of pollution abatement (such as buying a smaller car, newer car, better pollution control equipment, cleaner gas, or less gas). But emissions are not a market transaction and are easy to hide. Next, therefore, we rule out the emissions tax and consider alternatives.

A vehicle-specific gas tax or a miles-specific vehicle tax can attain the same efficient outcome.

The same efficient outcome attained by an emissions tax can be achieved by other policies. In each case, such a policy must affect all the same behaviors in the same way. The second policy we consider is a complicated gas tax, one that depends on the characteristics of the vehicle at the pump. If purchasers realize *how* their payments depend on these choices, then the gas tax itself can present them with incentives to buy smaller cars, newer cars, more pollution control equipment, and less gasoline. On the other hand, for this tax to be assessed, cars would need to be equipped with tamper-resistant computer chips.

A tax on the vehicle that depends upon the characteristics of the vehicle and the miles driven each year also achieves the same efficient outcome. If vehicle size and age were the determinants of emissions per mile *(EPM)*, then a tax rate per mile for that vehicle could be calculated on the basis of its size and age, and then multiplied by the year's miles to calculate the tax due. On the other hand, this policy requires yearly odometer readings, and it is thus subject to tampering. Thus we turn to other policies that might be more feasible and enforceable but that might *not* achieve the first-best efficient outcome.

Uniform rates that incorporate heterogeneity are "second-best".

More-realistic alternatives might be limited to charging the same uniform rate for all consumers — one tax rate per unit of engine size, one tax rate that depends on vehicle age, and one tax rate on each grade of gasoline, no matter who buys it. Therefore the fourth policy we consider is a simple use of our formulas that were derived for individual-specific optimal tax rates. Policymakers could just insert into those formulas the average engine size, average vehicle age, and average mileage. This single set of tax rates based on those average characteristics could then be applied to everybody's engine size, vehicle age, and use of gasoline. This procedure does not take advantage of available information *other than* those simple averages.

In general, available data can be used to calculate not only average size, age, and mileage, but also the correlations among these variables. If individuals with bigger cars also tend to choose more than average mileage, or conversely, then that information can be used to adjust the tax rates in a way that improves their effectiveness, even while each of those tax rates is still limited to be uniform across all consumers. Therefore the fifth and final policy option considered in Chapter 5 is the set of constrained-optimal tax rates on engine size, vehicle age, and gasoline. This policy uses all available information, but it is still limited to uniform rates across all consumers. It therefore does not perform as well as the first-best emissions tax, but it is the "second-best" as it out-performs all other *available* incentive-based policies.

A combination of three uniform rates can attain 71 percent of the emissions tax gain.

In Chapter 6, we evaluate different combinations of tax rates on gasoline, engine size, and vehicle "newness". Since these solutions use the heterogeneity among a thousand households in our computer model, it effectively makes use of the extent to which the demand for miles may be correlated with engine size or with vehicle age.

Our main result, using this model, is that the second-best combination of tax rates on gasoline, engine size, and vehicle "newness" achieves a welfare gain that is 71 percent of the maximum gain obtained by the ideal-but-unavailable tax on emissions. A gas tax reduces demand for gasoline by inducing people to drive fewer miles *and* to buy smaller more fuel efficient cars. An additional subsidy to newness helps induce them to buy newer cars with lower emission rates.

The magnitudes of the gas tax and newness subsidy depend on the environmental damages of vehicle pollution. The magnitude of damages depends, among other things, on the composition and density of a region's population, and on a region's topography. Second-best rates would therefore differ across regions in California. We do not, therefore, recommend a specific dollar value for either a gas tax rate or a newness subsidy rate. We do, however, reach conclusions about the *relative* magnitudes of a gas tax rate versus a newness subsidy. The gas tax is large relative to the newness subsidy. The overall message here is that the gas tax is the single most effective tool to reduce emissions.

A gas tax alone can attain 62 percent of the emissions tax gain.

The gas tax alone can achieve 62 percent of the maximum gain obtained by the ideal-but-unavailable tax on emissions. Without the gas tax, the tax rate on engine size or on vehicle newness can only achieve about 20 percent of the gain of the ideal emissions tax. Thus we conclude that a gas tax is the key ingredient of any market-based incentive policy – or at least one that cannot employ the ideal emissions tax.

A subsidy to vehicle newness would be regressive.

In Chapter 7 we use statistical techniques to explore the distributional impacts of our alternative policies. This estimation tells us the effect of demographic and vehicle characteristics on the probability that a household will choose a vehicle or combination of vehicles. Households in California are more likely to own larger cars than those in the Northeastern U.S., and households with more income are more likely to own more cars, larger cars, and newer cars. Thus we estimate the extent to which a subsidy to newer cars is regressive. Though it increases the number of newer, cleaner cars, this subsidy to "newness" mostly helps those with high incomes.

A tax on gasoline is not regressive across the lowest incomes but is regressive across higher incomes.

We find that the demand for vehicle miles traveled is relatively unresponsive to its price, but our estimate of the price elasticity (-0.67) is somewhat larger than previous estimates. The estimated income elasticity (0.23) is similar to those in previous studies. For each one-percent increase of income, vehicle miles (and gasoline demand) increase by only 0.23 percent. An implication is that a gas tax is regressive; high-income families buy more gas and would pay more gas tax than low-income families, but their extra gas purchases and gas tax are less than their extra income. Thus their tax as a fraction of income falls.

That overall elasticity estimate tends to mask some specific effects of income on gas purchases, however, as income increases from poor to rich. The very poor do not own cars, and do not buy gasoline, so a tax on gasoline would not hurt the poorest families. Thus the gas tax is not regressive at the very poorest levels, but it is regressive across most of the rest of the income spectrum.

Chapter 1

Introduction

Despite air quality improvements in California, most areas of the state still do not comply with State and Federal standards. Statewide emissions of oxides of nitrogen (NO_x) were generally rising until 1990, and then fell by about 15 percent from 1990 to 1995. Statewide emissions of reactive organic gases (ROG) have been falling for longer, with a 30 percent reduction since 1985. Both of these types of emissions are precursors of ground-level ozone, a contributor to respiratory and other health problems. And in both cases, the recent reductions were led by declines in motor vehicle emissions. Recent data on other types of emissions are reviewed below.

Yet all urban centers and many other areas of the state still violate the Federal standard for ozone. Even more areas violate the stricter California State standard. The San Joaquin and South Central Coast Air Basins are considered to be in "serious" nonattainment of the standard, while Sacramento and the Southeast Desert Modified Air Quality Management Area are in "severe" nonattainment. As is well known, the Los Angles area is in "extreme" nonattainment of the national ozone standard. These air quality problems are compounded by a rate of population growth for California that exceeds the national average. From 1980 to 1997, vehicle miles traveled *(VMT)* increased by 64 percent for the whole United States and by 78 percent in California.

So far, and with some success, the State of California has addressed vehicle emission problems with a variety of mandates and restrictions. "Certification standards" require that all vehicles sold in California have emission rates lower than specified levels, while "fleet composition" standards mandate that each manufacturer's total sales of new cars each year must include a certain percentage that are low-emission vehicles. "Inspection and Maintenance" programs require that each motorist pass a Smog Check every two years, and "reformulated gasoline" requirements ensure that all gasoline sold in California meets eight specifications for cleaner-burning fuel.

These command and control (CAC) regulations can guarantee vehicle emission reductions, but they do not provide much flexibility. In contrast, economic theory suggests that costs of achieving any particular level of air quality can be minimized by the use of incentive policies such as permits, taxes, or subsidies. If an individual has to pay the price of a permit or pay a tax per unit of emissions, then that individual has the incentive to find all of the cheapest and most convenient ways to reduce emissions. Rather than assuming that "one size fits all," a system of incentives might allow each individual to choose the extent to which to save tax (or receive more subsidy) by driving less, buying oxygenated gasoline, buying a low-emission vehicle, getting an inspection, or fixing the car's pollution control equipment. As described below, California does employ certain incentive programs such as the Mobile Source Offset Program, the Voluntary Accelerated Vehicle Retirement Program, and certain incentives for the purchase of alternative-fuel vehicles and fuels. Notably absent from the list of market-based incentives is a gas tax: California's rate of tax on gasoline is 18 cents per gallon, which is a bit lower than the national average.

The purpose of the research described in this monograph is to explore other incentive programs that might be added to the State's repertoire of effective pollution reduction policies. Any additional policy option must meet several important criteria. It must reduce pollution, and it should minimize the costs of doing so. It must be enforceable, which means that the authorities must be able to measure what is taxed or eligible for subsidy. And any such policy must be fair; legislators are legitimately concerned with the distribution of the burdens across families in different circumstances.

I. Market-Based Incentive Policies

The cost advantage of incentives becomes more important with differences among firms or individuals. At one extreme, if everybody were identical, then incentives would induce the same change in behavior for everybody, and thus regulators could just place the same requirement on everybody. If firms differ in terms of pollution abatement costs, however, a uniform regulation fails to take advantage of those differences. Every firm must meet the standard, even those for whom costs are very high. And no firm bothers to outperform the standard, even those for whom costs are very low. Similarly, if individual tastes differ, then some want classic cars or great acceleration while others could easily walk to work or take the bus. With these kinds of heterogeneity, the least-cost solution involves greater pollution reduction for some than for others.

California encompasses extreme heterogeneity. It includes mountains, coastline, deserts, ski resorts, urban sprawl, rural farms, and pristine wilderness. It includes all kinds of production, all ethnic groups, and all kinds of preferences. Thus we expect incentive policies to matter in California.

The ideal incentive policy, in the original theory of Pigou (1932), is a tax per unit of emissions. This Pigovian tax on emissions minimizes the total cost of pollution abatement by providing all individuals with incentives to reduce emissions by all of the least-cost means available to them. Some might walk or take the bus, while others might buy cleaner fuel or cars. Those for whom driving a classic car is most important could continue doing so, despite the extra pollution, so long as they are willing to pay for it. Others save money by undertaking the necessary abatement.

In this case, however, the implementation of a tax on emissions would require the measurement of each car's emissions. Thus the first and primary problem considered here is that such a tax would be extremely difficult if not impossible to implement. It is not a tax on a market transaction, like the purchase of labor services or the sale of a product, with an invoice confirmed by two parties to the transaction. To the contrary, emissions are hard to measure and easy to hide. We therefore look for alternative incentive instruments that apply to market transactions *rather* than to emissions.

Technological advances might soon make it feasible to levy a tax directly on emissions (Harrington et al., 1994). Three such methods can be discussed briefly, but each has problems. First, the most direct method would install on-board devices to measure the tailpipe emissions of each vehicle, but this method would be expensive — particularly to retrofit millions of existing vehicles. Also, this method misses evaporative emissions, and it is subject to tampering. Moreover, it may not satisfy legal restrictions against the search of a private vehicle. Second, authorities could simply measure each vehicle's rate of emissions per mile *(EPM)* once each year and multiply by the number of miles driven since the last reading. This method is subject to evasion, however, if drivers can roll back their odometers. And even with accurate mileage, the emission rate cannot be measured accurately because it depends on *how* the car is driven. Because of cold start-up emissions, Burmich (1989) finds that a five-mile trip has almost three times the emissions per mile as a twenty-mile trip at the same speed. Sierra Research (1994) finds that a car driven aggressively has a carbon monoxide emissions rate that is almost twenty times higher than when driven normally. A third approach discussed by Harrington et al. (1994) would use remote sensing at selected locations: "As vehicles pass the sensor, a tailpipe emission reading is taken and the license plate is identified electronically" (p. 24). If enough monitoring stations are set up frequently and moved randomly, authorities could approximate the total emissions of each vehicle and send the owner a monthly tax statement. With over-sampling during high-ozone periods, the tax bill could reflect the social cost of those emissions. Still, however, each driver's emissions are not exact. This method is expensive, and it misses evaporative emissions. And some drivers may disproportionately miss or intentionally avoid the sensor locations.

In our research below, we consider alternative scenarios about the availability of alternative instruments. We first consider a world where the emissions tax of Pigou is perfectly available and enforceable, and we use it to calculate the theoretically-ideal set of driving behaviors that would minimize the costs of achieving a given air quality. We then suppose that the ideal emissions tax is *not* available, and we consider alternative instruments. In order to take advantage of the cost-reducing characteristics of incentive instruments, we consider alternative taxes and subsidies on various choices that might affect emissions. We model specifically how emissions are affected by engine size, pollution control equipment, vehicle age, fuel cleanliness, and fuel use. We then calculate the optimal combination of taxes and subsidies on each of those choices.

The main advantage of such taxes and subsidies is that each applies to a market transaction: a purchase with an invoice and a seller who can help collect the tax. This reduces the cost of measuring the taxed activity, and it helps with enforcement of the tax. The tax on engine size can be collected at the time of sale by the manufacturer; subsidies to pollution control equipment and to newer cars can be paid upon annual inspection; and a gas tax can be collected at lower rates on cleaner fuels.

We then take three approaches to this problem. First, we build a theoretical model to identify the circumstances under which a set of taxes and subsidies on market transactions is logically identical to the emissions tax. These circumstances are not particularly "realistic," perhaps, but this model is important for understanding how actual policies *differ* from the ideal cost-minimizing outcome. Second, we build a computer model to simulate the effects of alternative policy instruments. We use a large set of data that captures considerable heterogeneity, and we use specific assumptions about costs and tastes. Using this model, we then calculate the effects of each policy. Third, we develop statistical models to estimate demands for car characteristics and fuels. This estimation accounts for the simultaneity of these choices: the demand for gasoline depends on the type of car, and the demand for each type of car depends on the price of gasoline.

The remainder of this introduction will summarize the rest of this monograph and a few key results.

II. A Summary of Results

In the second chapter below, we provide more background information on vehicle pollution trends in California, attainment of the standards for different parts of the state, and some discussion of the costs of pollution. The third chapter reviews current vehicle pollution control policies in California, including CAC regulations as well as market-based incentives (taxes, subsidies, and permit programs). Chapter 4 introduces non-economists to the basic theory of optimal pollution control, and it provides a simple framework to compare the costs and effectiveness of alternative policies such as CAC regulations as opposed to taxes, subsidies, or permit programs.

The fifth chapter begins our original research on the problems discussed above. It describes our vehicle-specific theoretical model, in which many different consumers buy cars and fuels of different types. For analytical tractability, this model ignores the style of driving. Thus we miss the effect on emissions of cold start-ups and aggressive driving, but we specifically model the consumer's choice of engine size, pollution control equipment, vehicle age, fuel cleanliness, and amount of fuel. Thus, we capture most of the important determinants of emissions. We also capture heterogeneity. In this model, individuals differ by income and tastes for engine size and miles. Moreover, by using a general equilibrium model, we capture the simultaneity of those choices by consumers facing budget constraints and firms facing competition. All markets clear simultaneously.

We then use the model to evaluate five different policies. The first is a Pigovian tax on emissions. We show how this single rate of tax on all different consumers minimizes the total cost of pollution abatement, even as it induces each consumer to change behavior to a different extent for each method of pollution abatement (such as buying a smaller car, newer car, better pollution control equipment, cleaner gas, or less gas). But emissions are not a market transaction and are easy to hide. Next, therefore, we rule out the emissions tax and consider alternatives. As it turns out, the same efficient outcome can be achieved by other policies. In each case, such a policy must affect all the same behaviors in the same way. The second policy we consider is a complicated gas tax, one that depends on the characteristics of the vehicle at the pump.

It may be feasible, for example, to place a computer chip on each vehicle that identifies the characteristics of that vehicle, and another type of chip at each gas pump that "reads" the vehicle information and charges accordingly. If so, then the amount of tax paid at the pump can be made to depend on the amount of gas *and* the type of car. If purchasers realize *how* their payments depend on these choices (and if they cannot go home and transfer the gas to their other older, larger car), then the gas tax itself can present them with incentives to buy smaller cars, newer cars, more pollution control equipment, and less gasoline. We derive a formula for the optimal gas tax of this type, and we show that it is functionally equivalent in our model to an emissions tax. It achieves the "first-best" allocation of resources, that is, amounts spent on each type of driving.

For a third policy, perhaps a tax on the vehicle could be made to depend upon the characteristics of the vehicle and the miles driven each year. If vehicle size and age were the determinants of emissions per mile *(EPM)*, then a tax rate per mile for that vehicle could be calculated on the basis of its size and age, and then multiplied by the year's miles to calculate the tax due. We show that this policy can also duplicate the first-best effects of the Pigovian tax on emissions, as it can be designed to provide all of the same incentives to reduce mileage and to buy newer, smaller cars. On the other hand, this is the policy that requires yearly odometer readings, and it is thus subject to tampering. Thus we turn to other policies that might be more feasible and enforceable but that might *not* achieve the first-best efficient outcome.

Note that each of these last two policies is individual-specific. The formulas we derive show the optimal tax rates for each consumer's vehicle and fuel use (mileage). In general, however, the purchaser is anonymous. Thus, more-realistic alternatives might be limited to charging the same uniform rate for all consumers — one tax rate per unit of engine size, one tax rate that depends on vehicle age, and one tax rate on each grade of gasoline, no matter who buys it. Therefore the fourth policy we consider is a simple use of our formulas that were derived for individual-specific optimal tax rates. Policymakers could just insert into those formulas the average engine size, average vehicle age, and average mileage. This single set of tax rates based on those average characteristics could then be applied to everybody's engine size, vehicle age, and use of gasoline. As it turns out, this procedure misses some opportunities. It does not take advantage of available information *other than* those simple averages. In general, available data can be used to calculate not only average size, age, and mileage, but also the correlations among these variables. If individuals with bigger cars also tend to choose more than average mileage, or conversely, then that information can be used to adjust the tax rates in a way that improves their effectiveness, even while each of those tax rates is still limited to be uniform across on all consumers. Therefore the fifth and final policy option considered in Chapter 5 is the set of constrained-optimal tax rates on engine size, vehicle age, and gasoline. This policy uses all available information, but it is still limited to uniform rates across all consumers. It therefore does not perform as well as the first-best emissions tax, but it is the "second-best" as it out-performs all other *available* incentive-based policies.

After that theoretical chapter, we proceed in Chapter 6 to describe our computer model and our use of actual data for more than a thousand individual cars and their owners. We start with data from the 1994 Consumer Expenditure Survey (CEX) that includes each household's income, gasoline expenditures, other expenditures, and automobile ownership (including make, model, and year). To obtain other information about each car, we use data on a large sample of cars from the California Air Resources Board (CARB). For each car in the CEX, we find a car in the CARB with the same make, model, and year, and we use the CARB data for that car's engine size, estimated miles per gallon *(MPG)*, and estimated emissions per mile *(EPM)*. After linking the data in this way, we have a large sample of households with information on income and gas purchases plus each car's age, engine size, *MPG*, and *EPM*. We can also multiply *MPG* times gallons of gas to get an estimate of miles driven. We specify the price paid to acquire one more gallon of gas, the price paid to get a car that is one year newer, and the price paid to get a car that has one more unit of engine size (measured in cubic inches of displacement, CID). Each such price could be affected by a tax or subsidy. Next, we assume that each household gets utility from miles driven, engine size, vehicle "newness," and "other commodities." Maximizing this utility function subject to a budget constraint, we derive demand behavior, that is, how each household reacts to changes in each of those prices. These demand functions recognize that the price of gasoline affects *all* choices: demand for gasoline, demand for relatively larger cars with lower fuel efficiency, *and* demand for relatively newer cars with higher fuel efficiency. Similarly, any change in the effective price of buying a newer car or a larger car affects demands for those characteristics, which affect fuel efficiency, which affects the demand for gasoline. Given any outcome for each household's chosen gasoline, engine size, and vehicle age, we can calculate that household's *MPG* and *EPM*. We multiply *EPM* by miles to get the household's emissions, and we add over all households to get total emissions. We can also calculate each household's utility, and the overall gain or loss in the welfare of all households.

Using this model, we evaluate different combinations of tax rates. As a basis for comparison, we calculate the effect of an ideal Pigovian emissions tax. This tax raises the price of emissions, which raises the cost of driving, which lowers the demand for miles. It also raises the effective price of engine size and lowers the effective price of getting a newer vehicle (since newer vehicles have lower emissions). All consumers change behavior in various ways, and we calculate the reduction in emissions and the increase in total welfare. We then suppose that the ideal emissions tax is not available and instead consider tax rates on engine size, vehicle newness, and gasoline. Assuming all three of these instruments *are* available, we use the computer to search over combinations of tax rates to find the one set of rates that maximize the gain in welfare. This set of tax rates is the "second-best" policy, given the constraint that the first-best emissions tax is not available. Also, since this solution uses the heterogeneity among a thousand households in our computer model, it effectively makes use of the extent to which the demand for miles may be correlated with engine size or with vehicle age.

Our main result, using this model, is that the second-best combination of tax rates achieves a welfare gain that is 71 percent of the maximum gain obtained by the ideal-but-unavailable tax on emissions. The glass is more than half full. What does this second-best policy look like? The tax on gasoline is relatively high, and the tax on "newness" is negative (that is, a subsidy to buying a newer car with lower emissions). However, the tax rate on engine size is slightly negative. Surprisingly, the second-best policy calls for a slight subsidy to engine size. As discussed more in Chapter 6, the reason is that the high gas tax already effectively raises the price of buying a larger car with lower fuel efficiency – even more than is necessary to achieve the optimal allocation of resources. The dollar values of the rates depend on the magnitude of environmental damages, which depend on regional characteristics. We do not, therefore, recommend exact values for the rates. We do conclude, however, that the gas tax rate is large relative to the newness subsidy rate. The overall message here is that the gas tax is the single *most* effective tool to reduce emissions. It reduces the demand for gasoline by inducing people to drive fewer miles *and* to buy smaller more fuel efficient cars. An additional subsidy to newness helps induce them to buy newer cars with lower emission rates.

Chapter 6 also considers situations in which policymakers are limited to just one or two of those three tax rates. Since the subsidy to size was so small, it can effectively be ignored: a policy with just a gas tax and newness subsidy does almost as well as the three-part policy (71 percent of the gain from the ideal emissions tax). Without the newness subsidy, however, the welfare gain falls to 62 percent of the gain from the ideal emissions tax. Actually, the gas tax alone can achieve this 62 percent gain, with or without the small subsidy to size. Without the gas tax, the other two instruments can only achieve about 20 percent of the gain of the ideal emissions tax. Thus we conclude that a gas tax is the key ingredient of any market-based incentive policy – or at least one that cannot employ the ideal emissions tax.

We might also note that these market-based incentive policies are not enough on their own. In particular, the subsidy to buying a newer car is one way to reduce emissions in this model, but only because newer cars have lower emissions rates. And newer cars have lower emissions rates only because of regulations that have become increasingly stringent over time. So regulations are important, but so are incentives. The regulations by themselves make newer cars *more* expensive, because of the additional technology necessary to meet the increasingly-stringent standards. The fact that the newer cars are more expensive makes consumers *less* likely to buy them, and more likely to prolong the life of their older, dirtier cars. The subsidy to buying a newer car helps overcome that hurdle and thus makes the air cleaner. Perhaps a new subsidy to buying a cleaner car could be financed by an increase in the gas tax, a combination that performs efficiently in our model.

While that combination is efficient, we have not yet provided any information on the distribution of the tax burdens. Chapter 7 uses statistical techniques to address that issue. In addition, while the computer model of Chapter 6 uses *assumptions* about consumer demand behavior, we now attempt to estimate such demands directly. For any normal market commodity, the usual approach is to use a large sample of households to estimate the quantity demanded as a function of price, income, and demographic characteristics. This regression indicates both price and income elasticities of demand, and it indicates how the demand for this good varies across households of different types. Such results can be used to calculate the burden of a tax on this good across households of different types. In this case, however, estimation is complicated by the simultaneity of consumer choices. The demand for gasoline reflects a demand for vehicle-miles traveled *(VMT)*, which depends on the price of gasoline and on the *MPG* of the family car. But *MPG* depends on vintage and engine size. The demand for engine size depends on the cost of getting a larger engine, but that cost depends in part on the price of gasoline. In other words, the household's choice of vehicle affects their demand for miles, and vice versa. Our estimation accounts for this simultaneity.

For each household in a large sample from the Consumer Expenditure Survey (CEX), we record the number of cars and each car's age and number of cylinders. We divide all possible bundles into 19 categories. Having no cars is one such bundle, as is having one car that is small and old, or two cars that are medium-sized and new, etc. We estimate *MPG* as a function of these vehicle characteristics. With data on gasoline prices and gasoline purchases, we can then calculate each household's miles traveled and cost per mile. We also calculate the cost of owning each vehicle bundle.

We then break down the estimation of demands into stages. First the household considers income and all relevant prices to decide from among the 19 vehicle bundles. This estimation tells us the effect of demographic and bundle characteristics on the probability that a household will choose each bundle. Results tell us, for example, the extent to which households in urban areas are more likely to own no cars, or the effect of the number of income earners on the number of cars owned. Households in California are more likely to own larger cars than those in the Northeastern U.S., and households with more income are more likely to own more cars, larger cars, and newer cars. Thus we estimate the extent to which a subsidy to newer cars is regressive. Though it increases the number of newer, cleaner cars, this subsidy to "newness" mostly helps those with high incomes.

In the second stage, we estimate *VMT* demand as a function of prices, incomes, demographic characteristics, and vehicle bundle. A problem with this estimation is that the *actual* vehicle bundle is chosen by the household, so the use of actual bundle in this regression would bias the estimates of the other coefficients. Instead, we use the estimates from the first stage above to predict the chosen bundle from other variables for the household that are not chosen by the household (like income, prices, and demographic characteristics). We then use *predicted* bundles instead of actual bundles in the second stage estimation of *VMT* demand to get unbiased estimates.

We find that the demand for *VMT* is relatively unresponsive to its price, but our estimate of the price elasticity (-0.67) is somewhat larger than previous estimates. The estimated income elasticity (0.23) is similar to those in previous studies. For each one-percent increase of income, vehicle miles (and gasoline demand) increase by only 0.23

percent. An implication is that a gas tax is regressive; high-income families buy more gas and would pay more gas tax than low-income families, but their extra gas purchases and gas tax are less than their extra income. Thus their tax as a fraction of income falls.

That overall elasticity estimate tends to mask some specific effects of income on gas purchases, however, as income increases from poor to rich. The very poor do not own cars, and do not buy gasoline, so a tax on gasoline would not hurt the poorest families. The next income bracket includes working low-income families who tend to spend a relatively high fraction of income on gasoline. They would bear the brunt of a gas tax, while successive income brackets spend successively lower fractions of income on gas. Thus the gas tax is not regressive at the very poorest levels, but it is regressive across most of the rest of the income spectrum.

The subsidy to newness is relatively regressive, because it helps the rich, and the gasoline tax is relatively regressive, because it hits relatively low-income working families. These effects present significant challenges to researchers and policymakers alike: how to reduce emissions efficiently by using incentive instruments without placing undue burden on low-income families. This question warrants a lot more attention, obviously, as we all proceed with this research agenda. The next step could introduce additional constraints to the "optimal policy" problem. We could then ask what is the second-best set of tax rates other than the unavailable emissions tax that effectively reduce emissions while protecting the real incomes of low-income families. Alternatively, perhaps emissions policy could be *combined* with a change in other redistributive policies. Even if a gas tax and newness subsidy are regressive, for example, they could be combined with a change in transfer programs, other aid to low-income families, or a change to the overall progressivity of the income tax. Exempting low-income families from a gas tax or other emissions policy reduces its effectiveness. If instead all households were ensured adequate incomes through other policies, then the most effective emissions policy would tilt all households away from driving and polluting by presenting all of them with incentives such as the gas tax and newness subsidy. These and other future research topics are discussed more in our concluding chapter.

Chapter 2

Vehicle Pollution in California: Trends, Attainment, and Costs

Why should we be concerned about vehicle pollution in California? Over the last few decades, pollution from vehicle exhaust has declined. Total statewide ozone precursors such as oxides of nitrogen (NO_x) and reactive organic gases (ROG), fell from 1980 to 1995, as did statewide carbon monoxide (CO) emissions. Particulate matter (PM10) from vehicle exhaust also declined over that fifteen-year period, although that created by tires passing over roads has increased. Air quality, even in the heavily-polluted South Coast Air Basin, has also improved over the last two decades. Despite this improvement, many areas in California have not yet attained State and national ambient air quality standards. Increases in population and vehicle-miles traveled puts into question California's ability to attain these standards.

Because much of California does not attain air quality standards, its population continues to bear the external costs of driving. The direct costs of pollution include increases in morbidity and mortality, diminished visibility, crop damage, building damage, and decreased housing values. In addition, Californians face other costs of transport including the costs of accidents, road wear, noise, and lost time due to congestion.

In section I, we present information on air pollution trends and attainment in California. Next, in section II, we discuss increases in population and vehicle-miles traveled. Last, in section III, we discuss the costs of such pollution, focusing on health costs.[1]

I. Air Pollution in California: Trends and Attainment Status

This section presents information on air pollution trends in California over the last few decades. The overall pattern is clear: California air is much cleaner now than it was thirty years ago. Yet much of California does not meet Federal air quality standards, much less the more-stringent California standards for ozone (O_3), carbon monoxide (CO), and particulate matter (PM10). And even with cleaner cars, emissions reduction is not a foregone conclusion, because of population growth, increases in miles driven, and preferences for larger vehicles. In this section, we present statewide historical trends for three main pollutants: ozone, PM10, and carbon monoxide. Then, we use maps to show the areas of nonattainment in California. We then focus on the most heavily polluted region in the state, the South Coast Air Basin, by showing air quality trends for the three pollutants mentioned above.

[1] For estimates of the other transport costs mentioned above, see Greene et al (1997).

A. Statewide Historical Trends

The following graphs are drawn using data from *The 1999 California Almanac of Emissions and Air Quality* (CARB, 1999). These statewide data are shown only for 1985, 1990, and 1995. These data place statewide emissions into categories according to their source. Stationary-source emissions consist of those from industrial fuel combustion, waste disposal, cleaning and surface coatings, petroleum production and marketing, and industrial processes. Area-wide source emissions consist of those from solvent evaporation, residential fuel combustion, road dust, and miscellaneous activities. Mobile-source emissions consist of those from on-road motor vehicles and other modes of transportation.

1. Ozone

Vehicle emissions contain reactive organic gases (ROG) and oxides of nitrogen (NO_x), which react in the presence of sunlight to create ground-level ozone (O_3), the main component of urban smog. Respiratory symptoms of ozone exposure include coughing, painful breathing, and temporary loss of lung function (Wijetilleke and Karunatatne, 1995). When ozone levels are high, hospital admissions for respiratory and cardiovascular problems, emergency room visits for asthma, and asthma attacks increase (EPA, 1999). Epidemiological studies suggest that there may be a positive relationship between ozone and premature mortality (see Ito and Thurston, 1996; Kinney et al., 1995; Moolgavkar et al., 1995; and Samet et al., 1997). In addition, ozone damages crops, buildings, rubber, and some plastics (CARB, 1999).

Ozone levels in California declined significantly from 1985 to 1995. To measure ozone levels in the state, the CARB measures the levels of its precursors, ROG and NO_x. Figure 2-1 shows statewide emissions of NO_x. These emissions increased slightly between 1985 and 1990, and fell from 1990 to 1995. In all three years, gasoline and diesel vehicles accounted for approximately 60 percent of the oxides of nitrogen emitted. NO_x emissions from on-road motor vehicles declined by 15 percent from 1990 to 1995.

As evident in Figure 2-2, declines in emissions from on-road vehicles accounted for most of the 30 percent reduction in statewide ROG emissions from 1985 to 1995. In 1985, gasoline and diesel vehicles accounted for 54 percent of ROG emissions. By 1995, this number dropped to 47 percent.

2. Particulate Matter (PM10)

PM10 refers to particles with an aerodynamic diameter of 10 microns or smaller. These particles are mixtures of substances that can include carbon, lead, nickel, nitrates, organic compounds, sulfates, diesel exhaust, and soil. These substances occur in the form of solid particles or liquid droplets. By penetrating deep into the lungs, PM10 causes or contributes to bronchitis, asthma, and respiratory illnesses. Due to the well-established link between PM10 and premature death (see Pope et al., 1995 and Dockery et al., 1993), particulate matter is considered to be the most damaging component of urban smog (Krupnick et al., 1997).

As shown in Figure 2-3, statewide PM10 levels rose by 18 percent between 1985 and 1995. Vehicle exhaust accounted for only 5 percent of PM10 in 1985, and 3 percent in 1995. Emissions from gasoline vehicles and especially from diesel vehicles declined over the fifteen- year period. However, dust caused by driving on roads accounted for approximately 50 percent of area-source PM10. Over the ten-year period, this component of PM10 rose by 22 percent. Thus vehicles remain responsible for much of statewide PM10 creation.

3. Carbon Monoxide

Carbon monoxide is a colorless and odorless gas that is directly emitted as a product of combustion. It impairs the oxygen-carrying capacity of blood. Healthy people exposed to high levels of CO experience headaches, fatigue, slow reflexes, and dizziness (CARB, 1999). High ambient levels of CO increase hospital admissions for respiratory and cardiovascular problems (EPA, 1999) and may raise the probability of heart attack for those at risk (Krupnick, 1991).

Figure 2-4 shows that statewide carbon monoxide levels fell 23 percent from 1985 to 1995. Reductions in emissions from gasoline and diesel vehicles account for all of this reduction; emissions from other mobile sources, stationary sources, and area-wide sources increased over the period.

B. Nonattainment Areas in California

Despite the decreases in statewide ozone precursors, many areas do not attain State and national standards for ozone ambient levels. A small part of California violates the standards for carbon monoxide, and most of the state violates standards for PM10. The State and Federal standards for the three pollutants are listed in Table 2-1. State standards for all three pollutants are more stringent than Federal standards.

Table 2-1: State of California and National Standards for Ozone, PM10, and Carbon Monoxide

Pollutant	State of California Standard	National Standard
Ozone	0.09 parts per million (ppm) for one hour, not to be exceeded.	0.12 ppm for 1 hour, not to be exceeded more than once per year, *and* 0.08 ppm for 8 hours, not to be exceeded, based on the fourth highest concentration averaged over three years.
PM10	50 micrograms of particulate matter per cubic meter of air (µg/m^3) for 24 hours, *and* 30 µg/m^3 annual geometric mean, neither to be exceeded.	150 µg/m^3 for 24 hours, based on the 99th percentile concentration averaged over 3 years, *and* 50 µg/m^3 annual arithmetic mean averaged over 3 years.
Carbon Monoxide	20 ppm for 1 hour, *and* 9.0 ppm for 8 hours, neither to be exceeded.	35 ppm for 1 hour, *and* 9.0 ppm for 8 hours, neither to be exceeded more than once per year.

Source: CARB (1999).

Based on these standards, state and national governments classify regions into three air quality designations: nonattainment, attainment, and unclassified. A nonattainment designation indicates that air quality violates an air quality standard, while an attainment designation indicates that air quality does not violate a standard. An unclassified designation indicates insufficient data for determining attainment or nonattainment. In addition, the State of California splits nonattainment areas into two categories: nonattainment and nonattainment-transitional. Areas classified as nonattainment-transitional have experienced air quality improvements that indicate that they may soon qualify as attainment areas.

1. Ozone nonattainment areas

Figures 2-5 and 2-6 show state and national nonattainment areas for ozone in 1998. With the exception of some areas in northern and central California, most areas of the state, including all major urban areas, have ozone concentrations that violate the State standard.

What is not shown in these maps, however, is that the Los Angeles area is the only area in the United States that is classified as being in “extreme” nonattainment of the national ozone standard. The Sacramento area, and the Southeast Desert Modified Air Quality Management Area are in “severe” nonattainment, and the San Joaquin and

South Central Coast Air Basins are in "serious" nonattainment. Most other urban areas in California also violate national ozone standards. Areas that do not violate the national 1-hour standard are categorized as areas where the standard no longer applies. These areas may violate the new national 8-hour standard, established in 1997, and the EPA is in the process of redesignating those areas.

2. PM10 nonattainment areas

As shown in Figure 2-7, in 1998 nearly all of the state is designated as nonattainment for the California PM10 standards. Three counties remain unclassified, and only one area, the Lake County Air Basin, is designated as being in attainment.

The national PM10 standards have two designation categories: nonattainment and unclassified. However, several areas in California have PM10 air quality that does not violate the national standards. Figure 2-8 shows that the San Joaquin Valley, Sacramento, the Mojave Desert, the Los Angeles area, and the Salton Sea Air Basin (which includes Imperial County and part of Riverside County) are designated as nonattainment areas by the Federal government.

3. Carbon monoxide nonattainment areas

In 1998, California had only two nonattainment areas for the State CO standards: Los Angeles County and the city of Calexico, located along the Mexican border. Figure 2-9 shows these two areas.

If one county in an air basin does not attain national ambient air quality standards, the entire air basin is designated nonattainment. This explains the fact that in Figure 2-10, the entire South Coast Air Basin, not just the county of Los Angeles, is shown to be in nonattainment of Federal standards.

C. South Coast Air Basin Air Quality Trends

The South Coast Air Basin is California's largest metropolitan region. It covers "a total of 6,530 square miles, is home to nearly half of California's population, and generates about one-third of the state's total criteria pollutant emissions" (CARB, 1999: p. 81). As we saw in Section B of this chapter, the South Coast Air Basin does not attain national standards for ozone, PM10, or carbon monoxide. However, maximum 1-hour levels of all three pollutants were lower in 1997 than they were in most previous years.

1. Ozone

As shown in Figure 2-11, maximum one-hour concentrations of ozone in the South Coast Air Basin decreased by 50 percent from 1980 to 1997. In 1980, the air basin experienced 210 days above the State of California standard. In 1997, ozone concentrations were above this standard on 144 days. For the national 1-hour standard, violations occurred in this air basin 167 days in 1980, and 64 days in 1997.

2. PM10

Data on PM10 air quality are available for years beginning in 1988. Figure 2-12 shows that the maximum 24-hour concentrations of PM10 were quite volatile between 1988 and 1993, and then leveled out between 1994 and 1997. Overall, concentrations fell from 289 $\mu g/m^3$ in 1988 to 227 $\mu g/m^3$ in 1997. In 1988, the basin experienced 65 days above the State 24-hour standard and 30 days above the national 24-hour standard. In 1997, the number of days above the State standard was 54, and 6 days were above the national standard.

3. Carbon Monoxide

As shown in Figure 2-13, carbon monoxide concentrations in the South Coast Air Basin decreased by 35 percent between 1980 and 1997. In 1980, the State standards were exceeded on 98 days, and the national standards on 94 days. In 1997, State standards were exceeded on 16 days, and national standards on 12 days.

II. Population and Vehicle-miles Traveled

As documented by the CARB (1999), population and vehicle-miles (*VMT*) growth rates are stunning. As shown in Figure 2-14, California's population grew from 23.6 million to 32.2 million between 1980 and 1997, an increase of 36 percent. According to the census, between 1990 and 1998, California's population grew faster than the national population: 9.7 percent, compared to the national growth rate of 8.7 percent.

As shown in Figure 2-15, *VMT* grew far more quickly than population: the number of miles traveled each day statewide grew by 78 percent between 1980 and 1997.

In the South Coast Air Basin, the growth rates were slightly lower than in the rest of the state. The basin's population grew by 37 percent from 1980 to 1997. Vehicle-miles traveled increased from 177 million miles per day in 1980 to almost 310 million miles per day in 1997, an increase of about 75 percent.

III. The Health Costs of Vehicle Pollution

Estimating the health costs of vehicle pollution is not a straightforward process. The extent to which air pollution affects a population varies according to the geographic characteristics of an air basin, population density, weather conditions, rush hour times, and a host of other factors. The first step is to model the link between emissions and concentrations of ambient pollution. Second, once exposure levels are known, physiological responses to pollutants must be estimated. Such "dose-response" functions have been estimated, but a scientific consensus has yet to emerge. Third, even if dose-response functions are well-determined, assigning a dollar value to physiological effects is extremely difficult.

Krupnick et al. (1997) discuss these issues and how they contribute to significant uncertainties in estimates of the costs of vehicle pollution. Modeling the link between emissions and the concentration of ambient pollutants is perhaps the most difficult step:

> The underlying air chemistry is complicated and understanding of it is rapidly evolving, with the models playing catchup. Although the EPA has approved some models for use in the State Implementation Plan process (under the Clean Air Act) and in other venues, many (such as the Urban Airshed Model used for ozone modeling) require too much input data and are too expensive for use in all but the most well-funded social cost studies. The alternative of using simpler models requires a reliance on assumptions whose credibility has yet to be established … Further, different models of the same pathway … offer different results (Krupnick et al., 1997, p. 357).

The second step, estimation of the physiological response to pollutants, is also problematic. For example, results from studies of the effects of PM10 on mortality differ according to whether the study used data from the same region over time, or data from many regions for the same year. Another debate in the PM10 literature concerns whether or not there is a "threshold" level in the response to PM10, that is, whether PM10 levels have to reach a certain minimum before any physiological responses occur. Studies of PM10 from electric facilities show that small changes in the assumed threshold can have large effects on cost estimates (Krupnick et al. 1997).[2]

The third step, in which a dollar value is assigned to effects such as increased morbidity or mortality, can be undertaken using a variety of methods, and each method can yield different results. The approach most often used to estimate the dollar value of costs is to determine how much a person would be willing to pay to experience, for example, one fewer day with severe coughing or asthma, or to decrease the chances of premature death due to pollution. The dominant approach for estimating willingness to pay is to estimate the wage premiums paid to workers that have increased risks of death (Viscusi, 1993). These wage premiums, or "compensating differentials," indicate how much an employer must pay an employee in order to get that worker to accept higher risks of death on the job. Presumably that worker, and other members of the

[2] The EPA considers Pope, et al. (1995) to be the "strongest" of the PM studies. Even so, the Pope et al. study has some limitations. For example, it does not consider the migration of people across study cities, or the possible correlation of PM with concentrations of other air pollutants (EPA, 1999).

population, would be willing to give up that wage premium if risks were reduced. Estimates of the implied "value of life" range from $0.6 million (Kneisner and Leeth, 1991) to $13.5 million (Garen, 1998), in 1990 dollars. The EPA (1999) analyzed 26 relevant studies to arrive at a "best-estimate" of $4.8 million. Krupnick et al. (1997) consider the best estimates to be from about $3 million to $4 million, but note that such studies suffer from many limitations.[3]

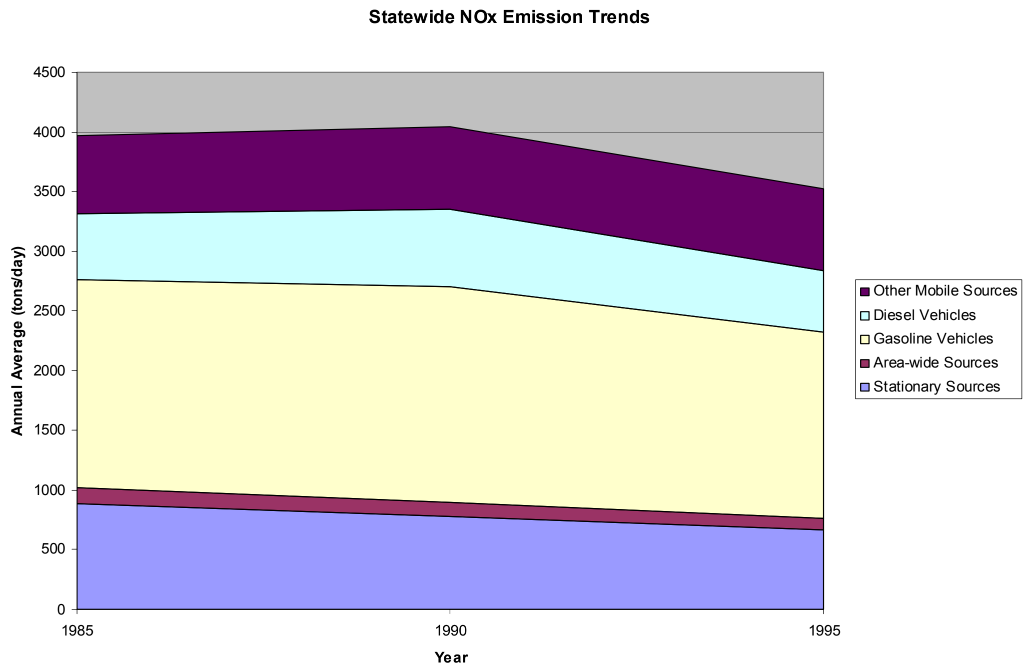
It should not be surprising, then, that estimates of the damage costs of pollution vary widely. Hall (1989) and Hall et al. (1992), estimate health-related benefits of ozone and PM10 reductions required in the South Coast Air Basin by the Federal government that are part of the 1989 South Coast Air Quality Management Plan (AQMP). The benefits are those that would be attained through 2010 from reducing pollution from 1990 levels to the standard levels. Estimates of the benefits of pollution reduction are equivalent to the costs of pollution. Their estimates, adjusted to 1998 dollars, range from a most-conservative estimate of $6.6 billion per year, to a high-range estimate of $28.0 billion, with a "best-conservative" estimate of $13 billion per year. PM10 morbidity and mortality benefits make up $9.8 billion of the $13 billion, and ozone morbidity the remaining $3.2 billion. NERA (1990) also estimate the same benefits, and conclude that Hall et al. "substantially overstate the likely benefits of the AQMP" (p. E-2). NERA's estimates range from $.28 to $9.2 billion per year, with a "best estimate" of $2.2 billion, of which $1.65 billion is PM10-related. Krupnick and Portney's (1991) estimates fall between those of Hall et al. and NERA. They estimate health benefits of the same plan to be $4.1 billion (also in 1998 dollars).

Small and Kazimi (1995) handle the disparities in cost estimates by presenting many different estimates of the costs of vehicle pollution for the Los Angeles region, using estimates from both Hall et al. (1992) and Krupnick and Portney (1991). They also experiment with a variety of allocations of the health costs of ozone between NO_x and volatile organic compounds (VOC, very similar to ROG). Results from their study are particularly useful because they are presented in cents per vehicle-mile. Per vehicle-mile, in 1998 dollars, they estimate the cost of VOC to be 1.7 cents, NO_x to be 2.04 cents, and PM10 to be .13 cents. They add these estimates to their estimate of the costs of oxides of sulfur to determine that health costs are about 4 cents per vehicle-mile. To give an idea of the magnitude of this number, they consider what might happen if people were assessed a gas tax that corresponds to this cost. At retail gasoline prices of $1.20 per gallon, and fleet average fuel economy of 22 miles per gallon, a gas tax would be more than 60 cents per gallon.[4]

[3]Krupnick at al. (1997) list four limitations of such studies: "(1) they reflect the risk preferences of perhaps a less risk adverse [sic] group than the average in society; (2) they reflect voluntarily borne risks; (3) more life years are lost to accidental death than those associated with pollution (cancer, for example, has a latency period, and the effects may be discounted because they occur far into the future; and (4) the source of the risk is an accident rather than a business polluting as part of its normal operations."

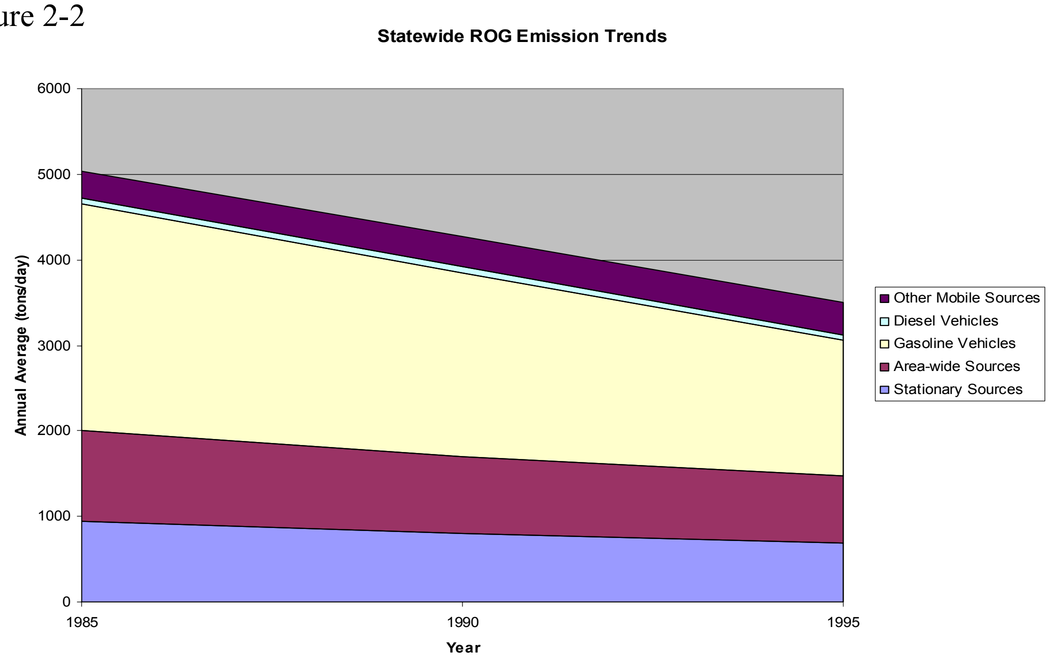
[4] Fleet fuel efficiency from ORNL (1999).

Figure 2-1



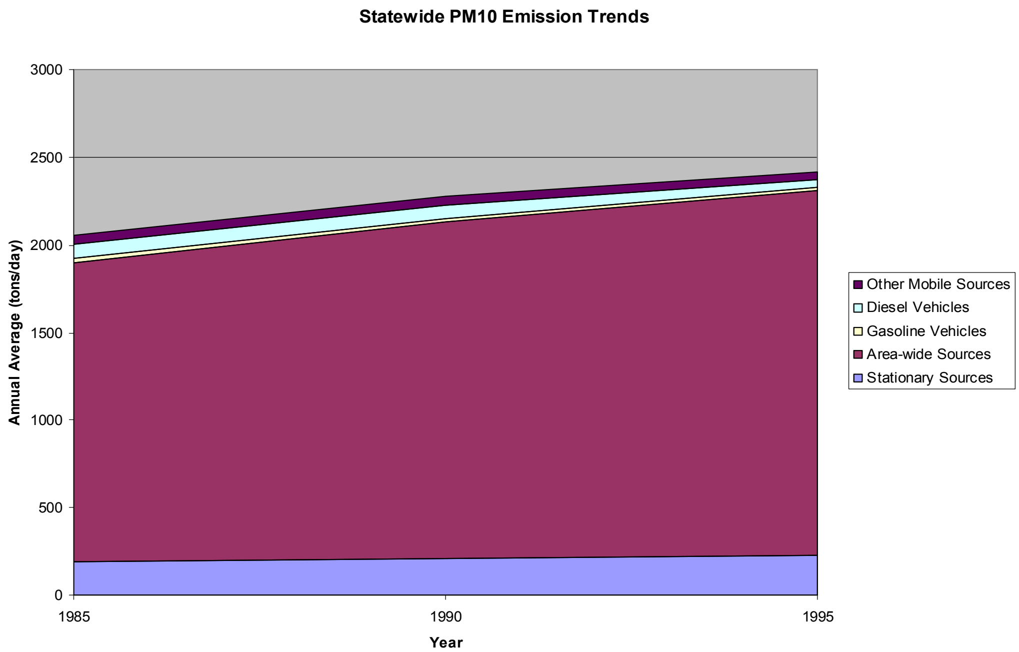
Source: CARB (1999).

Figure 2-2



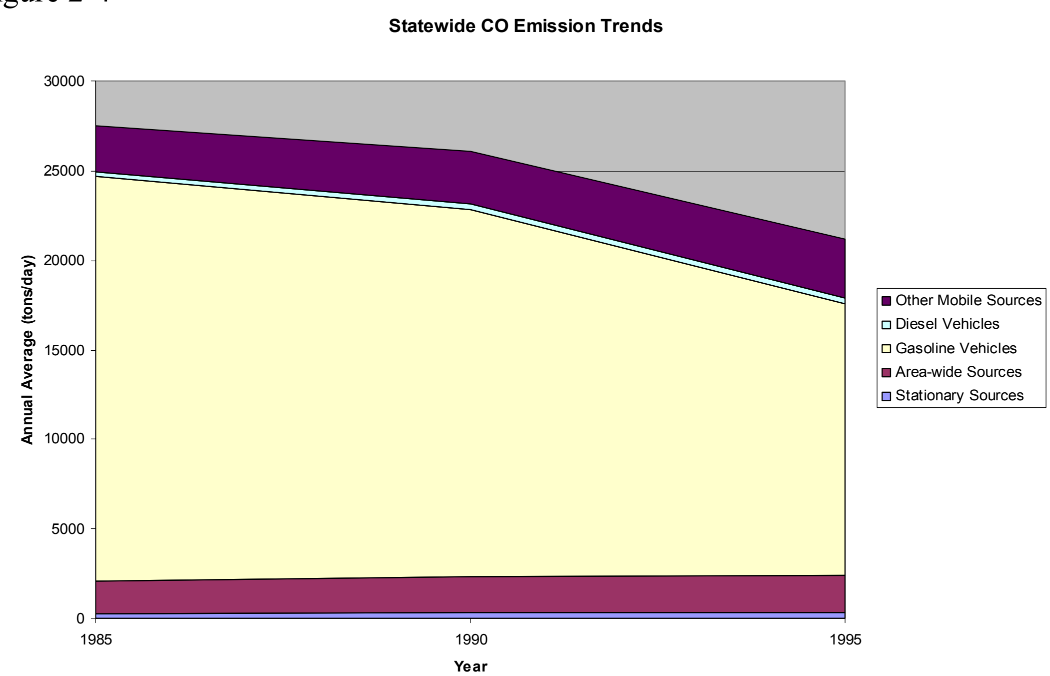
Source: CARB (1999).

Figure 2-3



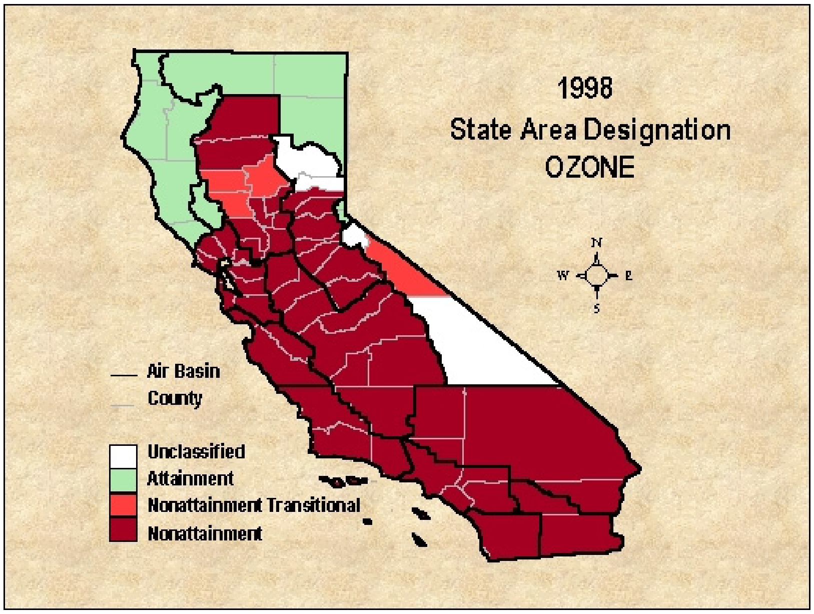
Source: CARB (1999).

Figure 2-4



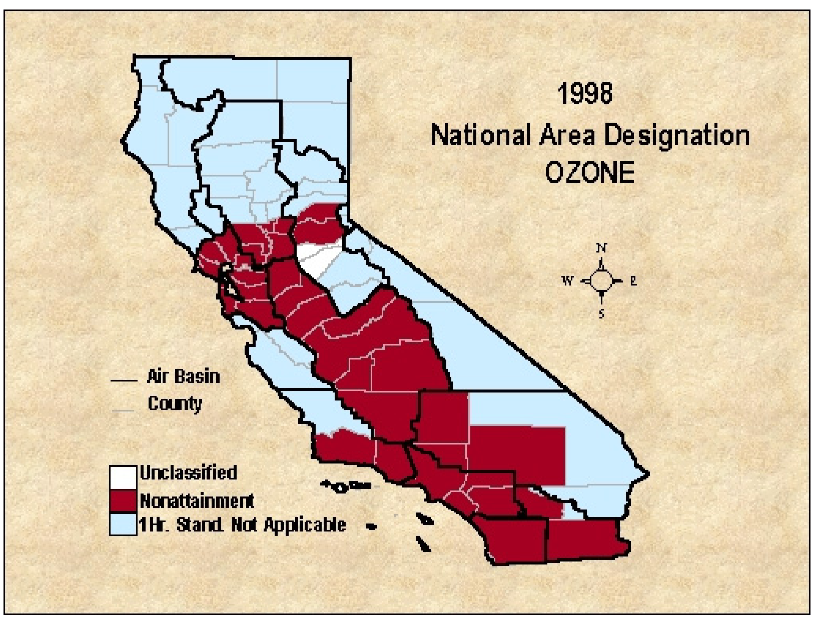
Source: CARB (1999).

Figure 2-5



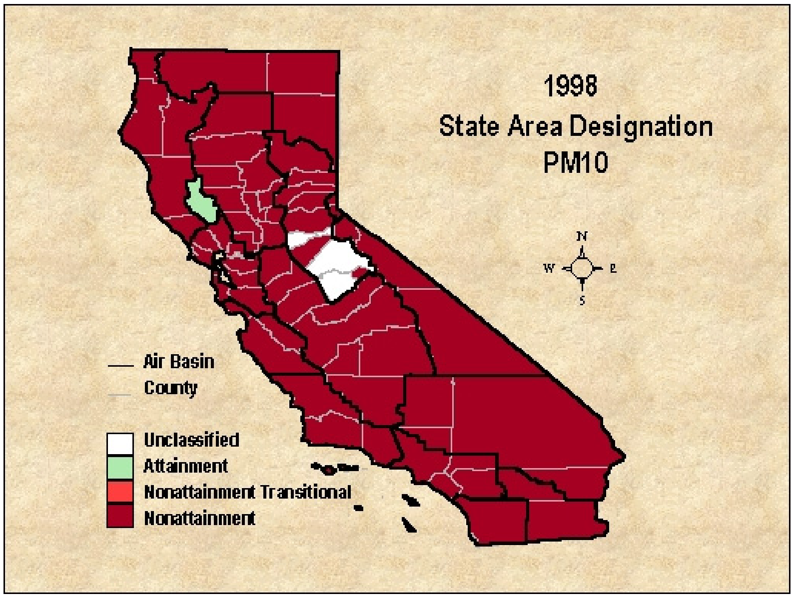
Source: CARB (1999).

Figure 2-6



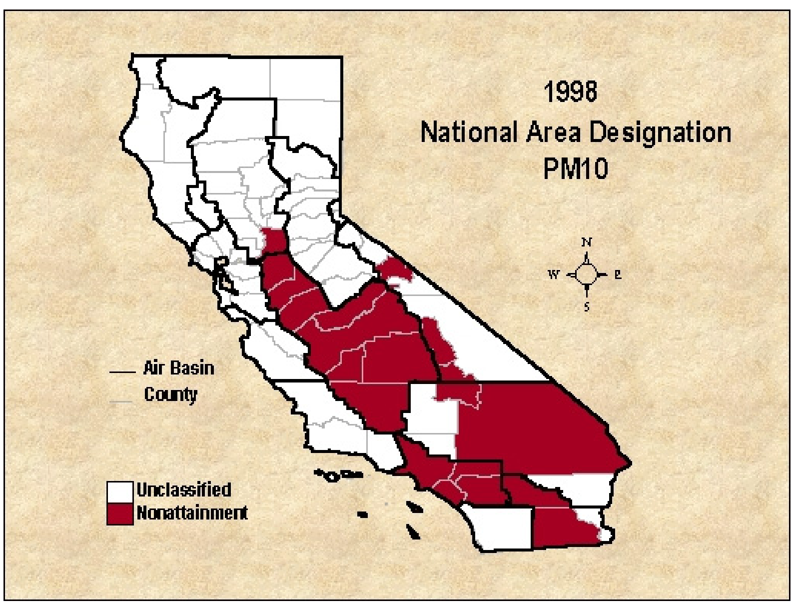
Source: CARB (1999).

Figure 2-7



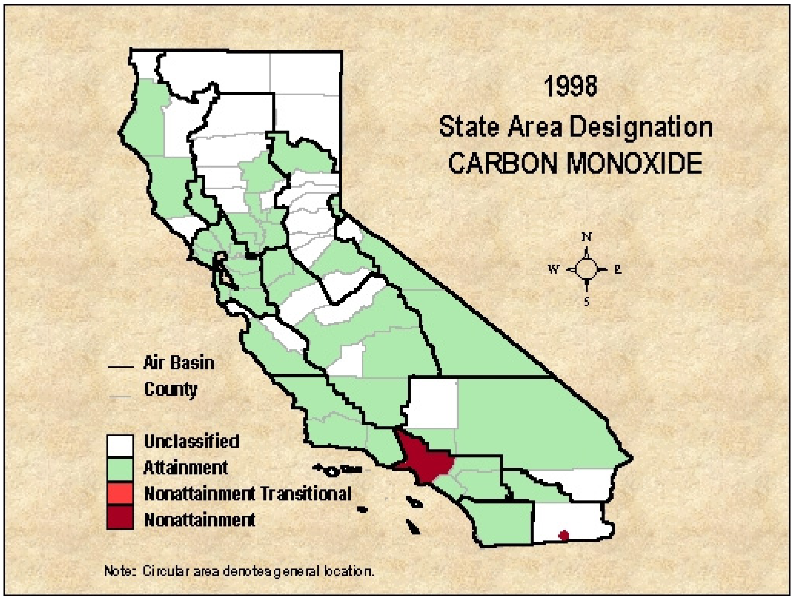
Source: CARB (1999).

Figure 2-8



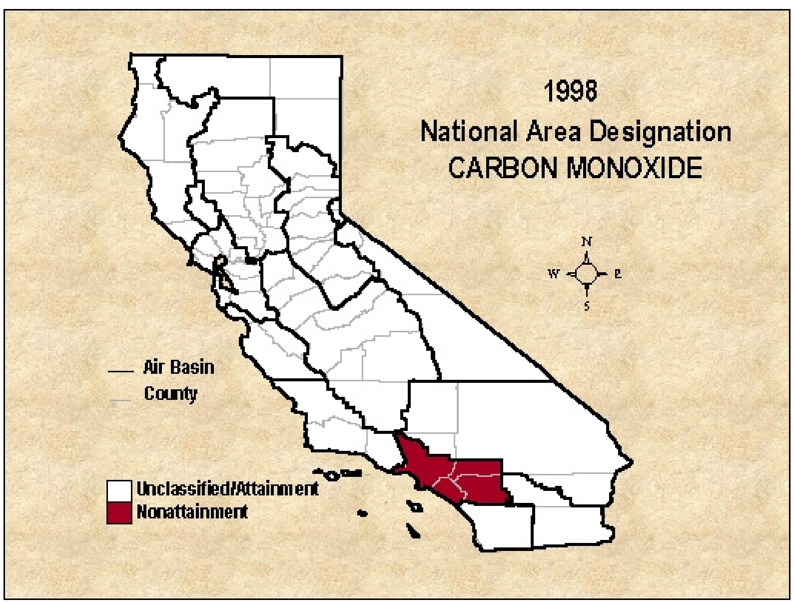
Source: CARB (1999).

Figure 2-9



Source: CARB (1999).

Figure 2-10

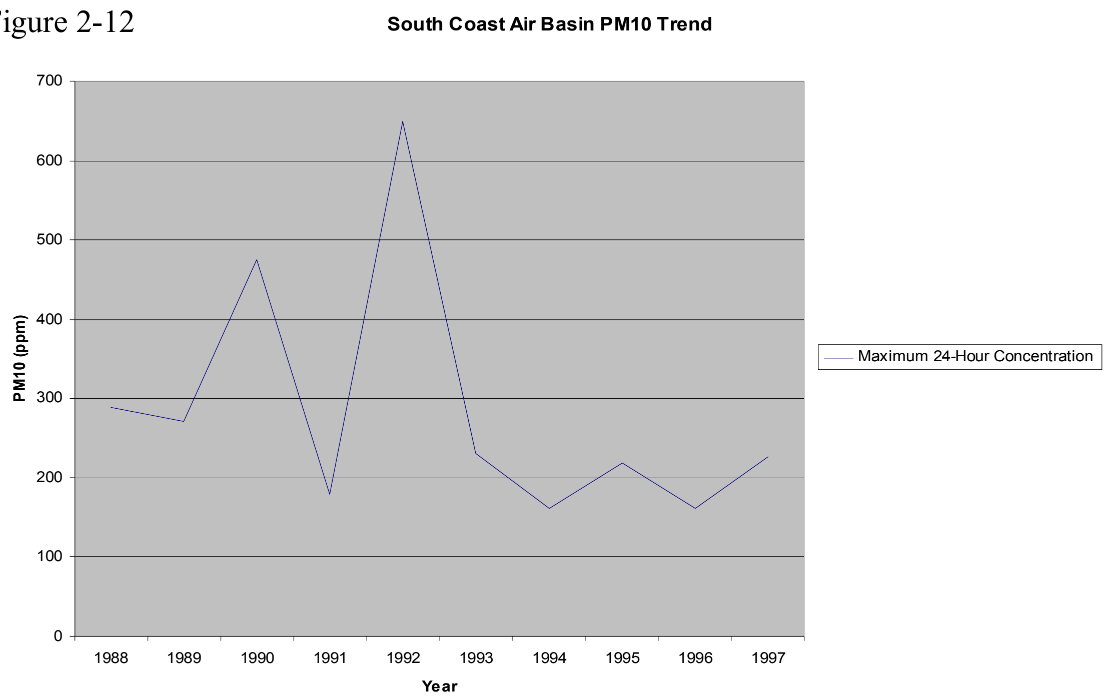


Source: CARB (1999).

Figure 2-11

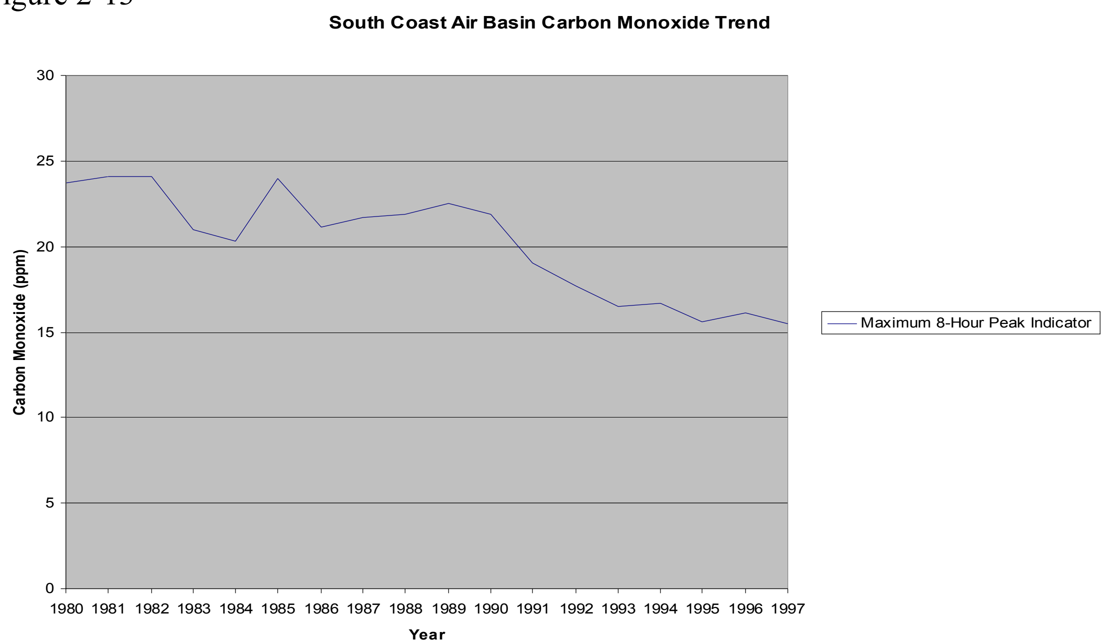
Source: CARB (1999).

Figure 2-12



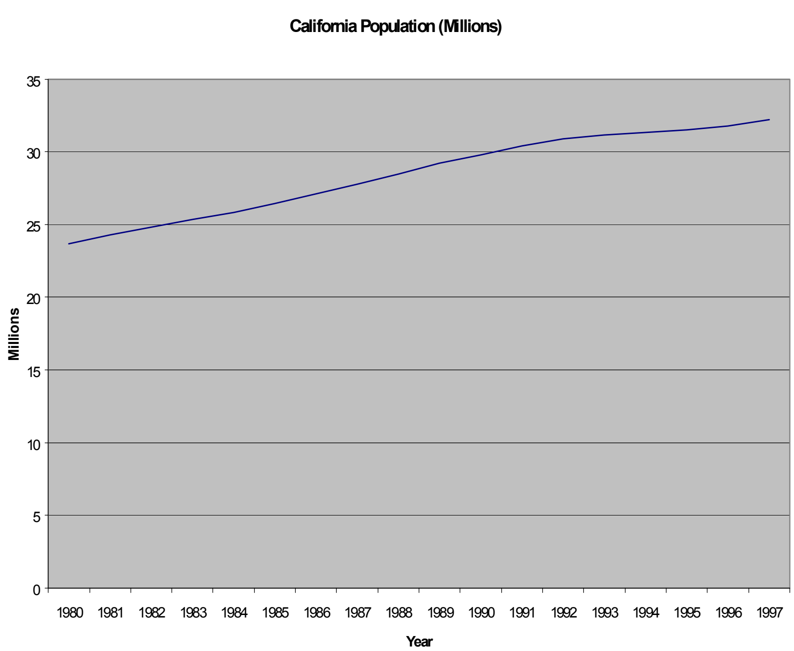
Source: CARB (1999)

Figure 2-13



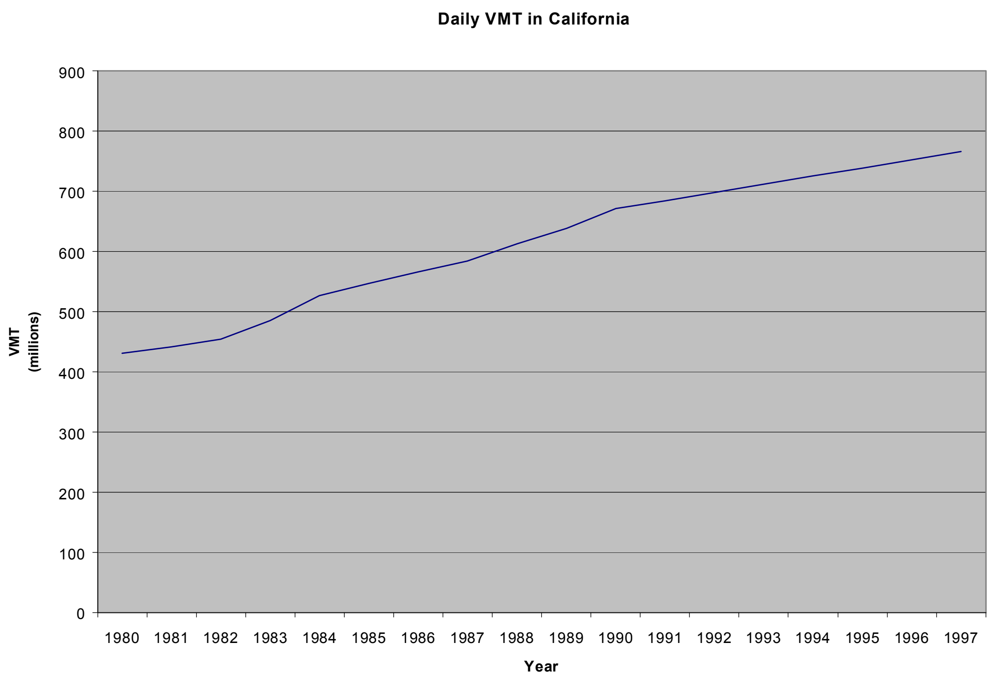
Source: CARB (1999).

Figure 2-14



Source: CARB (1999).

Figure 2-15



Source: CARB (1999).

Chapter 3

Current Vehicle Pollution Policies in California

As shown in Chapter 2, over the last twenty years, pollution from vehicle exhaust declined. Despite the fact that many areas in California have not attained State and national ambient air quality standards, pollution control policies have at least worked to some extent. California implements two categories of vehicle pollution control policies: mandates, or command-and-control policies, and market-based incentives. Mandates generally require all parties to undertake the same emissions-reducing actions, while market-based incentives encourage but do not force emissions reduction. Many small market-based incentive programs exist, but mandates are by far the most wide-reaching policies in the state. In this chapter, we describe policies from both categories, beginning with mandates.

I. Command-and-Control Vehicle Pollution Policies

California's mandates focus on requiring gasoline-burning vehicles to be cleaner. The state enforces four main vehicle pollution control mandates: certification standards, fleet composition standards, inspection and maintenance requirements, and reformulated gasoline requirements.[5] Certification standards require that all vehicles sold in California have emissions lower than specified maximums when they roll off the assembly line. New-vehicle "fleet" composition standards mandate that each vehicle manufacturer's total new car sales be made up of a certain percentage of low-emission vehicles. They also require carmakers to certify that a certain percentage of new vehicles sold meet these standards over the lifetime of the vehicle. Inspection and maintenance programs require most vehicles in most areas to pass a smog check in order to be registered. Reformulated gasoline must meet eight basic specifications for cleaner-burning fuel. In the following sections, we provide more detail about each of these mandates.

A. California Passenger Car and Light Truck Emission Certification Standards

California has the most stringent emission certification standards in the United States.[6] Taken in combination with fleet composition standards, they require that new vehicles' emissions of hydrocarbons and oxides of nitrogen be at least fifty percent lower in 2003 than the basic Tier 0 California standards (the basic standard before 1994).

[5] California also enforces a variety of other mandates, including standards that limit the evaporative and refueling emissions from vehicles 1978 model-year and newer.

[6] New York and Massachusetts have also adopted California's standards.

Table 3-1 lists California new vehicle emissions certification standards in grams per mile for passenger cars and light-duty trucks.

Table 3-1: California New Vehicle Emission Certification Standards (grams/mile)

		Vehicle Useful Life					
		5 years/ 50,000 miles			10 years/ 100,000 miles		
Vehicle Type	Emission Category	NMOG[a]	CO	NO_x	NMOG[a]	CO	NO_x
Passenger Car	Tier 0	-	7.0	0.4	-	-	-
	Tier 1	-	3.4	0.4	-	4.2	0.6
	TLEV	0.125	3.4	0.4	0.156	4.2	0.6
	LEV	0.075	3.4	0.2	0.09	4.2	0.3
	ULEV	0.04	1.7	0.2	0.055	2.1	0.3
	ZEV	0.0	0.00	0.0	0.0	0.0	0.0
LDT1	Tier 0	-	9.0	0.4	-	-	-
	Tier 1	-	3.4	0.4	-	4.2	0.6
	TLEV	0.125	3.4	0.4	0.156	4.2	0.6
	LEV	0.075	3.4	0.2	0.09	4.2	0.3
	ULEV	0.04	1.7	0.2	0.055	2.1	0.3
	ZEV	0.0	0.00	0.0	0.0	0.0	0.0
LDT2	Tier 0	-	9.0	1.0	-	-	-
	Tier 1	-	4.4	0.7	-	5.5	0.97
	TLEV	0.16	4.4	0.7	0.2	5.5	0.9
	LEV	0.1	4.4	0.4	0.13	5.5	0.5
	ULEV	0.05	2.2	0.4	0.07	2.8	0.5

Source: ORNL (1999): p. 4-35.

[a] For diesel-fueled vehicles, NMHC (non-methane hydrocarbons) are measured instead of NMOG

LDT1 = light-duty truck up to 3,750 lbs. loaded vehicle weight

LDT2 = light-duty truck greater than 3,750 lbs. loaded vehicle weight

Tier 0 = basic standard before 1994

Tier 1 = basic standard, partially implemented in 1994 and 1995, fully implemented in 1996

NMOG = non-methane organic gases

TLEV = transitional low-emission vehicle, LEV = low-emission vehicle

ULEV = ultra-low-emission vehicle, ZEV = zero-emission vehicle

Since 1996, all vehicles sold were required to meet Tier 1 standards. Unlike the previous Tier 0 standards, Tier 1 passenger car standards also apply to category 1 light-duty trucks (LDT1). Tier 1 also introduced standards, less stringent than for LDT1, for category 2 light-duty trucks (LDT2). In addition, Tier 1 standards extend the definition of a vehicle's useful life from five years to ten years. For example, to pass Tier 1 standards, a ten-year old vehicle must emit less than 4.2 grams per mile of CO. To prove that they fulfill this requirement, automakers simulate the likely deterioration that would take place over ten years by running a new vehicle for 100,000 miles. Then they conduct an emissions test. Before 1994, the standards listed in Table 3-1 under the 5 years/50,000 miles columns applied, and automakers ran vehicles for 50,000 miles before testing emissions. As this monograph was being written, the EPA was in the process of drafting Tier 2 standards, which will involve more stringent requirements for PM10 and will apply to a broader class of trucks.

Current standards also define the emissions levels required for a vehicle to be classified into four classes of lower-emission vehicles: transitional low-emission vehicles (TLEVs), low-emission vehicles (LEVs), ultra-low-emission vehicles (ULEVs), and zero-emission vehicles (ZEVs). For each category, Table 3-2 lists the emission reduction from Tier 0 standards for passenger cars and category 1 light-duty trucks.

Table 3-2: California Emission Reduction for Passenger Cars and LDT1

	Emission reduction from the Tier 0 Standards		
	HC	CO	NO_x
TLEV	50%	0%	0%
LEV	70%	0%	50%
ULEV	85%	50%	50%
ZEV	100%	100%	100%

Source: ORNL (1999): p. 4-36.
HC = hydrocarbons, the main ingredient of reactive organic gases (ROG)

The real impact of these standards is not due to the requirement that all cars meet Tier 1 standards. Instead, it is because these standards are combined with fleet requirements, which we explain in section B.

B. Fleet Composition Requirements

Beginning in 1994, California required a certain percentage of each car manufacturer's vehicles sold in the state to be transitional low-emission vehicles. From 1994 to 2003, each car manufacturer is required to meet increasingly stringent new-fleet composition requirements. Table 3-3 presents these requirements.

What is not shown in this table is that the original requirements, adopted in 1991, required that 2 percent of all vehicles sold be zero-emission vehicles in 1998. This requirement was to increase to 5 percent by 2002. A March 1996 amendment to the plan allows the market to determine the number of zero-emission vehicles from

1998 through 2002. Then, in 2003, ten percent of the vehicles sold by each car manufacturer must be zero-emission vehicles.[7]

Table 3-3: California New Fleet Composition Requirements

Year	Conventional Vehicles	TLEVs	LEVs	ULEVs	ZEVs
1993	100%				
1994	90%	10%			
1995	85%	15%			
1996	80%	20%			
1997	73%		25%	2%	
1998	48%		48%	2%	
1999	25%		73%	2%	
2000			90%	2%	
2001			90%	5%	
2002			85%	10%	
2003			75%	15%	10%

Source: ORNL (1999): p. 4-37.

In addition to imposing these statewide sales composition requirements, the state allows districts in non-attainment areas to require public and private fleet operators to purchase LEVs and operate them on clean fuels. All passenger vehicles for hire in non-attainment areas are required to be alternative fuel vehicles (AFV), and the state is required to purchase 25% AFVs as it replaces fleet vehicles (USDOE, 1998). The CARB also requires certain owners of retail gasoline stations to equip their stations to dispense alternative fuel if 20,000 or more vehicles in California are certified to a low-emission standard using that fuel. Through 2000, no alternative fuel has been the certification fuel for 20,000 or more vehicles.

C. Inspection and Maintenance Requirements: The Smog Check Program

California's first vehicle inspection program began in 1984. Most vehicles in most areas cannot be registered without passing a "Smog Check" once every two years. Motorists whose vehicles do not pass the Smog Check must repair their vehicle and have it tested again. The State of California Department of Consumer Affairs (DCA) and the Bureau of Automotive Repair (BAR) oversee the privately-owned stations that conduct these inspection and maintenance programs. In the 1990 amendments to the Clean Air Act, the U.S. EPA mandated a plan for enhanced emissions testing. It calls

[7] This discussion was valid as of year 2000.

for the elimination of privately-owned vehicle inspection stations, to be replaced by state-owned stations.

Beginning in 1994, the state implemented a compromise plan. The compromise has three main components. First, instead of eliminating all privately-owned inspection stations, it requires that 15 percent of vehicles in "enhanced areas", regions that do not meet Federal ozone ambient air quality standards, be sent to specially-authorized test-only stations.[8] The BAR uses a high-emitter profile of vehicles considered most likely to fail their smog checks, and it directs enough owners of these vehicles to the test-only stations to satisfy the 15 percent requirement.[9] Second, all enhanced area stations are required to use a treadmill-like machine called a dynamometer to test emissions. By simulating actual driving conditions, this equipment allows stations to obtain more accurate emissions readings. Third, the state focuses on gross polluters, those vehicles that far exceed allowable emissions levels for a particular model. Gross polluters must be repaired and have those repairs verified, and the vehicle certified, at a test-only station or at a gross polluter certification pilot station (DCA, 1998a and 1998b).

In 1998 the Smog Check program was modified in three ways. First, cars built in model year 1973 and earlier are now exempt from all aspects of the program. Second, vehicles four years old and newer are exempted from the biennial requirement, but still must have Smog Checks performed when sold or when registered for the first time in California.

Third, three financial assistance programs were created. In the first program, a vehicle may now be registered without passing its Smog Check if the vehicle owner makes $450 in emissions-related repairs at a licensed repair station. When a person makes these repairs, she receives a "Repair Cost Waiver" that lasts two years. An owner may only receive one such waiver while she owns the vehicle. In the second program, an "Economic Hardship Extension" is available for qualified low-income motorists. It is also valid for two years and may be obtained only once during the driver's ownership of a vehicle. To obtain the extension, the motorist must spend $250 on emissions-related repairs from a licensed Smog Check station, or have an estimate showing that a single repair would cost more than $250. The vehicle owner must also have an income that is at or below 175% of the U.S. poverty level. The third program is the low-income repair assistance program, which helps low-income motorists pay for emissions-related repairs. The vehicle-owner must make a $250 co-payment, and the state contributes an additional amount not to exceed $450 (DCA, 1998b).

The inspection and maintenance emissions requirements depend on the vehicle's model year and weight, and on the type of test to which the vehicle is submitted. Older

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[8]The followings areas are "enhanced": Sacramento, Davis, Vacaville, Stockton, Modesto, Fresno, Bakersfield, Hemet-San Jacinto, Palm Springs, Southern Ventura County, the South Coast Air Basin, and Western San Diego County. For a map of these areas and additional information about the Smog Check Program, see the Smog Check web site at http://www.smogcheck.org.

[9] The High Emitter Profile is a computer model that uses data from previous Smog Checks of vehicles.

and heavier vehicles are subject to higher passing limits. The tests measure hydrocarbons and oxides of nitrogen in parts per million, and carbon monoxide in percentage terms.[10]

D. Reformulated Gasoline

All gasoline sold in California for use in motor vehicles meets eight specifications: two specifications for reduced distillation temperatures; one for use of an oxygen-containing additive such as ethanol; and the remaining five for reduced sulfur content, benzene content, levels of aromatic hydrocarbons, levels of olefins, and vapor pressure.

The California Air Resources Board regulations allow refiners to sell fuel that satisfies only some of these requirements as long as the fuel provides "comparable air quality benefits".[11] In March 1999, Governor Gray Davis ordered the gradual elimination of the widely-used oxygen containing fuel additive MTBE from California gasoline. Most California gasoline in recent years has contained MTBE, even though there has never been any legal requirement for its use. MTBE has caused public concern because, like other gasoline components, it can contaminate groundwater when underground fuel tanks leak. MTBE moves faster in water than other fuel components and, in small amounts, renders drinking water unusable (CARB, 1999).

The California Energy Commission estimates that the use of cleaner-burning gasoline increased gasoline prices on average by 5 to 8 cents since 1996.

II. Market-based Incentives for Vehicle Emissions Reduction

Most of the state's broadest market-based incentive programs encourage the retirement or repair of gasoline vehicles, or they encourage the purchase of alternative-fuel vehicles or alternative fuels. A variety of smaller programs promote car-pooling. Notably absent from the list of market-incentives is a gas tax: California's gas tax is 18 cents per gallon, a little lower than the national average state gas tax.

In this section, we discuss the Mobile Source Offset Program, which provides incentives to repair or retire a vehicle, and another planned program that would encourage early vehicle retirement. Second, we list incentives that encourage the purchase of alternative vehicles and fuels. Third, we examine a variety of smaller incentive programs that target the number of miles driven.

[10] See http://www.smogcheck.ca.gov/smogweb/smog/cutpointsasm1099.asp for a table of these standards.

[11] Refineries can sell the gasoline as long as smog-forming emissions are reduced by at least 15 percent, and cancer risk from exposure to toxics is reduced by about 40 percent from levels associated with gasoline sold before Spring 1996 (CARB, 1996).

A. *Mobile Source Offset Program*[12] *and Voluntary Accelerated Vehicle Retirement Programs (VAVRs)*

The South Coast Air Quality Management District (SCAQMD) is a regional government agency in Southern California with jurisdiction over air quality in Los Angeles and Riverside Counties, and the non-desert portion of San Bernardino County. The SCAQMD implements the Mobile Source Offset Program, designed to give stationary sources more flexibility in meeting emissions reduction requirements. It is hoped that providing this flexibility for stationary sources will result in lower vehicle emissions. Under this program, businesses or individuals can receive credit for emissions reduction that occurs when they repair high-emitting vehicles, when they operate low- or zero-emission on-road vehicles, or when they retire, or "scrap" old vehicles. When a business or person undertakes any of these activities, they can document the activity to the SCAQMD, and receive mobile source emissions reduction credits (MSERCs).

These credits can then be sold or transferred in the RECLAIM program. RECLAIM is a mandatory allocation program for stationary sources in the South Coast Air Basin that emit four tons or more of NO_x or oxides of sulfur (SO_x) per year. Based on system-wide emission caps for the year, participating facilities receive an annual allocation of tradable permits, called RECLAIM Trading Credits (RTCs). Each permit allows its holder to emit one pound of emissions in the designated year. RTC allocations are diminished over time in accordance with emission reduction requirements in the air management plan. The permits can be bought, sold, or transferred. Those sources with high emissions reduction costs can buy permits on the permit market, thereby avoiding those higher costs. Sources with low reduction costs sell permits. Stationary sources that purchase MSERCs from vehicle owners get credit for emissions reduction and these credits can be traded like permits.

Mobile source emissions reduction credits (MSERCs) can also be used as new source review offsets, as an alternative method or compliance with SCAQMD Regulation XI rules that have future compliance dates, as a method of compliance with on-road motor vehicle mitigation options, and as an alternative method of compliance with any other SCAQMD regulations that allow the use of credits.

For vehicle repair to qualify for MSERCs, a vehicle must be 1966 model year or newer and must have its emissions detected by a remote sensing device. If the device measures emissions of CO or HC above certain cutpoints, the vehicle owner can opt to have the vehicle tested at a Smog Check station. If the vehicle does not pass Smog Check, the owner can repair the vehicle to bring it into compliance. The testing and repair of these vehicles is voluntary, and therefore the emissions reduction that results is considered to be in "surplus" of the amount normally attained through the Smog Check program. If vehicles had not been voluntarily tested and repaired, they would have

[12]Information on the Mobile Offset Program that appears below was taken from the EPA website: http://www. epa.gov.omswww/market.htm.

remained out of compliance until their next required emissions test. The formulas that calculate MSERCs take into account the number of days until the next required test, and vehicles that fail the required tests are not eligible for MSERCs.

Operation of low- or zero-emission passenger cars, light-duty trucks, and medium- and heavy-duty vehicles also generates MSERCs. In order to obtain the MSERCs, the vehicle operator must submit an application that documents the purchase, retrofit, or repowering (providing a replacement engine that is certified to meet certain emission standards), as well as the operation of cleaner vehicles. Following approval of the application, the vehicle operator must demonstrate vehicle operation by reporting actual vehicle miles traveled (VMT) for the first six months following the vehicle's initial service date, and projected VMT for the following six months. The SCAQMD issues MSERCs on approval of the application and verification of actual and projected VMT.

MSERCs are also generated by scrapping old (pre-1982) vehicles. Such "gross-polluters" account for only 18 percent of all vehicles in the SCAQMD, but generate an estimated 60 percent of VOC emissions and 54 percent of NO_x emissions from vehicles. Vehicle owners voluntarily give up their vehicles to a licensed scrapper, typically in return for an incentive payment. Scrapped vehicles must be operable and driveable, and they must have been continuously registered as an operable vehicle for the two years prior to scrapping. The scrapper can receive MSERCs for each of four pollutants: VOCs, NO_x, CO, and PM, and can sell them in each pollutant's respective permit market. MSERCs are generated according to a formula that assumes that a vehicle had a remaining useful life of three years, and is replaced by a vehicle with the average current in-use emissions rate.

Another voluntary accelerated vehicle retirement program is scheduled to be implemented in the SCAQMD beginning in 2001. Under a plan outlined in the 1994 California State Implementation Plan for Ozone, as many as 75,000 older, high-emitting light-duty vehicles would be purchased each year by the state from their owners, and then destroyed. Private entities would purchase eligible vehicles from willing vehicle owners. To be eligible, a vehicle must be registered within the SCAQMD for two consecutive years prior to the sale, must not be out of compliance with Smog Check rules or due for a Smog Check within the next 90 days, be in good working condition, and be at least 15 years old. Dixon and Garber (1999) explain the rules of the program:

> To participate in the program as an enterprise, an organization must either be an auto dismantler licensed by the State or have a binding agreement with a licensed dismantler to dispose of LDVs purchased under the program. The private entities will obtain their revenues from the program by selling emissions credits to the State. The emissions credits earned for scrapping an LDV will depend on its age and are based on CARB's estimates of emissions levels from LDVs of that age (Dixon and Garber, 1999, p. 4).

Both programs discussed above grant credit, either in the form of tradable emissions credits or cash, because vehicle owners voluntarily retire dirty vehicles earlier than they would have without the program.

B. Incentives for the Purchase of Alternative Fuel Vehicles and Fuels

California has a wide variety of incentives for the purchase of alternative fuel vehicles and fuels. These incentives include rebates on the purchase of a low-emission vehicle, lower excise taxes on alternative fuels, and discounts on electricity used in electric vehicles.

While some gasoline-powered vehicles may be eligible for these incentives because of their low emissions rates, most of these incentives apply to vehicles that are powered by compressed natural gas (CNG), methanol, or electricity. Some methanol vehicles qualify as LEVs, while others are only transitional low-emission vehicles (TLEVs). Generally, CNG vehicles are in the ultra-low emissions vehicle (ULEV) category. Electric vehicles are in the zero-emissions vehicle (ZEV) category. Table 3-4 lists and describes alternative fuel vehicle incentives.

Table 3-4: Alternative Fuel Vehicles Incentives in California

Program Type	Location of Program	Description
ZEV Buy-down (Subsidy)	SCAQMD	$5,000 paid directly to manufacturers who then apply it directly to the sticker price of an electric vehicle. Vehicles must cost less than the level subject to a luxury tax (less than $34,900).
ULEV and LEV Buy-downs	SCAQMD	$3,000 for ULEVs, $1,000 for LEVs
ZEV Buy-down	Bay Area AQMD Sacramento Metropolitan AQMD San Diego APCD Santa Barbara APCD Ventura County APCD	$5,000 subsidy from the California Energy Commission, in partnership with 5 air districts
Natural-gas vehicle incentive	San Diego APCD	$1,000 for purchase of or conversion to a natural gas vehicle
Clean Cities AFV incentive	San Diego	$1,000 for AFV purchase or conversion from the San Diego Regional AFV Coalition

Sources: USDOE (1998) and the EPA, www. epa.gov/omsww/market.htm
SCAQMD = South Coast Air Quality Management District
AQMD = Air Quality Management District
APCD = Air Pollution Control District

The South Coast Air Quality Management District (SCAQMD) offers vehicle buyers in that district a $1,000 subsidy for the purchase of a LEV, a $3,000 subsidy for the purchase of a ULEV, and a $5,000 subsidy for the purchase of a ZEV. Vehicle buyers in five other districts can receive a $5,000 subsidy for the purchase of a ZEV. Residents of San Diego that buy or convert to a natural gas vehicle are eligible for $1,000 subsidies from both the San Diego APCD and the San Diego Regional AFV Coalition.

Excise taxes on ethanol, methanol, and other alcohol fuels are one-half the rate imposed on gasoline (which is 18 cents per gallon). Neat (100%) alcohol fuels are exempt from fuel taxes.

Some utilities offer special discounts for electricity used in electric vehicles (EVs). Table 3-5 lists these discounts.

Table 3-5: Electric Utility Discounts on Electricity used in Electric Vehicles (EVs)

Utility	Discount
Los Angeles Department of Water and Power	Discount of $0.025/kWh, up to a maximum of 500 kWh/month limited to off-peak hours.
San Diego Gas and Electric	Discounts during off-peak periods. See http:/www.sdge.com/ev for rates
Sacramento Municipal Utility District	Discounted rate of $0.04187/kWh for residential customers, a lower rate for commercial customers, off-peak periods
Southern California Edison	Special time-of-use rates for customers who install a meter to recharge EVs during off-peak hours.

Source: USDOE (1998).

Residents of Los Angeles of San Diego can opt for a discount from their local power companies for electricity use during off-peak periods, or for special rates from Southern California Edison if they install a meter to recharge their EV.

C. Carpooling and Other Incentives

All of the major urban centers in California have at least one program that provides incentives for carpooling. The list of these programs is too long to include in this monograph, but we provide a smaller set of examples below.

San Francisco and the Bay Area have a variety of incentives designed to encourage car-pooling. In addition to allowing carpools to use high-occupancy lanes and pay lower tolls when crossing bridges, San Francisco gives preferential on-street parking to certified carpools in designated areas adjacent to surrounding participating workplaces. Qualifying institutions must have 200 or more employees and must be located in a neighborhood that is primarily residential. Eligible carpools must have three or more riders who commute within San Francisco or from suburban areas. Riders can work at the institution for which the carpool permit parking area is designated or at another site as long as it is within a half mile of the parking area.

In San Diego, one project uses congestion pricing to manage commuter traffic flow on an eight-mile stretch of Interstate 15 in northern San Diego County. Since 1988, the road has contained two express lanes that are accessible, free of charge, to high-occupancy vehicles (in this case, vehicles with two or more occupants). These lanes had been underutilized, and so to increase traffic on these lanes, single-occupancy vehicles may now use the lanes for a fee. These lanes would then be high-occupancy toll (HOT) lanes, that is, high-occupancy vehicle (HOV) lanes to which otherwise ineligible vehicles may purchase access.

In 1994, the Southern California Association of Governments (SCAG) obtained a congestion-pricing implementation study grant from the Federal Highway Administration to develop pilot projects that use transportation fees. A task force, called REACH, was formed by the SCAG to determine what kinds of projects to pursue. The task force's main recommendation, given in 1997, was to begin conducting feasibility studies for high-occupancy toll (HOT) lane projects. These projects would consider the use of both congestion fees and emissions fees, and the fees would be closely related to the actual costs of congestion and air pollution.

III. Conclusion

Command-and-control mandates dominate California's vehicle pollution reduction policies. Performance standards require carmakers to produce vehicles that meet emissions standards, and to sell a certain proportion of low-emissions vehicles. Design standards require refineries to sell gasoline that meets content specifications. While the Smog Check program now targets gross polluters, its repair requirements still apply to all cars, regardless of the different costs of abatement faced by different vehicle owners. These command-and-control policies are the most stringent in the United States, and they impose equal emissions-reduction requirements on all affected parties, regardless of differences in abatement costs.

Current market-based incentives in California consist of smaller programs implemented at regional or city levels. While incentives for carpooling and travel in HOV lanes encourage miles-reduction, most programs do not closely relate their incentives to the actual costs of congestion and air pollution. Possible exceptions are the projects proposed by the Southern California Association of Governments, which would consider the use of congestion and emissions fees. While the Smog Check program now targets gross polluters, its repair requirements still apply to all cars, regardless of the different costs of abatement faced by different vehicle owners. New proposals for accelerated vehicle retirement programs encourage the retirement of older cars and thus the purchase of newer ones. Notably absent from California policy is a higher-than-average tax on gasoline. New mandates focus on heavier cars, but no incentives act to encourage consumers to buy smaller vehicles. And no incentives encourage all drivers across the board to drive fewer miles.

The development of new programs, including the SCAQMD's accelerated vehicle retirement program, may signal that California is moving toward use of more market-based incentives. As we explain in the next chapter, such a movement may increase the efficiency of California policy by reducing total abatement costs.

Chapter 4

Theory of Optimal Pollution Control

In chapter 3, we described the existing command and control (CAC) and market-based incentives for the control of vehicle pollution in California. In this chapter, we provide broader analysis of these policies. We use economic theory to evaluate these policies, focusing on two criteria. First, we analyze their efficiency in two respects. For a pollution policy to be "cost-effective," it must be designed to achieve any given level of pollution reduction at minimum total cost. Then, to achieve overall efficiency, it must also reduce pollution to the right level. A policy can achieve both kinds of efficiency if it can properly induce polluters to balance the costs of pollution reduction with the benefits of this reduction. If all polluters properly balance these costs and benefits, pollution will be reduced at minimum cost to its efficient level.

Then later, we evaluate the policies in terms of the information required to implement them. The amount of information required for CAC policies to achieve the lowest-cost abatement is large, but market-based incentives require information on the costs of pollution and may require more expensive emissions monitoring.

I. Command-and-Control and Market-based Incentive Policies

California implements two forms of command and control policies: "performance standards", which impose restrictions on emissions from each source, and "design standards", which restrict the kind of technology used by polluters. Vehicle certification and fleet composition standards, because they act to put a cap on the amount of pollution generated by each automaker's new fleet of vehicles, are performance standards. The inspection and maintenance requirements in the Smog Check program impose performance standards on drivers. Under such performance standards, polluters may choose how to attain the required cleanliness. Automakers, for example, may choose to add more or better pollution-control equipment to their vehicles. Alternatively, they may focus on increasing the fuel-efficiency of their fleet. To pass the Smog Check, drivers may change their vehicle's oil, replace an air filter, or ensure that their pollution control equipment functions properly.

Requirements that all vehicles have certain pollution-control equipment, such as catalytic converters, are design standards. To satisfy reformulated gasoline requirements, refiners must meet specific content specifications. While the requirements allow some flexibility (refiners have some choice over types of oxygen-containing additive), they are quite specific technically. This requirement, therefore, is more similar to a design standard than a performance standard.

Market-based incentives include policies such as taxes, subsidies, or permits. As suggested by Arthur Pigou (1932), the pollution problem could be addressed by a tax per unit of pollution, or by a subsidy to pollution abatement. The best kind of Pigovian tax applies to the pollutant itself, rather than to output, at a rate equal to the pollutant's marginal environmental damages (MED). The term "market-based incentives" includes both the Pigovian type of tax and the subsidy to abatement, and it includes other policies that involve taxes, subsidies, or permits. In this context, a permit system acts much like a tax. Instead of paying a tax per unit of pollution, the polluter pays the price of a permit per unit of pollution. Either way, the polluter has the incentive to cut back on pollution.

California does not *directly* tax vehicle pollution or *directly* subsidize abatement. However, subsidies for alternative-fuel vehicles and smaller excise taxes on alternative fuels are *indirect* abatement subsidies, as are carpooling incentives and voluntary accelerated vehicle retirement programs. Mobile source emissions reduction credits, which can be used as trading credits in the RECLAIM program, are a type of pollution permit.

II. Evaluating Pollution Control Policy Options

A. Efficiency

Much of the environmental economics literature finds that the use of incentives is more "cost-effective" than command and control restrictions.[13] With imperfect information, the regulatory authorities may or may not know what is the cheapest form of abatement technology. Thus CAC regulations, especially design standards, may require technology that is more expensive than necessary. With a tax or a price per unit of emissions, however, each polluter has incentives to find and to undertake any form of abatement that is cheaper than paying the tax or buying a permit. Since only the cheapest forms of abatement are undertaken, these incentive policies can minimize the total cost of achieving any given level of pollution protection. In this section, we analyze and compare the *efficiency* impacts of a tax on emissions, a subsidy to abatement, and a command and control (CAC) limit on emissions.

To do this, we use a simple framework and focus on one market. We discuss the outcome in this market when polluters do not acknowledge the costs they impose on society by polluting, and we discuss the "social optimum", the outcome that results when polluters are made to account for the costs of the pollution they create. In this simple framework, several different kinds of policies, if designed correctly, can shift the economy to the same social optimum allocation of resources.

Just as we can use supply and demand curves to determine the most efficient price and quantity of any good that is sold in a market, we can use similar curves to determine the most efficient quantity of pollution and the size of the most efficient tax on pollution. Figure 4-1 graphs these curves. The horizontal axis represents the amount of pollution (Z), and the vertical axis represents a price or cost (in dollars per unit of emissions). The private cost of pollution, called the "price" of pollution, P^o, represents

[13] See reviews of this literature in Bohm and Russell (1985), Cropper and Oates (1992), and Stavins (1998).

the minimal amount that the driver would pay (in terms of gasoline, maintenance, and other variable costs) per unit of pollution—without any government pollution policy. We assume that this price is constant. Thus drivers face a flat private marginal cost (labeled PMC). The demand for pollution (labeled "marginal benefits") starts out high, because some minimal level of pollution is necessary for driving, and it slopes down because additional units of pollution are successively less crucial. In the absence of any regulations or taxes, drivers would keep polluting as long as the marginal benefits exceed the private cost, and they would stop where the marginal benefit of pollution intersects the private marginal cost. Thus, unregulated pollution is at point Z^o.

Yet the social cost of pollution is higher than the private cost, because it imposes negative external costs on others. As we discussed in chapter 2, Small and Kazimi (1995) estimate the health costs of vehicle pollution to be about 4 cents per vehicle-mile. These costs represent the "marginal environmental damages" (MED) of vehicle pollution. The social marginal cost (SMC) of pollution includes the private marginal cost plus MED. The social marginal cost curve in Figure 4-1 starts slightly above the private cost to indicate that the very first unit of pollution has only small external cost, but the upward slope indicates that successive units of pollution become more costly. It might become very steep, for example, if the air is already dirty enough that one additional unit is enough to send many people to the hospital.

Vehicle pollution has social benefits by allowing us to drive and it also has social costs. The net gain to society is maximized by polluting only as long as the social benefits exceed the social costs. The intersection of these two curves indicates the optimal amount of pollution, Z', and the problem for policy is to cut pollution from Z^o to Z'.

1. Emissions tax

The solution of Arthur Pigou (1932) is to impose a tax per unit of pollution, at a rate t_z, equal to the marginal external damages per unit of pollution at the optimum. This Pigovian tax raises the private cost of pollution from P^o to $P' = P^o + t_z$. Then drivers face costs P' and stop at Z'. [14] The tax revenue would be the tax rate times the amount of pollution subject to tax, that is, the rectangle area 2+3 in the figure. Welfare improves by the triangle area 5+6. This area measures the extent to which social marginal cost exceeds the (social) marginal benefits, for each of those units of pollution beyond Z', up to Z^o.

[14] Alternatively, if the tax rate could rise with pollution, then the driver could be made to face the entire SMC curve in Figure 1. Such a driver would compare marginal benefits to SMC and choose Z'. For elaboration on this point, see Kaplow and Shavell (1997).

2. Abatement subsidy

The other Pigovian solution is for the government to pay drivers to cut back on pollution. They could earn this subsidy by driving less, buying cleaner gas, or switching to a cleaner vehicle. Suppose the policy states that each driver will be paid t_z (the same amount as before, $P' - P^o$) for every unit of pollution *reduced* from the initial point $Z°$. Then for each unit of pollution, the driver bears a "cost" equal to the subsidy it must give up by not reducing that unit of pollution. The full cost of pollution is P', the private marginal cost (P^o) *plus* the subsidy foregone. The driver pollutes as long as the marginal benefits exceed this cost P', that is, to Z'. In other words, the subsidy for abatement induces the driver to abate. Because the abatement is the same as before, the net efficiency gain is the same as before—area 5+6.

3. Command-and-Control Regulations

As discussed in chapter 3, California's environmental policies do not use taxes to discourage pollution. Instead, the policies tend to employ command-and-control regulations that apply mainly to automakers. In the model of Figure 4-1, a CAC "performance standard" might be represented by the mandate that "pollution shall not exceed Z'." If designed properly, and if revenue is not an issue, such a regulation can move the economy to the same reduced optimal amount of pollution (Z') and provide the same triangle welfare gain (area 5+6).

4. Abatement Costs

So, in Figure 4-1, all of the policies provide the same gain. More generally, however, economic efficiency also requires minimizing the cost of achieving any given level of abatement. On this basis, these policies are likely to differ. To avoid paying a price per unit of pollution, a driver can choose the cheapest methods for controlling emissions: each driver can decide how large or new an automobile to buy, how well to maintain the vehicle, and whether to drive more or less aggressively. In contrast, a CAC policy is only able to match this efficiency if the regulator knows exactly which combination of abatement technologies minimizes costs. The regulator would have to tell each different driver what vintage and size vehicle to buy, how well to maintain the vehicle, and how often to accelerate rapidly. The amount of information required to ensure the lowest total-cost abatement is enormous.

In general, each driver (or auto manufacturer) is likely to have much better information than the regulator about the cost and effectiveness of alternative abatement technologies. A market-based incentive instrument is likely to impose lower economic costs than a CAC instrument because it induces the driver to *find* the lowest cost combination of abatement methods. In particular, CAC regulations typically require all drivers or auto manufacturers to reduce pollution to the same level. Yet some drivers can carpool more easily than others; some can find alternative fuels more easily than others; and some are more willing to accept poor acceleration than others. Thus, for various reasons, some drivers have lower costs of pollution abatement than others. The CAC regulations cannot easily account for these differences. With a tax system, however, some drivers or auto makers with low abatement costs may undertake most of the total abatement, while other drivers or auto makers with high abatement costs may not abate much at all. Still other drivers may stop driving all together. Previous researchers have investigated the difference between these policies empirically (in general, not just for vehicle emissions), and they have found that typical CAC policies are *six to ten times* as expensive as the minimum abatement cost made possible by market-based policies like taxes or permits.[15]

B. Information Requirements

As mentioned above, the amount of information required for CAC policies to achieve the lowest total-cost abatement is large. But emissions taxes or abatement subsidies have their own information requirements. The ideal incentive-based tax rate would reflect the marginal external cost of pollution, but as explained in chapter 3, this cost is difficult to measure. Actual U.S. environmental tax rates are not set on this basis at all. Each tax is set instead at a rate that will yield a pre-specified revenue. For example, gasoline taxes pay for the costs of highway construction—costs that bear no relation to the external cost of driving.

In addition, effective environmental policy needs to reflect monitoring capabilities. A Pigovian tax may require counting grams of emissions, whereas a design standard simply requires authorities to confirm the use of a particular kind of pollution control equipment. Smog Check inspectors can easily check that a vehicle's pollution-control equipment is in working order, but the technology is not yet available to measure each car's emissions during regular driving in a reliable and cost-effective manner. On-board diagnostic equipment is too costly because millions of vehicles would need to be retrofitted (Harrington, et al., 1994). Remote sensing is inexpensive, but it cannot "distinguish unambiguously the car that is dirty on the average from the car that is clean on the average" (Sierra Research, 1994, p. 17). Thus the information requirements of some kinds of CAC regulations may be less prohibitive than those of *traditional* market-based incentives. For these reasons, we explore alternative nontraditional market-based incentives for the control of vehicle pollution.

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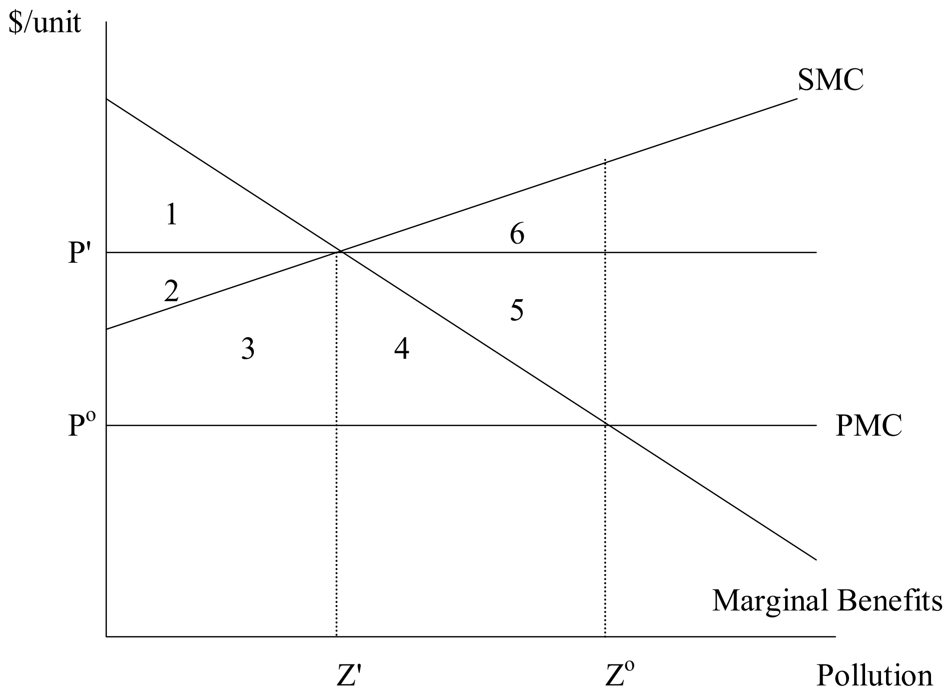
[15] See, for examples, Atkinson and Lewis (1974), Seskin, Anderson, and Reid (1983), and other studies surveyed in Cropper and Oates (1992).

Figure 4-1

Equivalence of Efficiency Effects from Alternative Policies



Chapter 5

Alternative Market-Based Incentives

We concluded chapter 4 by saying that traditional market-based incentives such as a Pigovian tax are generally more efficient than command and control policies but require the measurement of emissions. In the case of vehicle emissions, such traditional incentives are therefore still unavailable to policy makers. So, we explore alternative market-based incentives that can be used to mimic the effects of an ideal, but unavailable, tax on vehicle emissions. The goal of the emissions tax is to raise the price of pollution and to affect behavior in a variety of ways. To be as efficient, alternative instruments must also induce consumers' responses that are identical to those responses induced by the emissions tax. But to avoid the problems involved in measuring vehicle emissions, these instruments can apply to activities that are market transactions.

If a true Pigovian tax on vehicle emissions were available, it would reduce pollution by inducing households to drive fewer miles, to buy fuel-efficient cars, to install and maintain pollution control equipment, to purchase cleaner fuel, to perform general maintenance, to avoid cold start-ups, and perhaps to drive less aggressively.[16] Households would choose between paying more in emissions taxes or taking steps to reduce pollution. We presume that these households would take these pollution-reducing steps if the costs of doing so were lower than what they would pay in emissions tax. Households with lower abatement costs would reduce pollution by more than households with higher abatement costs. For example, drivers that live close to gas stations with cleaner fuel might buy this fuel and abate more than those who live far from these stations. And, households with vehicles that are very dirty simply because pollution control equipment is not connected would make this inexpensive repair, while households that could only reduce emissions by making more costly repairs might elect instead to pay taxes on the extra emissions.

Any efficient alternative policy would need to induce this same set of behaviors. We focus on policies that apply to those behaviors that are associated with measurable market transactions. To determine the specific form of these alternative policies, in Fullerton and West (2002), we derive a mathematical model of each different household's choice of miles, vehicle attributes, pollution control equipment *(PCE)*, fuel cleanliness, and other goods and services. In Fullerton and West (2000), we use the model to solve explicitly for the optimal tax on emissions, and to examine precisely how consumers would respond to such a tax. And, we use the model to solve for and investigate combinations of policies that would, like an emissions tax, influence people

[16] Because of cold start-up emissions, Burmich (1989) finds that a 5-mile trip has almost three times the emissions per mile as a 20-mile trip at the same speed. Sierra Research (1994) finds that a car driven aggressively has a carbon monoxide emissions rate that is almost 20 times higher than when driven normally.

to drive fewer miles and to buy smaller cars, newer cars, better pollution-control equipment, and cleaner fuel.

In this chapter, we present a non-technical description of our model and results from that more-rigorous derivation. We provide a theoretical framework for household choice, compare these choices with the socially optimal choices, and provide intuition for why and how our alternative market-based incentives can mimic an ideal emissions tax.

Other researchers explore market incentives that could be used in place of the emissions tax.[17] Because vehicle emissions cannot be monitored at the source, Eskeland and Jimenez (1992) analyze indirect instruments relating to cars and fuels. Eskeland (1994) expands this analysis and builds a simple model with identical consumers. These papers explore optimal combinations of mandates and taxes that can mimic the unavailable emissions fee, with identical consumers. Eskeland and Devarajan (1996) proceed to discuss the problem when consumers are not identical, and they show how combinations of policies can be used to approach the effect of a Pigovian tax.

Harrington, et al. (1998) consider the cost-effectiveness of a mandated vehicle inspection and maintenance (I/M) program compared to an incentive program. The incentive is a fee that is based on the vehicle's emission *rate*, assuming miles are not observable. Thus, motorists can reduce their fee by repairing their vehicle, but not by driving less. Sevigny (1998) incorporates the choice of miles with an emissions tax, but this tax requires knowledge of each vehicle's average emissions per mile and the accurate measurement of miles traveled.[18] Innes (1996) also analyzes combinations of feasible policy instruments when consumers differ. Our model clarifies Innes' results, and expands the model to allow consumers to differ in three ways rather than two.

Using our model, we examine five kinds of policies. First, we solve for the ideal Pigovian tax on emissions. Second, we find that the emissions tax can be replicated by a complicated tax on gasoline. However, this ideal outcome requires that the gasoline tax depend on vehicle characteristics. Third, if vehicle characteristics cannot be measured at the pump, the efficient outcome could instead be attained by a vehicle tax that depends on miles driven. Fourth, if policymakers cannot assess individual-specific

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[17] Plaut (1998) compares instruments one at a time. Kohn (1996) shows that any combination of a tax on emissions and subsidy to abatement are equivalent. For any such combination to be administered, however, emissions must be measurable. Train, et al. (1997) analyze "feebates," in which rebates are provided to vehicles with higher-than-average fuel efficiency and fees are levied on less efficient vehicles. These feebates are feasible incentives because fuel efficiency can be measured, but they are not perfectly efficient because they do not depend on miles driven.

[18] All of these schemes are imperfect. Emissions per mile *(EPM)* cannot be measured perfectly, because it depends on how the car is driven. Miles cannot be measured perfectly, because drivers can roll back the odometer. Harrington et al (1994) discuss remote sensing at a selection of locations as a good approximation, but some drivers may disproportionately miss or intentionally avoid those locations. Our schemes are not perfect either, as they miss some behaviors mentioned above (cold start-ups, aggressive driving).

rates, they could implement uniform rates on gasoline and on vehicle characteristics calculated using the population averages of miles and vehicle characteristics. Such rates would not fully account for the technological relationships between vehicle characteristics and emissions per mile and fuel efficiency, nor would they fully account for the possible correlation in consumers' tastes for miles and vehicle characteristics. These rates, therefore, may reduce emissions by too little or by too much. Fifth, policymakers could explore these technological relationships and correlation among tastes, and impose uniform taxes that more fully account for these relationships. This method, while still imperfect, would enable policymakers to more closely approximate the effects of an ideal emissions tax.

Section I presents the household choice framework. Section II contrasts household choices with socially optimal choices. Section III discusses the five alternative market-based incentives and Section IV concludes.

I. The Household Choice Framework

In this section, we use a theoretical framework to provide the intuition behind our mathematical model of household choice. In the spirit of Baumol and Oates (1988), we assume perfect information, perfect competition, and no market failures other than a negative externality from emissions.[19] Each household owns one vehicle, and each vehicle is made up of characteristics that affect emissions such as engine size, vehicle vintage, fuel efficiency, and *PCE*, and characteristics that do not affect emissions (such as leather seats or a sunroof). Households buy gasoline in order to drive miles, and they choose among grades of fuel-cleanliness. They also buy other goods. Figure 5.1 provides a schematic diagram of household choice.

We measure engine size as cubic inches of displacement (CID). We use "newness", the counterpart of vehicle age, to describe the household's choice of vintage. Pollution-control equipment *(PCE)* includes catalytic converters and other emissions-reducing equipment directly installed on a vehicle. In general, consumers also choose the condition as well as the amount of *PCE*. Fuel cleanliness is an attribute of gasoline such as volatility or oxygenation.[20] We assume that cleaner fuel is more expensive. Households enjoy driving and consuming other goods, and they are negatively affected by total auto emissions.

[19] We ignore existing mandates in the theoretical framework below, but we recognize that these mandates affect the estimated ways in which actual emissions per mile depend on engine size and other car characteristics. Thus, incentive policies may work because they encourage purchase of regulated cars.

[20] More volatile gasoline leads to more evaporative emissions. The addition of oxygenates to gasoline alters the stoichiometric air/fuel ratio. Provided the carburetor setting is unchanged, this alteration may reduce emissions of carbon monoxide (CO) and hydrocarbons (HC), but can also increase emissions of oxides of nitrogen (NO_x). And, if the mixture becomes too lean (high air/fuel), HC emissions can increase due to misfiring (OECD, 1995).

Cars with larger engines have greater emissions per mile *(EPM)*, and cars that are newer have more or better pollution control equipment and have lower *EPM*. Obviously, households that buy cleaner fuel will also generate lower *EPM*. Each household's emissions can be calculated by multiplying their *EPM* by the number of miles they drive. Then total emissions is calculated by adding together all of the households' emissions. Each car's fuel efficiency is measured in miles per gallon *(MPG)* and depends on vehicle newness, engine size, and the quantity of the clean-car good *(PCE)* on the vehicle.[21] Cars with larger engines get lower gas mileage, while newer cars get higher gas mileage. The addition of a clean-car characteristic such as a catalytic converter adds weight to a vehicle, and diminishes fuel efficiency.[22]

Consumers do not purchase miles directly, but through the combination they choose of gasoline, vehicle newness, engine size, and the clean-car characteristic *(c)*. To determine each household's demand for gasoline, we divide their desired miles by *MPG*. Since fuel efficiency depends on vehicle characteristics, so does demand for gasoline and miles.

While we allow tastes for miles and vehicle characteristics to differ among households, in order to analyze different choices and abatement costs, we are not concerned with differential benefits from environmental protection. We therefore assume that households experience the same detrimental effects of aggregate pollution.

II. Household Choices versus Socially-Optimal Choices

To decide how much of each good to purchase, each household weighs the benefits they receive from consuming an additional unit of each good with the costs of that consumption. Our mathematical formulas assume that consumers "maximize utility," which just means that each keeps buying more of a good until the marginal *private* benefits fall to the level of private marginal cost—the price for one more unit. They take into account any tax or subsidy on each good, but households do not recognize that their own choices affect total emissions. For example, when deciding whether to drive another mile, a household only takes into consideration the private costs of doing so: the cost of gasoline, wear on tires, and other per-mile costs. Its decision does not depend on environmental costs of driving the extra mile.

So, as we graphed the costs and benefits of pollution in Figure 4-1, we can graph the costs and benefits of buying a market commodity. We use one diagram for consumption of a "dirty" good (one that increases pollution, such as gasoline or engine

[21] Fuel efficiency may also be affected by the clean-fuel characteristic. Oxygenated fuel contains methyl tertiary butyl ether (MTBE) or ethanol, each of which have lower energy content per gallon than conventional gasoline. For simplicity, we do not incorporate the clean-fuel characteristic into the calculation of *MPG* .

[22] According to Duleep (1992), the addition of one cylinder decreases fuel efficiency by 3 percent. Also, the equipment mandated in U.S. tier 1 emissions regulations lowers fuel efficiency by 1 percent.

size), and a different diagram for consumption of a "clean good" (one that reduces pollution such as cleaner fuel, *PCE*, or other clean car characteristics).

Figure 5-2 shows a household's choice of a dirty good such as gasoline or engine size. The horizontal axis represents the amount of either gasoline or engine size consumed (X), and the vertical axis represents a price or cost (in dollars per unit of that good). The private cost of the good, P^o, represents the price per gallon of gasoline or the price per cubic inch of displacement. We assume that these prices are constant, and so households again face a flat private marginal cost (PMC). The demand for gasoline or engine size ("marginal benefits") starts out high, as some minimal amount of each is necessary for driving. Each additional unit of the good is less important than the previous good, and so the marginal benefits curve slopes downward. In the absence of any taxes on gasoline (or engine size), the household would face price P^o consume X^o units of gasoline (engine size). Each different household would be represented by a different version of the graph in Figure 5-2, however, since some households drive more miles, or purchase more gasoline, or have larger vehicles than others.

To determine the "optimal" choices, we introduce the concept of an informed and benevolent policymaker. This decisionmaker *does* recognize that individual amounts of gasoline and engine size affect aggregate emissions. We assume that this policymaker chooses the amount of each dirty good for each household to maximize utility, but we assume that this takes into account the additional environmental damage caused by an increase of one gallon of gasoline or one cubic inch of displacement. That is, the decisionmaker perceives the social marginal cost of the good, which includes the private marginal cost plus the value of the environmental damage per unit of the good. In Figure 5-2, social marginal cost is labeled SMC. The net gain to society of gasoline and engine size is maximized by consuming these goods as long as the social benefits exceed the social costs. The intersection of marginal benefits and social marginal costs indicates the optimal amount of the dirty good, X'.

The next problem for policymakers, then, is how to cut consumption of the dirty goods from X^o to X'. Since each household has different marginal benefits, even for the same marginal costs, the optimal reduction of each dirty good would be different for each household. For those households that particularly enjoy driving, the marginal benefits of gasoline or larger cars would be higher, and so their socially-optimal abatement would be lower than that of other households.

Figure 5-3 shows the household's choice of a clean good, that is, a good that reduces pollution when consumed. In our model, these goods are newness, a clean fuel characteristic, and *PCE*. Consumption of each of these goods results in environmental benefits. When households decide whether to buy a newer car rather than an older one, they weigh their own private costs of buying one versus the other, but they do not consider the benefits of pollution reduction that would result from buying the newer vehicle. The social marginal benefits (SMB) of such a good in Figure 5-3 includes both the private marginal benefit (PMB) plus the environmental benefits per unit of the good. In the absence of any subsidy on newness (or clean fuel characteristic or *PCE*) the household consumes Y^o. The net gain to society of this clean good is maximized by consuming it as long as the social benefits exceed the social costs. The intersection of social marginal benefit and marginal cost indicates the optimal amount of the clean good, Y'. The problem for policymakers in this case is to *increase* consumption of the clean goods from Y^o to Y'. A subsidy can decrease the private marginal cost of the good to P'. Then, when the household follows PMB down to P', it chooses the optimal quantity. Since each household has different marginal benefit and different marginal cost, each will have a different optimal increase in consumption of each clean good.

Households also weigh the costs and benefits of consuming other goods. For each good that neither increases nor decreases pollution, the private marginal cost is the social marginal cost and the private marginal benefit is the social marginal benefit. Policymakers need not act directly to change consumption of these other goods. However, when households respond to policies that induce them to consume more or less of emissions-related goods, they may substitute toward or away from consumption of other goods.

III. Solutions

The goal of this research is to find a combination of taxes on dirty goods and subsidies to clean goods so as to replicate the effects of the ideal-but-unavailable tax on emissions. The problem is that vehicle emissions cannot be measured accurately, in order to apply that tax. We seek to induce the same behaviors, however, with the right tax rates on gasoline and engine size, plus subsidies to newness and pollution control equipment. We use our mathematical model to determine the forms of these tax rates.

Using our model, we examine five kinds of policies. Implementation of each policy requires different information. Table 5-1 summarizes these policies.

First, we use our model to solve for the ideal Pigovian tax on emissions (Policy 1). To assess this tax, policymakers would need to be able to measure tailpipe emissions. Second, if emissions cannot be measured, we find that the emissions tax can be replicated by a complicated tax on gasoline (Policy 2). However, this ideal outcome requires that the gasoline tax depend on vehicle attributes. Third, if vehicle characteristics cannot be measured at the pump, a vehicle tax that depends on miles driven can also attain the ideal outcome (Policy 3). Fourth, if policymakers cannot assess individual-specific rates, they could implement uniform rates calculated using the population averages of miles and vehicle characteristics (Policy 4). Such rates would not fully account for the technological relationships between vehicle characteristics and emissions per mile and fuel efficiency, nor would they fully account for the possible correlation in consumers' tastes for miles and vehicle characteristics. Fifth, policymakers could explore these technological relationships and correlation among tastes, and impose uniform taxes that more fully account for these relationships (Policy 5). This method, while still imperfect, would enable policymakers to more closely approximate the effects of an ideal emissions tax.

Table 5-1: Five Alternative Policies for the Control of Vehicle Emissions

Policy Set	**Effect**	**Efficiency**	**Information Requirements**
Policy 1: Pigovian Emissions Tax	Reduce gasoline, miles, and engine size; Increase newness, *PCE*, *MPG* and fuel cleanliness	Most efficient	Constant measurement of emissions during driving
Policy 2: Complicated Gas Tax		Most efficient: Identical to emissions tax	
Gas tax differing by vehicle at the pump	Reduce gasoline, miles, and engine size; Increase newness, *PCE*, *MPG* and fuel cleanliness.		Identification of vehicle type at gas pump
Policy 3: Miles-specific Vehicle Tax			
Vehicle tax that depends on miles and on vehicle characteristics	Reduce gasoline, miles, and engine size; Increase newness, *PCE*, *MPG* and fuel cleanliness.	Most efficient: Identical to emissions tax	Measurement of miles driven: Odometer readings or accurate estimate of lifetime miles
Policy 4: Uniform Rates Based on Averages (ignore PCE and clean-fuel characteristics):		Least efficient: Do not fully account for technological relationships and taste correlations	
Gas tax using average vintage and engine size	Reduce gasoline and miles; Increase *MPG*		Average vintage and average engine size
Newness subsidy using average miles	Increase newness and *MPG*		Average miles
Engine size tax using average miles	Decrease engine size, increase *MPG*		Average miles
Policy 5: Alternative Uniform Rates (ignore PCE and clean-fuel characteristics):		Less efficient: More fully accounts for technological relationships and correlation among tastes	
Gas tax	Reduce gasoline and miles; Increase *MPG*		Information about the distribution of vintage, engine size, and miles over the population
Newness subsidy	Increase newness and *MPG*		
Engine size tax	Decrease engine size, increase *MPG*		

Because consumers differ, the decisionmaker cannot seek the best outcome by considering the choices made by one household. No one household is perfectly representative of the rest. Instead, the decisionmaker must maximize a weighted sum of household utilities, and therefore must give each household a certain weight in this sum. To simplify this problem, we specify household weights that meet two criteria. First, in order to focus on efficiency rather than on distributional considerations, initially, we choose weights so that a dollar given to any household has the same effect on social welfare. Second, in the counterfactual case where an emissions tax *is* available, we want the maximization of our social welfare sum to yield the Pigovian emissions tax. These two considerations determine the weights, but we then use that same set of weights when the ideal emissions tax is *not* available. In this way, we ensure that the effects of our policies are directly comparable with the effects of an ideal emissions tax.

A. First-best Policies

1. Policy 1: A Pigovian Tax

A tax on emissions provides the basic efficient policy against which alternatives can be compared. Given the weights we have chosen, our model with heterogeneous consumers generates a result that matches the result of a simple representative-household model. In particular, a uniform Pigovian tax that is equal to the marginal environmental damages per unit of emissions at the same rate for all households, will induce all households to make all the optimal choices about miles, car size and vintage, fuel, and pollution control equipment. In response to the one tax rate on emissions, each household chooses the extent to which it will reduce consumption of gasoline or engine size (from X^o to X' in Figure 5-2). In addition, each would choose the optimal extent to which it will increase consumption of vehicle newness, the clean fuel characteristic, and *PCE* (from Y^o to Y' in Figure 5-3).

2. Policy 2: A Complicated Gas Tax

In the case where the measurement of emissions were difficult or impossible, so that an emissions tax could not be implemented, we then find a different policy that attains the exact same efficient outcome. This policy is a tax schedule for gasoline that depends on characteristics of the gasoline *and* on characteristics of the car at the pump. This tax is equal to the damage per unit emission *(MED)* times emissions per mile *(EPM)* times miles per gallon *(MPG)*. Emissions per mile and miles per gallon both depend on vehicle characteristics, and so therefore does this gas tax.

Since the gas tax depends on vehicle characteristics, are separate taxes on newness, engine size, and *PCE* necessary? Under some assumptions, these additional policies may not be necessary (Innes, 1996). Assuming individuals know that their individualized gas tax rate will depend on their own choices of newness, engine size, and *PCE,* then that gas tax alone can induce the optimal size, vintage, and pollution-control equipment. To influence drivers to reduce gasoline or engine size consumption from X^o to X', the gas tax effectively raises the private cost of these goods from P^o to P'. And, when consumers see that their gas tax rate depends on the type of car they drive, they increase their purchase of newness, the clean fuel characteristic, and *PCE*: the gas tax effectively lowers the private cost of these goods from P^o to P'.

3. Policy 3: A Miles-Specific Vehicle Tax

The gas tax in Policy 2 is very complicated. It seems reasonable for a gas tax to depend on the characteristics of the fuel. But in order for the efficient outcome to be attained using just the complicated gas tax, it must depend on vehicle characteristics. Individual-specific gas taxes would be costly to administer:

> For example, a tamper-resistant computer code would likely be required on each automobile; similarly, gasoline pumps would have to be equipped to automatically tack the appropriate tax onto any gasoline that is dispensed to a particular automobile. Moreover, since a simple siphoning of gas will permit consumers to bypass taxes on high-emission vehicles, the scope for abuse, particularly among those high-emitting consumers who are arguably the most important targets of the tax, would be tremendous. (Innes, 1996: p. 226).

As it turns out, a different combination works just as well as the complicated gas tax. To induce drivers to buy newer, smaller cars with more *PCE*, policymakers can use a tax on vehicles that depends on miles driven. To implement this tax, policymakers would calculate each vehicle's emissions per mile by using the *EPM* function, which relates emissions per mile to engine size, vehicle vintage, fuel cleanliness, and pollution control equipment *(PCE)*. Then, to determine the household's total emissions, policymakers could multiply the vehicle's *EPM* by the number of miles driven in the car. The vehicle tax rate would be higher for vehicles with larger engines, and lower for cars that are newer or that have more *PCE.* When consumers see that their vehicle tax rate depends on the number of miles they drive, they decrease their purchases of gasoline. Because the vehicle tax effectively raises the private cost of engine size from P^o to P', it would induce drivers to reduce consumption of this good from X^o to X'. And because the vehicle tax would effectively lower the private cost of newness and *PCE* from P^o to P', drivers would increase consumption of these goods from Y^o to Y'.

Implementing the miles-specific vehicle taxes would also be difficult or costly. If the vehicle tax were assessed when the vehicle is purchased, then some measure of the total expected miles for the life of the vehicle would be necessary. Since conditions change, however, the one-time vehicle tax would not provide the right subsequent incentives (e.g. choice of mileage, choice of *PCE* maintenance or purchase, and choice of retirement date). If the vehicle tax were assessed annually, then annual odometer readings could be helpful. However, this would provide incentive for individuals to roll back their odometers to reduce their vehicle tax.[23]

4. Additional Implications for Policy 2 and Policy 3

Both the complicated gas tax (Policy 2) and the miles-specific vehicle tax (Policy 3) induce households to make optimal choices, given that they consume positive amounts of each good. A more complete analysis is required to deal with situations in which households do not wish to consume any of the clean fuel characteristic or any *PCE*. If households dislike pollution control equipment enough, then the subsidy to *PCE* within the complicated gas tax or within the vehicle tax may not induce them to buy any of it. In this case, the subsidy to *PCE* can only induce consumers to buy any pollution equipment if it is equal to the *entire private cost of PCE*, including both the direct cost of equipment and the extra gasoline costs incurred due to the negative effect that *PCE* has on fuel efficiency. With a 100 percent subsidy, however, the choice of *PCE* is indeterminate. That is, with the subsidy, consumers may buy less, more, or exactly the socially optimal amount of *PCE*. Thus, if people do not care for *PCE*, but also are not hurt by *PCE*, then incentives do not work. The optimal *PCE* can only be achieved by a mandate (as in Innes, 1996).

The same analysis applies to the clean-fuel characteristic. For households to choose cleaner gas, the subsidy must equal the entire cost of the attribute.

We think that people are unlikely to feel exactly neutral about clean cars and clean fuel. People may like using the latest technologies, or feel peer pressure to do so. On the other hand, *PCE* may negatively affect performance by increasing vehicle weight and decreasing acceleration. In addition, if cleaner fuel can be found only in a limited number of locations, the inconvenience costs of refueling could be high. A high enough subsidy could then induce households to purchase the optimal amount of clean fuel and clean car characteristics.

The optimality of these results also depends on our assumptions about the available abatement technologies. Since emissions depend on newness, engine size, clean fuel, and *PCE*, both the complicated gas tax and the miles-specific vehicle tax attain the same efficient equilibrium as that reached by the Pigovian tax. Despite the fact that emissions are never measured, both policies can attain 100 percent of the improvement in social welfare achieved by the Pigovian tax. If technologies that we do not consider here also increase or reduce emissions, then those technologies would need to be taxed or subsidized in order to achieve the greatest possible welfare gains.

[23] "Even if only a small proportion of consumers cheat in this way, those who cheat are likely to be those who drive the most, who therefore have the greatest incentive to cheat and who are arguably the most important targets of mileage taxation" (Innes, 1996: p. 226-227).

B. Second-best Policies: Uniform Tax Rates

If the gas tax cannot be made to depend on vehicle type, or a vehicle tax cannot be made to depend on miles-driven, then separate taxes on size and gasoline and a separate subsidy to newness become important.

In the next sections we therefore go on to consider taxes or subsidies that do not vary with vehicle characteristics at the pump or with mileage. Because of this extra complication, we now drop consideration of the clean-car and clean-fuel characteristics. Since we know that these goods would require subsidies equal to their total cost, further discussion would provide no additional insight. And, doing so enables us to focus on the problems of setting only three tax or subsidy rates. Thus fuel efficiency and emissions per mile depend only on newness and engine size. We consider two ways to set uniform rates. First, we examine the use of average values of vehicle characteristics to set the gas tax, and average miles to set the tax rates for size and newness. Rates set using this method do not fully incorporate information about the technological relationships between vehicle characteristics and *EPM* and *MPG*, nor about the correlation among tastes for miles, size, and newness. Some households facing these rates, therefore, would reduce emissions by too much, and others would reduce emissions by too little. Then, we discuss a method that would more fully account for these technological relationships and correlation among tastes. This method, while still imperfect, would enable policymakers to approximate more closely the effects of an ideal emissions tax.

1. Policy 4: Setting Uniform Tax Rates Using Averages

To set the uniform gas tax rate, policymakers could use the averages of engine size and newness. For example, in 1994, the average U.S. vehicle was six years old and had six-cylinder engine. Such a vehicle would have, on average, an engine with about 170 cubic inches of displacement. If the policymaker knows the mathematical relationship between these vehicle characteristics and emissions per miles and fuel efficiency, she could estimate the average vehicle's *EPM* and *MPG*. Then, she could plug these values into the equation for the vehicle-specific gas tax rate (in Fullerton and West (2002)), and impose this rate on all vehicles.

This is a fairly straightforward process, and so the information requirements for this averages-based rate is low. If the relationship between vehicle characteristics and *EPM* and *MPG* is a simple one, and in particular if the relationship is linear, then these rates would be the same as the average of all of the individual-specific rates. Then knowing all of the vehicle's individual *EPM*s and *MPG*s would not give the policymaker any additional helpful information. The tax rate set using averages would be the same as the best uniform rate that could be set using information about each vehicle. If, however, the technological relationships are more complicated, then the use of averages would ignore important information. Rates set using averages would be different from the best uniform rates set using information about each vehicle. For example, if emissions per mile increase very rapidly with engine size, a vehicle with an engine double the size of another would emit more than double the amount of pollution per mile. Or, if fuel efficiency decreases very quickly with vehicle age, a car that is double the age of another would use more than double the amount of gasoline. A gas tax rate calculated using average values of size and newness simply does not incorporate these kinds of relationships. In the next chapter, we provide evidence that these relationships are important.

For now, we just consider the case where tax or subsidy rates for newness and engine size, are set by the policymaker using the characteristics of the average vehicle. For miles, she could use the average number of miles driven. Doing so would not only ignore the potentially-complicated technological relationships discussed above; it would also ignore the fact that households' tastes for driving-related goods may be correlated. For example, households who live far from their place of work have a high demand for miles, and so they may prefer either a small car (for better gas mileage) or a large car (for comfort and safety). Households that prefer older cars may do so because these vehicles are larger. And, households that own newer, more-reliable vehicles may drive more miles than households with older vehicles that are more likely to break down.

These kinds of correlation among tastes imply that the tax on size, for example, would affect not only the choice of engine but also the characteristic with which taste for engine size is correlated. If households that drive more miles prefer smaller cars, then a tax on size that induces households to purchase even smaller cars would also induce them to drive more miles, because their cost per mile is lower in the more fuel-efficient car. If households that drive more miles prefer larger cars, then a size tax would induce them to drive fewer miles, because their commutes are no longer so comfortable.

The same is true for a newness subsidy. In the presence of correlation among tastes, such a subsidy affects not only the choice of vintage, but also the choice of the characteristic with which taste for newness is correlated. For example, if households that like older cars also like larger cars, then a newness subsidy, because it influences them to buy newer cars, would influence them to buy smaller cars.

If such correlation is not accounted for, tax and subsidy rates could be set too high or too low, and induce some households to reduce pollution by too much or by too little. In the next chapter, we present evidence that tastes for miles and vehicle characteristics are correlated.

2. Policy 5: An Alternative for Setting Uniform Rates

In order to approximate more closely the effects of an ideal emissions tax, we suggest an alternative method that more fully accounts for the technological relationships and correlation among tastes discussed above. This case is still limited to a gas tax than cannot depend on the car, and car taxes that cannot depend on miles driven, so the outcome will not perfectly match the efficient outcome of the Pigovian tax, but we seek the best possible tax rates subject to these constraints. To find the best such rates, we must find the single size and gas tax rates, and newness subsidy rate that maximize social welfare, taking as given households' demand behavior for miles, size, newness, and other goods and services. In essence, we would like to find the rates that move each household nearest to its optimal consumption of these goods. Because we are not using individual-specific taxes, only by coincidence would any one household move from its old X^o and Y^o to its optimal X' and Y'.

For this problem, the decisionmaker considers the general technological relationship between vehicle characteristics and *EPM* and *MPG*. The planner also incorporates information about the distribution across the population of vehicles and miles driven, and determines the correlation among newness, engine size, and miles.[24] The tax rates on size and gasoline and subsidy rate on newness should each be raised or lowered until the aggregate additional gain in private welfare just equals the aggregate loss from the effect on emissions. The extent to which emissions are reduced depends on the degree of responsiveness in the choice of miles, size, and newness. Thus optimal uniform tax or subsidy rates on size, newness, and gasoline depend on the elasticities of demand for these goods. But the way in which changes in size and newness affect emissions is through the technological relationships that size and newness have with emissions per mile and fuel efficiency. The functions *EPM* and *MPG* are therefore major determinants of the uniform tax rates. Correlation among preferences will also affect the optimal uniform rates.

Unlike the framework we use to solve for individual-specific tax rates, the mathematical model we use to determine the general form of optimal uniform rates does not give us explicit equations for the rates. Only with data on households' vehicles and miles driven and responses to tax rates can we solve for optimal uniform rates.

IV. Conclusion

We find that the ideal Pigovian tax on emissions (Policy 1) can be replicated perfectly by a complicated gas tax (Policy 2). However, this ideal outcome requires that the gasoline tax depend on engine size, newness and *PCE*. Alternatively, the policymaker, then, attain the ideal outcome by using miles-specific vehicle tax schedules (Policy 3). If these individual-specific tax rates are too difficult or costly, they could implement uniform tax rates on gasoline, engine size, and newness. To do this, they could implement uniform rates calculated using the population averages of miles and vehicle characteristics (Policy 4). Last, policymakers could explore these

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24 For those readers with more background in economics, the decisionmaker maximizes the weighted sum of indirect utilities, taking as given households' demand behavior, with respect to the three tax rates. For the sake of clarity, here we consider linear second-best tax rates. Perhaps policymakers could assess nonlinear size and newness tax schedules fairly easily. The use on nonlinear schedules could incorporate heterogeneity by accounting for convexity or concavity of *EPM* and *MPG*, but not for the possible correlation among size, newness, and miles.

technological relationships and correlation among tastes, and impose uniform taxes that account for these relationships (Policy 5). We do this in the next chapter.

Figure 5-1: Consumer Choice Framework

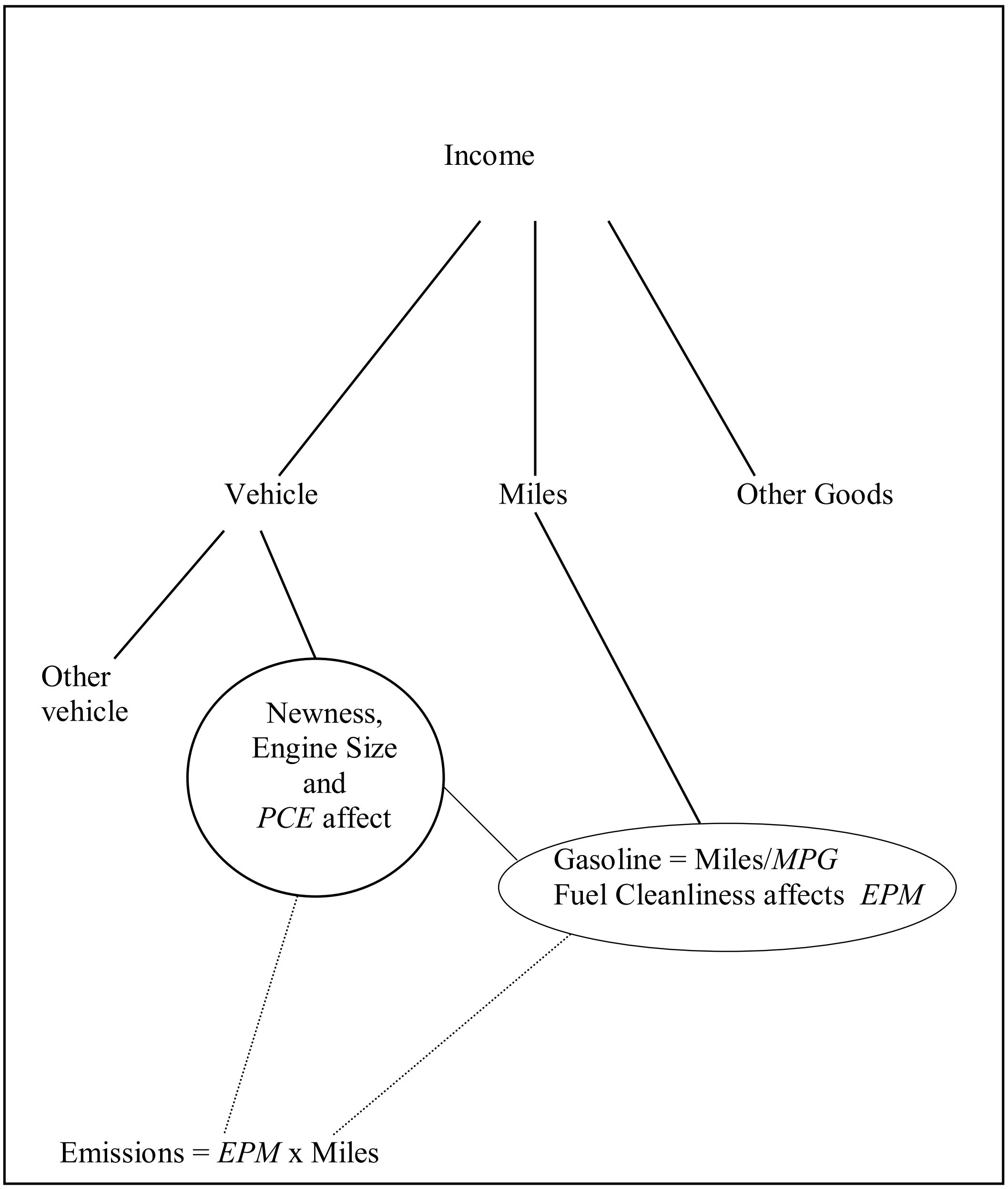


Figure 5-2

Consumption of Dirty Goods (Gasoline and Engine Size)

(Each Household has a Different Graph)

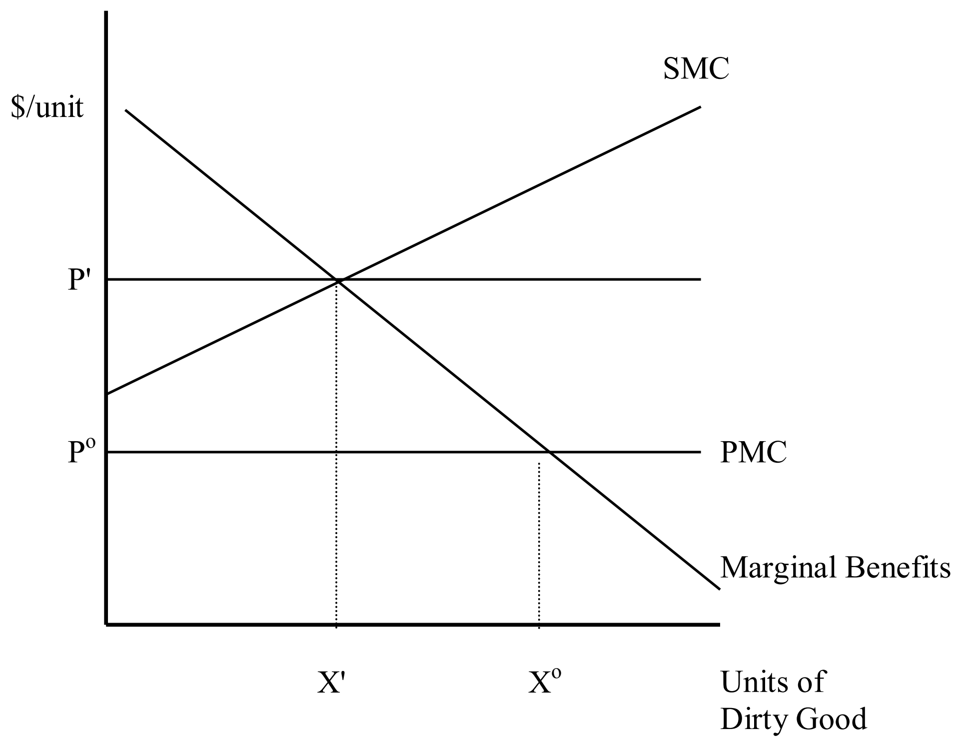
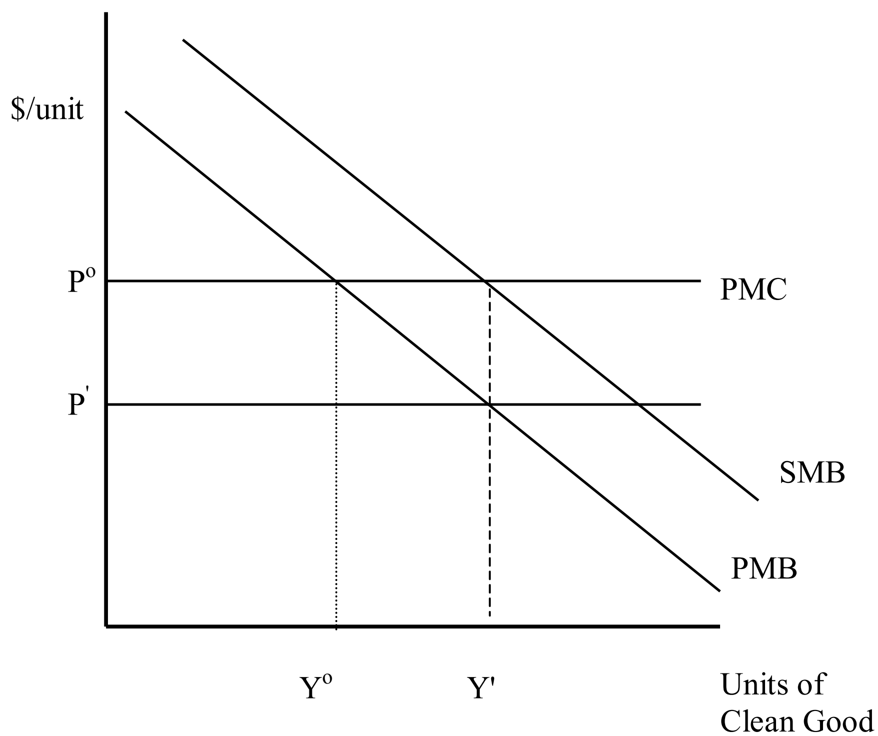


Figure 5-3

Consumption of Clean Goods (Vehicle Newness, Clean Fuel Characteristic, *PCE*)

(Each Household has a Different Graph)



Chapter 6

Calculations of Uniform Tax Rates

So far, we have shown that a Pigovian tax on emissions achieves the optimal degree of abatement through a set of behaviors that minimize costs. We also showed that such "first-best" results can also be achieved by tax rates on gasoline that depend on the vehicle at the pump, or by a vehicle tax that depends on miles driven. Yet such taxes would be difficult to administer. For this reason, we now consider taxes that are constrained to be uniform across households: a gas tax at the same rate for all vehicles, a tax on vehicle size that does not depend on miles driven, and a tax (or subsidy) to vehicle newness that does not depend on miles. Whereas the unconstrained tax rates achieved "first-best" results, this constrained set of tax rates cannot perform as well. Thus we solve for "second-best" uniform tax rates on gas, newness, and engine size.

To solve for optimal uniform taxes or subsidies on gasoline, newness, and engine size, first we explicitly state how households evaluate the tradeoff between the marginal benefits and costs of each good. In addition, we specify the degree to which households substitute among goods in response to price changes that result from taxing or subsidizing goods. Second, we gather information on households' choices of vehicle-related goods and other goods, so that we incorporate correlation among preferences into the framework. This household information includes data on expenditures, prices, and each vehicle's size, newness, fuel efficiency, and emissions per mile. We use these data to determine how newness and engine size relate to emissions per mile and fuel efficiency.

If consumers were identical, each would drive the same type of car the same number of miles, and so uniform rates set using averages would perform just as well as rates set using data on all households. So, more differences among individuals imply that the constrained uniform rates do less well.

We use our data and model to simulate a scenario in which individuals face no taxes. Then, we solve the model under eight different policy scenarios. We first simulate a uniform emissions tax, the optimal policy against which we evaluate the performance of other potentially-more-feasible tax combinations. All other policies are combinations of uniform taxes or subsidies on gasoline, engine size, and vehicle newness. One combination would use all three instruments. We then consider three policy options that consist of only two of the three instruments. The remaining three policies involve a single tax or subsidy.

We solve the model under these varying assumptions about the availability of these policy instruments, and we rank the policy combinations according to welfare. To compare the performance of the less-efficient instruments with that of the most-efficient emissions tax, we calculate the percentage of the Pigovian tax improvement gained by each policy. Despite the considerable extent to which individuals in our data differ, some combinations of uniform taxes perform quite well. We find that the three-part instrument attains 71 percent of the Pigovian tax improvement (relative to the zero-tax scenario). A gas tax alone reaches 62 percent of the Pigovian welfare gains.[25]

We also use this numerical model to evaluate the welfare gains of uniform rates calculated using the averages of observed miles, size, and newness. Since EPM and MPG are nonlinear functions of size and newness, and since preferences for miles, size, and newness are significantly correlated, the use of averages to set the three tax rates gains only 61.5 percent of the Pigovian tax welfare gains, less than that gained by the optimal uniform gas tax. Thus ignoring heterogeneity may result in significant welfare losses.

I. Numerical Model

In this section, we clarify the theoretical framework that we use as a basis for our computer simulations.

A household may be composed of one or more drivers, each of whom makes decisions regarding vehicle type and miles driven. In our model, we focus on the individual; households that have two vehicles thus have two decision-makers.[26] Our data do not provide the amount and type of pollution control equipment on each vehicle, maintenance of this equipment, or the cleanliness level of the fuel. So, for the purposes of this model, we ignore effects of these characteristics on emissions. We are able to identify the make, model, engine size, and year of each car in each household, matched with other data on income and all expenditures for each household, however, so that we do capture the effects on emissions of choices about age and engine size.

As explained in chapter 5, individuals gain utility, or satisfaction, from consumption of newness, engine size, miles, and other goods. They are negatively affected by total auto emissions, but do not recognize how their choices contribute to total emissions. The marginal benefits of each good are essentially the "demand" for each good, based on the contribution of each good to an individual's utility.

In the absence of taxes, the private cost of each good is determined by its market price. Since the price per mile driven depends on fuel efficiency, which depends on newness and engine size, the choice of miles depends on the choice of these vehicle characteristics. Since vehicle characteristics affect the amount of gasoline required to drive a mile, the prices of these goods involve not only a direct component, but also an indirect component through the effect on the cost of gasoline. All relative prices can be altered by taxes or subsidies on emissions, gasoline, engine size, newness, or on all

[25] Since California already administers a gas tax, one might be tempted to use our results to conclude that the existing gas tax reaches 62 percent of the Pigovian welfare gains. This is not necessarily true, however, because the magnitude of the existing gas tax was not set according to the environmental damages that are caused by burning gasoline.

[26] In our model, one driver does not affect the decisions made by another driver in the same household. We ignore possible interdependence among choices rather than making arbitrary assumptions about those interdependencies.

other goods. Table 6-1 explains the price of each good and the tax or subsidy rate associated with each good.

Table 6-1: Prices and Tax or Subsidy

Good	Direct Component of Price	Indirect Component of Price	Tax or Subsidy
Miles	The price per gallon of gasoline, divided by miles per gallon	None	Gas tax, or increase in emissions tax due to an extra mile
Engine Size	The price per cubic inch of displacement (CID)	Higher cost of gas from effect of using larger car	Size tax, or increase in emissions tax due to an increase in size
Newness	Equals one, so that "spending" on newness each year is the amount that the vehicle falls in value (depreciation)	Lower cost of gas from effect of using newer car	Newness subsidy, or decrease in emissions tax due to an increase in newness
Other Goods	Equals one	None	None

To choose the number of miles to drive, individuals evaluate the direct cost per mile, which is determined by the price per gallon of gasoline and fuel efficiency, and, they evaluate how much they would have to pay either in gas tax or in the emissions tax attributable to driving an extra mile. To determine what size engine to buy, individuals consider the price per cubic inch of displacement (CID), and they evaluate the cost of the extra gas that must be paid, given a number of miles, when using a larger vehicle with lower *MPG*. Individuals may also face a tax on size or on emissions associated with the extra size of the car.

Newness is the counterpart of vehicle age. An arbitrarily "old" vehicle does not depreciate any further, and newer vehicles depreciate more than older vehicles, so the individual's "spending" on newness each year is related to the amount it falls in value. We assume that the price of newness is one. Therefore the "quantity" of newness purchased in a given year is the amount "spent" on the vehicle's depreciation. Individuals evaluate this expenditure when deciding what vintage vehicle to purchase. And, they consider the lower cost of gasoline when using a newer vehicle with higher *MPG*. They may also face a subsidy to newness, or they may experience a decrease in emissions tax paid when driving a newer car.

We use a mathematical expression for utility to specify preferences for goods, and the assumed maximization of this utility function determines the demands for (marginal benefits from) these goods as functions of income and prices. This equation incorporates the complicated interrelatedness of each individual's choices. And, each individual is allowed to have his or her own preferences about goods.[27] Some of our results depend upon the degree to which consumers can respond to policies by substituting consumption of one good for consumption of another. For example, when faced with a gas tax, individuals could spend less on miles and engine size, and spend more on newness and other goods. We experiment with different degrees of substitutability, and explain how this affects our results.

II. Data and Derivations

To implement the model discussed above, we need data on individual expenditures, prices, and each vehicle's engine size, vintage, fuel efficiency, and emissions per mile. In this section we describe the three main sources of data used in this study: the Consumer Expenditure Survey (CEX), the California Air Resources Board (CARB) Light-Duty Surveillance Program, and the American Chamber of Commerce Researchers' Association (ACCRA) cost-of-living index. In addition, we explain the derivation of prices and other values used in the calculations.

The 1994 Consumer Expenditure Survey is the first component of our data. This survey is published annually by the Bureau of Labor Statistics of the U.S. Department of Labor, and it provides comprehensive and detailed information on the quarterly expenditures of approximately 5000 consumer units.[28] Each consumer unit participates in the survey for five consecutive interview quarters. All CEX observations include the amount spent on gasoline as well as total expenditures. The 1994 survey also contains files with detailed information on each consumer unit's vehicles. Just a few of the variables included in the vehicle file are year, make, model, and number of cylinders.[29] The CEX is a rotating panel survey. Each quarter, 20 percent of the sample is rotated out and replaced by new consumer units. We pool households across the four quarters in the 1994 CEX and treat each observation as a different household.

Next, we need the fuel efficiency and emission characteristics of each car. Between November 1995 and March 1997, the CARB tested the emissions per mile and

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[27] We assume a Constant Elasticity of Substitution (CES) form of utility over the four chosen commodities, and that total emissions has a linear negative effect on utility. For a full derivation of this model, see Fullerton and West (2000).

[28] A consumer unit can comprise either "(1) all members of a particular household who are related by blood, marriage, adoption, or other legal arrangements; (2) a person living alone or sharing a household with others or living as a roomer in a hotel or motel, but who is financially independent; or (3) two or more persons living together who use their income to make joint expenditures." (BLS, 1996, p. 236).

[29] In addition, the vehicle file lists each vehicle's cumulative mileage. In order to obtain a number for miles driven in a quarter, we originally planned to match households across quarters and subtract the previous quarter's odometer reading from that of the current quarter. When we did this, however, we discovered that most odometer readings are only rough estimates. And, for some households, the current quarter's reported odometer reading is less than that of the previous quarter. Thus we elected to derive miles using data to be described shortly.

fuel efficiency of 345 vehicles in California.[30] They recorded numbers for emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x). In addition, they compiled vehicle information such as make, model, year, number of cylinders, and cubic inches of displacement. Unfortunately, the CARB did not measure emissions of PM10, the only pollutant whose overall levels have been rising in California.

We drop the three vehicles in the CARB that are motor homes, and 342 vehicles remain. We then find vehicles in the CEX that match a CARB vehicle's make, model, year, and number of cylinders. This match enables us to use the CARB vehicle's cubic inches of displacement for that car in the Consumer Expenditure Survey. For single-car households in the CEX with complete expenditure and vehicle data, we obtain 567 usable matches.[31] We then select all multi-car households that have complete expenditure and vehicle data and that have at least one vehicle that exactly matches a CARB vehicle.[32] For the other vehicles of those multi-car households, we impute displacement by using CARB data to estimate displacement as a function of cylinders, newness, and an indicator for whether the vehicle is a truck or van.[33] The final sample consists of 567 vehicles from one-vehicle CEX households and 694 vehicles from multi-vehicle CEX households.[34] We also assign values for income of each driver. Individuals from one-car CEX households are assigned the total expenditures listed for their household. For drivers in multi-car households, income is total expenditures divided by the number of vehicles.

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[30] The Light-Duty Vehicle Surveillance Program, Series 13, was conducted as part of an ongoing effort by the California Air Resources Board to accumulate vehicle emissions data, to investigate vehicle maintenance practices and deficiencies, and to determine the frequency and effect of tampering with pollution control equipment. To undertake this project, the CARB compiled a list of candidate vehicles from a randomized set of registered vehicles belonging to households within a 25-mile radius of the CARB office in El Monte, California.

[31] Some matches were not used because high consumption of one or more goods rendered expenditure shares that summed to more than one, or because our simulation program could not solve the household's demand system due to the nonlinearity of the system in combination with that household's particular parameters.

[32] Vehicles from multi-car households are also selected according to whether information on mileage is available. We explain this further below.

[33] With standard errors in parentheses, N=Newness, and CID=Cubic Inches of Displacement, the estimated equation is:

$$\underset{(49.48)}{CID = -101.75} + \underset{(14.1)}{35.88cylin} + \underset{(1.07)}{2.68cylin^2} + \underset{(1.75)}{5.83N} - \underset{(.03)}{.06N^2} \underset{(.17)}{-.74N*cylin} + \underset{(4.3)}{26.08\ truck/van\ dummy}$$

#obs = 342, $R^2 = .8753$

[34] Thus 45 percent of the vehicles in our final sample are from single-car CEX households and 55 percent are vehicles from multi-car CEX households. This distribution corresponds fairly well to the distribution of single-car and multi-car households in the U.S. population: in the 1990 census, 38 percent of all households owned one vehicle, while 62 percent owned two or more vehicles (ORNL, 1998: p. 10-8).

To establish a base from which to compare welfare levels, we need to assign prices to gasoline, size, newness, and all other goods. For the price of "all other goods," we define a unit as the amount that costs one dollar, so the price per unit is one. For gas prices, we use the ACCRA cost-of-living index. This index compiles prices of many goods as well as overall price indexes for approximately 300 cities in the United States. It is most widely used to calculate the difference in the overall cost-of-living between any two cities. It also lists average gasoline prices for each city in the survey each quarter. For each state, we average the city gas prices to obtain a state gasoline price for each calendar quarter.[35] We then assign a gas price to each CEX household based on state of residence and CEX quarter, and divide gas expenditures by this price to get gallons of gas consumed.

In order to simulate a scenario with no pre-existing gas taxes, we need to know the 1994 state and federal gas tax rates. The federal gas tax was $.184 per gallon. For each state's gas tax, we relied on *The Transportation Energy Data Book 16* (ORNL, 1996). The average of these 1994 state gas tax rates was 19 cents.

Ohta and Griliches (1986) provide the information necessary to calculate the price per cubic inch of displacement (CID). They estimate that an increase of one cubic inch of displacement increases the price of a vehicle by .253%. To translate their estimate into dollars per cubic inch in 1994, we use $19,676 as the average 1994 price of a new car in 1994 (ORNL, 1996, p. 2-38).[36] Thus the initial outlay per cubic inch of displacement in 1994 is ($19,676)(0.00253) = $49.78. The 1990 vehicle model year average survival rate is 13.7 years (ORNL, 1996, p. 3-9). So, to obtain a price per quarter for one CID, we find the amount that would be paid each quarter for 56 quarters with a present value of $50, assuming a 5% annual interest rate. This results in a price per CID of $1.23 per quarter.

We use a similar unit definition to set the price of newness equal to one. Thus the "quantity" of newness is total expenditure on newness, that is, vehicle depreciation. To calculate depreciation for each vehicle, we assume that vehicles depreciate geometrically at a rate of .20 per year.[37] While vehicles differ in value across types, and thus each has a different depreciation amount, some of that depreciation pertains to leather seats or other features not related to emissions. We want to use the same measure of emission-related newness for all vehicles. Thus we apply the depreciation schedule to a base vehicle's value, the average value for a new vehicle. The

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[35] Because gas prices from municipalities that are not Metropolitan Statistical Areas (MSAs) are incomplete, we removed non-MSAs from the sample. All households in the sample from the CEX are urban dwellers.

[36] This average price is in 1994 dollars and includes prices of imported vehicles.

[37] Estimates of this depreciation rate range from .33 (Hulten and Wykoff, 1981; Jorgenson 1996) or .30 (Hulten and Wykoff, 1996) to .15, the rate implicit in the vehicle depreciation schedule currently used by the Bureau of Economic Analysis (authors' calculations based on a depreciation schedule provided by Arnold Katz, BEA). We use .20 because it falls between these estimates.

approximate average price of a new vehicle from 1960 to 1995 is $15,000 in 1994 dollars, so a new 1995 car depreciates by $15,000 x (.2) = $3000 per year, or $750 per quarter. Thus the owner of a 1995 vehicle (regardless of make or model) consumes 750 units of newness, while the owner of a 1980 vehicle consumes only 26.38 units of newness per quarter.

We used the CARB data to experiment with a variety of specifications for *MPG* and *EPM* as functions of newness and engine size. For our measure of *EPM*, we use a weighted sum of the three pollutants in our sample: HC, CO, and NO_x. We weight each pollutant according to its contribution to *MED*; in accordance with Small and Kazimi (1995), we assign the highest weight to NO_x (.495), followed by HC (.405) and CO (.10).[38]

We estimate the relationship between vehicle characteristics and fuel efficiency to be as follows (N=Newness, and standard errors are in parentheses):

$$\underset{}{MPG} = \underset{(.986)}{34.15} - \underset{(.009)}{.116*CID} + \underset{(.00002)}{.0001*CID^2} + \underset{(.003)}{.015*N} - \underset{(.000004)}{.00001*N^2} + \underset{(.00001)}{.0000007*(N*CID)}$$

These estimates show that fuel efficiency decreases with size. Specifically, an increase of one cubic inch of displacement decreases *MPG* by about .1158 miles per gallon. And, fuel efficiency increases with newness. Also, the multipliers or "coefficients" on the vehicle characteristics that have been squared (CID^2 and N^2) are statistically significant. This means that the relationship between vehicle characteristics and fuel efficiency is not a simple linear one. If it were linear, then an increase in engine size would decrease fuel efficiency at a constant rate, and an increase in newness would increase fuel efficiency at a constant rate. Instead, the positive coefficient on CID^2 means that an increase in engine size decreases fuel efficiency at an increasing rate. The difference in fuel efficiency for a vehicle with an engine with 250 *CID* and one with 200 *CID* is greater than the difference in *MPG* for a vehicle with 200 *CID* compared with one with 150 *CID*. And, the negative coefficient on N^2 means that an increase in newness increases fuel efficiency at a decreasing rate.

To estimate the relationship between vehicle characteristics and *EPM*, we used a slightly more complicated equation.[39] The results of this estimation show that emissions per mile increase with engine size at a decreasing rate. Emissions per mile decrease with newness at a decreasing rate.

As explained in chapter 5, the magnitude of welfare gains from calculating optimal tax rates using data on heterogeneous households (as opposed to using average

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[38] Small and Kazimi (1995) do not calculate a value of *MED* for CO, but they say it is small, so we use .10 for CO. We then use their *MED* estimates for HC and NO_x to assign weights to those two pollutants.

[39] With standard errors in parentheses, and N=Newness, the estimated equation is:

$$\ln(EPM) = \underset{(.252)}{1.101} + \underset{(.002)}{.004*CID} - \underset{(.000005)}{.000004*CID^2} - \underset{(.001)}{.009*N} + \underset{(.0000009)}{.000008*N^2} - \underset{(.000003)}{.000001*N*CID}$$

values of miles, size, and newness) depends in part on how nonlinear are the functions for MPG and EPM. The results in the last two paragraphs show that both functions are quite nonlinear.

We use the estimated equations to assign each vehicle with a function that provides MPG and EPM, not only for baseline values of size and newness, but also for simulated changes in choices about vehicle characteristics. Then, to obtain baseline miles driven, for each individual from a one-car household, we multiply MPG by gallons of gas consumed. Calculating miles driven for each car of a multi-car household is not so straightforward, because each household has only one value for gas expenditure. To allocate gas expenditure to each driver or car in such a household, we need to know the number of miles driven and MPG of all vehicles. To obtain an estimate of miles driven for these cars, we match CEX vehicles across quarters and subtract the previous quarter's odometer reading from that of the current quarter. We keep vehicles from households for which we have at least two vehicles with positive miles driven that quarter, assuming that vehicles with missing or negative miles are not used by the household. Then, we divide each miles number by the vehicle's estimated MPG to get estimated gasoline consumption. We divide each vehicle's estimated gas consumption by the sum of all of the household's vehicles' estimated gas consumption to assign the *proportion* of gas used by each vehicle. Finally, we allocate the actual total gas consumption (recorded in the CEX) for that household among their vehicles by these proportions. Each car's share of total gas reported in the CEX is divided by that car's MPG to obtain our final estimate of miles driven.

We also have to assign values to each individual that account for that person's tastes. To do this, we use a method called calibration. We observe the amount of each good that an individual has purchased, given income and prices. And, for each good we have a mathematical equation that relates the quantity demanded by an individual to prices and income. This equation contains a parameter that corresponds to the preference for each good. So, we have all of the information that we need to solve for the value of each such parameter. People that are observed to drive more miles than others will be assigned a higher value for their preference for miles. We use these preference parameters in every subsequent simulation. These parameters guide the individual's selection of new quantities for miles and car characteristics in response to a change in tax rates and subsidy rates; these quantities react to changes in tax rates, not changes in preferences.

Lastly, we need a number for marginal environmental damages, MED. As summarized in chapter 2, the literature includes many diverse estimates of the MED per unit of car pollution, but methodological issues and other difficulties preclude consensus. Moreover, MED by its very nature depends on whether the area is densely populated. We use Small and Kazimi's estimates to assign weights to the three pollutants measured by the CARB. But we avoid problems with the determination of MED by assigning it a value that would result in an optimal gasoline tax close to that which already exists. We find that if *MED* is .0076 (that is, .76 cents per gram of emissions) then the optimal uniform gas tax is $.29 per gallon.[40]

Table 6-2 summarizes the starting point for our simulations. The average miles, size, newness, and other goods are those chosen when households face no taxes (the "zero-tax" scenario).

Table 6-2: Parameter and Variable Descriptions and Means (1261 individuals)

Description	Mean in Zero-Tax Scenario
Total quarterly expenditure	5011.37
Percent of expenditure spent on miles	3.0
Percent of expenditure spent on engine size	7.0
Percent of expenditure spent on newness	4.0
Percent of expenditure spent on other goods	86.0
Marginal environmental damages (MED)	.0076
Price per gallon gasoline after removing pre-existing taxes ($)	.72
Price per cubic inch of displacement per quarter ($)	1.23
Price per year of newness per quarter ($)	1.00
Price per unit other goods ($)	1.00
Miles per quarter	3685.83
Cubic inches of displacement	166.45
Newness (depreciation per quarter)	181.39*
Other goods	4455.45
Gallons of gasoline	169.63
Miles per gallon	21.74
Grams per mile of emissions	2.04

* This depreciation corresponds most closely with that of a vintage 1988 vehicle.

The 3 percent average for the percent of expenditure spent on miles matches the mean gasoline expenditure for the 1994 CEX. The average individual allocates 14 percent of total expenditure to gasoline, size, and newness. Since this figure excludes non-emission-related car characteristics (such as a sunroof or leather seats), it corresponds well to data for the average CEX household, which spends 19 percent of its income on transportation (including gasoline, vehicle purchases, maintenance, and other charges). The average vehicle in the sample is a 1988 model year, has six-cylinders, and is driven 14,743 miles per year. On the national level in 1994, the average car was also a 1988 model year, driven 11,400 miles per year (ORNL, 1996, p. 3-11).

[40] We assume that the individuals in our sample live and drive in an airshed with perfect mixing.

III. Simulation Results

A. Eight Scenarios

We use the data set and parameters just described to simulate a baseline and eight different tax scenarios. To obtain the baseline, we remove the pre-existing federal and state gas taxes and solve the model.[41] When we solve for optimal tax rates, we must specify what happens to tax revenue. We assume that the government has the ability to levy lump-sum taxes and thus faces no particular revenue requirement in this problem. We add an individual's tax revenues to that individual's income and subtract tax subsidies from income.

We are interested in eight alternative tax combinations. In each case, we specify which tax rates are allowed for each specific policy combination, and we set all other tax rates to zero. We then use the numerical model to find the values for the allowable tax rates, positive or negative, that maximize welfare (given individual demand behavior). The first policy, a uniform emissions tax, is the optimal policy against which we evaluate the performance of other potentially more feasible instruments. Our theory predicts that this optimal Pigovian tax will be equal to *MED*, which we have specified to be .0076, and we use this fact to test that our model correctly implements the underlying theory.

For the seven remaining scenarios, we set the tax on emissions to zero and solve for combinations of other tax rates (assuming that each tax rate must be uniform across heterogeneous households). Because the gas tax reduces miles most directly, and thus reduces emissions more directly than the size tax or newness subsidy, we expect the combinations that involve a gas tax to result in higher welfare gains than those without.

We also simulate the effects of using uniform tax rates on gasoline, engine size, and vehicle newness calculated using equations from Fullerton and West (2000) and the sample averages. Since these rates ignore the nonlinearity in the functions for *EPM* and *MPG*, and correlation among tastes for miles, engine size, and vehicle newness, we expect these rates to result in lower welfare gains than the three-part instrument that incorporates heterogeneity among households in the data. Results of this exercise appear in section D below.

Starting for the case in which people are assumed to have a moderate degree of flexibility in substitution among goods, Table 6-3 shows the results. For each policy, it lists the percentage improvement relative to the zero-tax scenario, and the welfare gain as a percentage of that achieved by the ideal-but-unavailable Pigovian tax on emissions.

[41] We do not remove other pre-existing policies such as the Corporate Average Fuel Economy (CAFE) standards, emissions standards, and gas-guzzler taxes, but these controls are embodied to some extent in the functions that relate *MPG* and *EPM* to engine size and vehicle newness. Without these regulations, our tax policies that alter choices about these car characteristics would not have the same impact on *EPM* or *MPG*. An appropriate extension to this project would model other regulatory policies explicitly.

Table 6-3: Simulation Results (Moderate Degree of Substitution)

Scenario	*Pigovian Tax Rate*	*Gas Tax Rate*	*Size Tax Rate*	*Newness Subsidy Rate*	% Improvement from Zero-Tax	% of Pigovian Tax Improvement
Pigovian Tax	.0076	0	0	0	.2511	100.00
Three-part	0	.267	-.007	-.107	.1795	71.49
Two-part #1	0	.268	0	-.107	.1794	71.45
Two-part #2	0	.291	-.004	0	.1565	62.33
Gas tax	0	.291	0	0	.1565	62.31
Two-part #3	0	0	-.023	-.148	.0501	19.96
New subsidy	0	0	0	-.148	.0493	19.61
Size subsidy	0	0	-.020	0	.0007	.29
Zero taxes	0	0	0	0	0	0

In accordance with Pigovian tax theory, our simulation program finds that a tax on emissions equal to .0076 improves welfare to the greatest extent. The optimal three-part instrument includes a 27 cent tax per gallon of gasoline, a .7 cent subsidy per cubic inch of displacement per quarter, and a 10.7 cent subsidy to newness per quarter. Because the dollar values of these rates depend on *MED*, and different regions have different values for *MED*, our results *do not* imply that the California should impose a statewide gas tax of 27 cents, or a newness subsidy of 10.7 cents. Before implementing these policies, policymakers in a particular region would have determine the *MED* for that region. If, for example, estimates of *MED* were double the value we use in this study, the optimal rates would be double the values in Table 6-3.

Our results *do* imply that the gas tax rate is large relative to the newness subsidy rate. This emphasizes the importance of the gas tax, and of reducing miles driven, for reducing vehicle emissions. The fact that the size tax is negative also emphasizes the importance of reducing miles for significant welfare gains to be attained. A subsidy to size acts indirectly to reduce miles driven. A size subsidy increases the amount of size purchased, which has a small positive effect on emissions per mile *(EPM)* but a larger negative effect on fuel efficiency *(MPG)*. This raises the overall price per mile, and it thus reduces miles driven. In other words, a small subsidy to size has a net negative effect on emissions through the decrease in miles driven. Despite the heterogeneity of the consumers in our model, the three-part instrument performs adequately well. These size and newness subsidies plus gas tax, even at uniform rates for all consumers, can attain approximately 71% of the gain in social welfare achieved by a Pigovian tax.

Because the size subsidy is so small, a two-part instrument involving just a 27 cent gas tax and 10.7 cent subsidy to newness attains nearly the same 71% gain of the three-part instrument. A different two-part instrument, with a gas tax and size subsidy, attains 62% of the maximum gain. A 29 cent gas tax alone also achieves about 62% of the gain from the ideal Pigovian tax. This gas tax alone gains more welfare than the combination of only subsidies to size and newness, a result that emphasizes the fact that miles reduction is the most direct way to cut emissions.

Table 6-4: Average Miles, Size, and Newness, and Percent Emissions Reduction

Scenario	*Miles*	*Size (CID)*	*Newness*	%Emissions Reduction	% Pigovian Tax Emissions Reduction
Pigovian tax	2850.01	169.22	204.00	42.70	100.00
Three-part	2692.92	168.36	202.68	32.12	75.22
Two-part #1: Gas tax, Newness Subsidy	2697.50	167.41	202.68	32.11	75.20
Two-part #2: Gas tax, Size Subsidy	2627.10	168.60	182.18	28.79	67.42
Gas tax	2629.92	168.01	182.84	28.79	67.42
Two-part #3: Size subsidy, newness subsidy	3670.13	168.90	210.01	9.80	22.95
Newness subsidy	3696.65	165.74	210.01	9.65	22.60
Size subsidy	3675.53	167.66	181.35	.06	.14
Zero taxes	3685.83	166.45	181.39	-	-

Three policies that do not involve a gas tax attain less than one quarter of the welfare gain of the Pigovian tax: the combination of a size subsidy and newness subsidy, and single subsidies to newness or size. In the absence of a gas tax, the optimal size subsidy becomes more negative, as it assumes more of the burden of reducing miles. Since the size subsidy reduces miles more indirectly than does the gas tax, welfare gains for the size subsidy alone or in combination with the newness subsidy are lower than for combinations involving a gas tax.

For each scenario, Table 6-4 lists the means of choices for miles, size, and newness, and it shows the percent emissions reduction. Emissions are reduced by 42.7% with the Pigovian tax, and by 32.1% with the three-part instrument.

B. Discussion

How big is the absolute size of each such welfare gain in dollars? Translating the gains in welfare into dollar terms implies a gain from the Pigovian tax equal to $12.49 per individual per quarter. This gain over all individuals is 0.25% of the sum of individual income in the sample. Both the three-part instrument and the first two-part instrument provide a welfare gain of about $8.92 per individual, or a total over all individuals that is 0.18% of the sum of individual income.

The *added* gain from the ideal Pigovian tax is the difference, 0.1% of income. Thus, if the additional *administrative* costs of implementing a Pigovian tax are greater than 0.1% of the sum of all affected individuals' incomes, then the three-part and first two-part instrument may be overall more efficient than the Pigovian tax. However, the distributional effects of the Pigovian tax and these other combinations may differ. The impacts of alternative tax scenarios may differ even further if household composition is taken into consideration. In addition, we assumed that our *EPM* and *MPG* functions generated the true emissions and fuel efficiencies of each car in the sample. Any error in this assumption would change the relative gains from these instruments.

Under our assumptions, a gas tax of 29 cents per gallon yields 62% of the Pigovian tax improvement. Whether the government should elect to impose just a gas tax depends on the ease with which it could implement a newness subsidy. Such a subsidy could be paid upon the purchase of a new vehicle, or implicitly assessed in a program to buy up old vehicles as examined in Alberini et al. (1995) or Dixon and Garber (1999). Another alternative is the gas tax and size subsidy combination. A positive size tax is already implicitly incorporated into the gas-guzzler tax that consumers must pay when purchasing an automobile that has an EPA fuel economy rating of less than 22.6 *MPG*.[42] These U.S. gas-guzzler tax schedules could be modified to incorporate the externalities from pollution that result from larger engines. California could introduce its own tax schedules. Instead of indirectly taxing size through low *MPG*, this tax could be made to depend on emission rates. However, since the increase

[42] For example, a tax of $1,000 is assessed on all automobiles whose fuel economy is between 22 and 22.5 *MPG*. This existing tax increases in a nonlinear fashion and reaches a maximum of $7,700 for vehicles with fuel efficiency ratings under 12.5 *MPG*. In 1996, the Federal government collected nearly $53 million in gas-guzzler taxes (ORNL, 1998, p. 6-15, 6-16).

in welfare due to the size subsidy is so small, we hesitate to recommend its implementation.

C. Sensitivity Analysis

The relative welfare gains discussed in the previous section result from simulations in which households have moderate ability to substitute among goods. In this section, we evaluate the robustness of those results by undertaking the same kinds of simulations assuming that households have greater or lesser flexibility in their choices of goods. Relative welfare gains using all three levels of flexibility are listed in Table 6-5.

Table 6-5: Sensitivity Analysis

	Less Flexibility		Moderate Flexibility (from Table 6-3)		Greater Flexibility	
Scenario	% Improvement in Welfare from Zero-tax	% of Pigovian Tax Improvement	% Improvement in Welfare from Zero-tax	% of Pigovian Tax Improvement	% Improvement in Welfare from Zero-tax	% of Pigovian Tax Improvement
Pigovian Tax	.1185	100	.2511	100	.4409	100
Three-part	.0802	67.70	.1795	71.49	.3211	73.05
Two-part #1: gas, newness	.0800	67.49	.1794	71.45	.3153	71.49
Two-part #2: gas, size	.0694	58.54	.1565	62.33	.2780	63.05
Gas tax	.0692	58.40	.1565	62.31	.2773	62.90
Two-part #3: size, newness	.0189	15.93	.0501	19.96	.1075	24.38
Newness subsidy	.0189	15.90	.0493	19.61	.1036	23.49
Size subsidy	.0001	.11	.0007	.29	.0038	.86
Zero-taxes	0	0	0	0	0	0

Note two characteristics of these results. First, for all policies compared to the zero-tax scenario, the gains in welfare increase as flexibility increases. As individuals are allowed to substitute more easily among goods, all policies reduce emissions at a lower cost. Second, the welfare gains from the alternative policies relative to the Pigovian tax gains also increase with the degree of flexibility. Yet the rankings of the policies are identical for all degrees of flexibility. So, while welfare gains are sensitive to the degree to which households can substitute consumption of one good for consumption of another, the choice among instruments is not.

D. Uniform Rates Using Averages

We found that *MPG* and *EPM* are curved functions. In addition, miles and size in our sample are negatively correlated, which means that individuals with large engines tend to drive fewer miles. Size and newness are negatively correlated, while miles and newness are positively correlated. Because people differ, the most-efficient individual-specific taxes would reflect many combinations of miles, size, and newness. Thus it is not possible to predict the effect of these correlations on the optimal uniform tax rates.

Table 6-6 lists tax and subsidy rates calculated using tax rate equations from Fullerton and West (2000) and the averages of miles, size, and newness.

Table 6-6: Comparison of 3PI Rates Evaluated using Averages and Optimal Uniform Rates

Tax Rate	Value at Averages	Optimal Uniform Rates (from table 6-3)
Gas Tax	.21	.27
Size Tax	-.03	-.007
Newness Subsidy	-.20	-.107

The size subsidy calculated using sample averages is four times the magnitude of the optimal uniform rate. Probable sources of this difference are the negative correlation between size and miles, and the nonlinearity of *EPM*. The size subsidy reduces emissions by reducing miles. Since size and miles are negatively correlated, the size subsidy induces more miles reduction than would be expected were consumers identical. So a smaller subsidy is optimal. The newness subsidy calculated using averages is nearly double the size of the optimal uniform rate, indicating that the negative correlation between size and newness could be affecting the optimal rates. Due to the negative correlation, the newness subsidy increases newness and decreases size (on average), and so a smaller newness subsidy is optimal.

What impact do these correlations have on welfare gains? The three-part instrument using rates evaluated at observed means obtains 61.5 percent of the welfare gains of the Pigovian tax (compared with 71.5 percent under the computed optimal 3PI). Thus, ignoring heterogeneity could result in sizeable welfare losses.

IV. Conclusion

In this chapter, we solve for a variety of combinations of uniform tax rates on gasoline, engine size, and vehicle newness, using data from the 1994 Consumer Expenditure Survey, the California Air Resources Board Light-Duty Surveillance

Program, and the ACCRA Cost of Living Indexes. We thus combine information on 1261 individuals' expenditures with other information on vehicle characteristics including engine size, vehicle vintage, fuel efficiency, and emissions per mile.

With three main determinants of emissions (miles, engine size, and vehicle newness), we solve for eight different tax and subsidy combinations. We have excluded, however, other individual choices that impact vehicle emissions, such as the choice of pollution-control equipment and its maintenance, fuel cleanliness, the number of cold-start-ups, and driving aggressiveness. If data on individuals' choices of these goods become available, we could expand this numerical model to include them. Then, to affect emissions without a direct tax on emissions, the model would require a tax or subsidy to each of these additional choices. As it stands, our model measures the determinants of emissions imperfectly. We also ignore the interdependencies in a multi-car household's choice of miles allocation across vehicles. In our model, a gas tax causes all drivers in the household to drive fewer miles. In general, however, a gas tax may cause a household to drive fewer miles in their old gas-guzzler and *more* miles in their newer, more fuel-efficient car. Allowing for substitution among vehicles within the household would enable the same emissions reduction to occur at a lower cost to the household, and welfare gains of our simulated policies could be larger.[43]

In addition, we do not explicitly incorporate pre-existing policies such as the Corporate Average Fuel Economy (CAFE) standards, the gas-guzzler tax, and emissions standards. These policies are embodied to some extent in our estimated functions for *MPG* and *EPM*. Without these standards, our alternative instruments would not perform as they do in our model. The gas- guzzler tax indirectly taxes engine size and thus affects the magnitude of the optimal uniform size tax rate in our model. Also, CAFE standards change the effect that newness and size have on fuel efficiency and thus affect the magnitude of all our tax rates and especially the gas tax rate. The newness subsidy is effective in our model in part because emissions standards have become increasingly stringent over time. A more complete numerical implementation would explicitly model existing and potential mandates and incentives.

We compare the performance of second-best instruments with that of a first-best emissions tax by calculating the percentage of the Pigovian tax improvement gained by each policy combination. Despite the considerable heterogeneity among households in the data, two combinations of uniform taxes perform well.[44] We find that 71 percent of the Pigovian tax improvement from the zero-tax scenario can be gained by the three-part instrument involving a gas tax, a size subsidy, and a newness subsidy. The two-part instrument involving a gas tax and newness subsidy also attains about 71 percent of

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[43] Green and Hu (1985) find that this substitution occurs to a large extent in some households, but that its overall effect is negligible. A calibrated numerical model like ours could incorporate such substitution, as could a simulation model that uses regression-based estimates of responsiveness.

[44] Since we can observe size and newness, taxes or subsidies on these goods need not be uniform. Instead, a vehicle tax could be any nonlinear function of size and newness. Use of such a tax schedule in our model would generate welfare gains that are greater percentages of the Pigovian tax gains.

the Pigovian tax improvement. Adding the size subsidy to this two-part instrument does not significantly increase welfare because of the small impact that engine size has on *EPM*. For the most part, then, we can conclude, that a size tax or subsidy is not essential.

A gas tax alone reaches 62 percent of the gains from an ideal Pigovian tax. The ultimate choice of policy depends on these estimated welfare effects and on other effects not estimated here such as distributional effects and administrative costs of implementing each tax or subsidy.

Chapter 7

Distributional Impacts of Taxes on Gas or Cars

In chapter 6, we focused on the efficiency effects of taxes or subsidies on gasoline, the newness of the car, and engine size. We explicitly ignored the differential effects that these policies might have on groups with different income and demographic characteristics. In this chapter, we discuss a more general empirical model of the choice of vehicle, including the choice of vintage and engine size and the choice of vehicle-miles-traveled *(VMT)*. We use results from this estimation to describe the likely distributional effects of a gas tax, size tax, and newness subsidy. In addition, we evaluate the degrees of responsiveness of demand for *VMT* and gasoline to changes in the price of gasoline.

The joint nature of the demands for vehicles and miles complicates estimation of these demand functions. The choices of vehicle and *VMT* are related because characteristics that influence a household to purchase a certain vehicle may also influence that household's choice of miles. For example, an individual that lives far from work may gain more enjoyment from commuting in a large, comfortable vehicle. Residence location also makes it likely that the individual will drive more miles. The two choices are also related through the effect that vintage and engine size have on fuel efficiency, and thus on the price per mile. The price per mile is the price per gallon of gasoline divided by fuel efficiency (miles per gallon), which is itself a function of vintage and engine size. Since the demand for *VMT* depends on the price per mile, and thus fuel efficiency, the household's choice of vehicle affects their demand for miles, and vice versa.

Section I explains the estimation approach. Section II describes the data, explains the classification of vehicle bundles, details the derivation of variables used in the estimation, and provides summary statistics. Section III presents results from the two stages of estimation. Section IV offers conclusions and directions for future research.

I. Estimation Approach

Several studies examine either the choice of vehicle or vehicle characteristics, and other studies examine the demand for miles. Many studies conducted in the 1970s estimate the aggregate demand for vehicles using time-series data (see, for example, Hess (1977) and Johnson (1978)). Some studies estimate the choice of vehicle, but not the demand for miles (Berkovec (1985), Berkovec and Rust (1985), McCarthy (1996)). Still other researchers use "hedonic" analysis to estimate the contributions of vehicle characteristics to vehicle price, and then use these estimates for second-stage estimation of the demand for characteristics.[45] While many studies of the demand for miles include indicator variables for vehicle choice in equations that estimate miles demand, they do not explicitly model the joint nature of the choice.[46] Hundreds of studies of gasoline demand do not include vehicle choice at all.[47]

Recognizing that estimates obtained from these studies are biased, a few gasoline demand studies have modeled the choice of vehicle explicitly. Because an automobile is durable, and miles-driven is the service provided by an automobile through gasoline use, an appropriate framework for modeling this joint choice is found in Dubin and McFadden (1984). They derive models to estimate the joint demand for durables and energy use, and apply them to the demand for appliances and electricity.

Four studies use the Dubin and McFadden framework to estimate the joint demand for vehicles and miles. Two use data from the 1970s. First, Mannering and Winston (1985) develop a dynamic model of vehicle ownership and utilization, with discrete choices, a model in which utilization is the sum of miles driven by all vehicles in the household. Second, Train's (1986) model is not dynamic, but it does examine the number of miles driven in each vehicle in the household. While both studies explicitly incorporate vehicle choice in the demand for *VMT*, their results using 1970s vehicles may not apply today. Two studies use more recent data for foreign countries. Using Canadian data from the 1980s, Berkowitz et al. (1990) expand upon previous studies to include choices between vehicles and alternative modes of transportation. Hensher et al. (1992) use Australian panel data from 1981 to 1985 to estimate a dynamic model of vehicle holdings and use.

Each of these studies uses one method to control for the effect of vehicle choice in estimation of miles demand. All except Train (1986) treat vehicles as durable goods. However, none of these studies uses recent data from the United States. In addition, all use traditional measures of income. Since current income includes transitory components, a better measure of permanent income is current total expenditures (Bohi (1981), Poterba (1991), and Slesnick (1994)). Finally, no study models vehicle choice in a way that can be used to determine the effects of household characteristics on the demand for newness and engine size, attributes that are important for analyzing emission-reduction policies.

In our framework, households face choices regarding the number of vehicles to own and the engine size and vintage of each vehicle. They also face the choice of vehicle-miles-traveled, *VMT*. To model these related choices, we combine the choice of the number, engine size, and vintage of vehicles into one choice, the choice of vehicle bundle. A household chooses from among a set of these bundles. The choice of

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[45] See for example Agarwal and Ratchford (1980), Arguea, Hsiao, and Taylor (1994), Atkinson and Halvorsen (1984), Bitros and Panas (1990), and Goodman (1983).

[46] See Archibald and Gillingham (1981), Sevigny (1998), and Walls et al. (1994).

[47] See Dahl (1986), Dahl and Sterner (1991), and Espey (1996) for reviews of the literature on the demand for gasoline.

vehicle depends on income, the quarterly cost of the vehicle bundle, the cost per mile for vehicles in each bundle, household characteristics, and attributes of the bundle such as newness and engine size.

Unobserved household characteristics that affect the utility of miles driven in a particular vehicle bundle are likely to affect both the probability of selecting that bundle and the intensity of its use. For example, a household with many children may gain more enjoyment from driving in a spacious vehicle. The household may also have to drive the children to more activities, and so they may drive more miles. Moreover, factors that affect the intensity of use will affect the probability of choosing particular vehicle bundles. A person living in a region with long commutes drives more miles, and may be more likely to choose a vehicle bundle that has low operating costs.

Dubin and McFadden (1984) suggest three alternative methods that incorporate the interrelated nature of the choices of vehicle and *VMT*. Here, we present the results of the "reduced form method." To use this method, we first estimate the probability that households choose each one of the available vehicle bundles. Then, we include these probabilities in the estimation of *VMT*. Doing so ensures that we have properly accounted for the effect that vehicle choice has on the demand for miles traveled.

II. Data and Summary Statistics

To estimate the model discussed above, one needs data on individual expenditures, prices, and household and vehicle characteristics. We use the three sources of data described in chapter 6. To consider the distributional effects of our policies, we do not need to match vehicles from the CEX with vehicles from the CARB. Thus we are able to use a larger national sample from the CEX. This sample contains information on 5740 households from around the United States. Of the 5740 in the full sample, 642 are from California. We estimated vehicle and *VMT* choice for both the national sample and the California sample. Both samples yield similar results, and so we report those using the larger national data set.

A. Classification of Vehicle Bundles

We classify vehicle bundles according to three characteristics: number of vehicles, vintage, and engine size. We use vintage and engine size rather than other characteristics because they, of the vehicle characteristics included in the CEX, have the most measurable impact on the price per mile.[48] This classification also enables us to estimate the effects of household characteristics on the demand for size and vintage.

[48] To classify vehicles, Train (1986), and Mannering and Winston (1985) use vintage, but no measure of vehicle size. Berkowitz et al. (1990) classify bundles using vintage, and type (sedan or truck), which is one measure of size. They estimate fuel efficiency, but they do not reveal whether they include type in this estimation. Hensher et al. (1992) uses type, but not vintage, to classify bundles.

First we classify bundles according to three "number of vehicles" categories: zero, one, or two. Then, within the one- and two-vehicle categories, we further classify each vehicle according to vintage and engine size. Since we are primarily concerned with the effect of vintage on fuel efficiency, initially we hoped to divide vehicles into vintage groups in accordance with the years in which larger-than-average changes in Corporate Average Fuel Economy (CAFE) Standards took effect. Doing so would imply three categories such as pre-1981, 1981 to 1989, and 1990 and newer.[49] However, the CEX lumps 1980- through 1982-vintage cars into the same category. So, we divide vehicle bundles into the following vintage categories: all cars are pre-1980 (old), at least one car is built between 1980 to 1989 and no car is built since 1990 (newer), or, at least one car is built since 1990 (newest). For engine size, the three categories are: all 4-cylinder (small), at least one 6-cylinder and no 8-cylinder (medium), or at least one 8-cylinder (large).

Table 7-1: Vehicle Bundle Description and Statistics

Bundle Number	Bundle Description			Frequency	Percent of total
	Number of vehicles	Engine Size	Vehicle Age		
1	0	-	-	1541	26.85
2	1	small	old	45	.78
3	1	small	newer	632	11.01
4	1	small	newest	371	6.46
5	1	medium	old	61	1.06
6	1	medium	newer	483	8.41
7	1	medium	newest	302	5.26
8	1	large	old	158	2.75
9	1	large	newer	212	3.69
10	1	large	newest	68	1.18
11	2	small	old	3	.05
12	2	small	newer	166	2.89
13	2	small	newest	200	3.48
14	2	medium	old	16	.28
15	2	medium	newer	329	5.73
16	2	medium	newest	476	8.29
17	2	large	old	36	.63
18	2	large	newer	384	6.69
19	2	large	newest	257	4.48
			Total	5740	100.00

[49] For a table of CAFE standards across time, see ORNL (1996), p. 3-43.

This classification generates nine one-vehicle bundles and nine two-vehicle bundles. Table 7-1 describes each bundle and shows the total number of households choosing each bundle. Households that own no cars make up 27 percent of the sample, whereas 41 percent own one car, and 32 percent own two cars. The most common bundle is one 4-cylinder 1980s-vintage car (small, "newer"), and the next most common bundle is one 6-cylinder 1980s-vintage car (medium, "newer"). The most common two-car bundle is a one with at least one 6-cylinder 1990s-vintage car.

B. Derivation of Bundle-Specific Attributes and VMT

Two key bundle-specific attributes are employed in our estimation. They are price per mile and capital cost. The price per mile for each vehicle is the price of gasoline divided by fuel efficiency. The ACCRA gives the price per gallon of gasoline, by state. To obtain fuel efficiency, we use the CARB to estimate a regression of *MPG* on indicator variables for the three size categories and for the three vintage categories. The results of this regression appear in Table 7-2.

Table 7-2: Fuel Efficiency Regression

Dependent Variable	Constant	6-cylinder	8-cylinder	1980s	1990s	R^2	F-stat
MPG	21.74	-6.36	-9.34	2.43	4.75	.68	175.27
	(.51)	(.40)	(.51)	(.51)	(.56)		

Standard errors are in parentheses; the number of observations is 342.
Given the omitted indicator variables, the constant represents the estimated fuel efficiency of a 4-cylinder, pre-1980 vehicle.

The regression shows that fuel efficiency decreases with both vehicle age and engine size. For one-vehicle bundles, fuel efficiency is calculated directly from the regression results. For two-vehicle bundles, first we calculate the fuel efficiency of each two-car pair within the bundle by averaging the two cars' estimated efficiencies. Then, we assign the two-vehicle bundles that consist of more than one possible two-vehicle pair the average, weighted by the number of each two-vehicle pair, of the pairs' average efficiencies.

Unfortunately, the CEX only lists the total gas expenditure for each household, not the gas expenditure for each vehicle. Thus we cannot assign *VMT* to each vehicle, and must use total *VMT* by a household. To calculate *VMT*, we first divide the household's gas expenditure by its gas price to get gallons of gas consumed. Then, we multiply gallons by fuel efficiency (for that household's bundle) to obtain *VMT* for the household.[50]

The quarterly cost of a vehicle bundle includes the capital cost of each vehicle and the typical cost of driving. For capital costs, we use the average purchase price of a bundle. Households in the CEX are asked how much they paid for each vehicle they own, and what year they bought the vehicle. We use prices of new and used vehicles purchased in 1994 to calculate the capital cost of each size-vintage combination. For two-vehicle bundles, we calculate the capital cost of each two-car pair within the bundle by adding the two cars' average prices. Then, we assign the two-vehicle bundles that consist of more than one possible two-vehicle pair the weighted average of the pairs' capital costs.

Typical fuel costs depend on the typical number of miles a household expects to drive. To construct a measure of the typical miles driven by a household, we calculate the average number of miles driven in each bundle (averaged over all households). Then, we allow typical miles to differ by the household's total expenditures and the number of drivers.

C. Summary Statistics: Household and Vehicle Characteristics

This section presents summary statistics for household and vehicle characteristics by number of vehicles, engine size, and vintage. These statistics allow us to make hypotheses about the effects of these characteristics on the probability that a vehicle bundle is chosen.

Table 7-3 lists these summary statistics by a CEX household's number of vehicles.

[50] Using total *VMT* rather than the *VMT* in each vehicle ignores the possibility that households respond to changes in gasoline price by driving more in one vehicle and less in another. Thus, estimates of the elasticity of *VMT* with respect to the price per mile are likely to be biased downwards. However, Greene and Hu (1985) find that substitution among vehicles in response to changes to the price per mile is negligible, and so the bias is not likely to be large.

Table 7-3: Summary Statistics by Number of Vehicles

Household and Vehicle Characteristics*	Number of Vehicles			
	0	1	2	All
Number of households	1541	2332	1867	5740
Household size	2.00	2.01	2.94	2.30
% Households with kids	23.3	24.2	48.1	31.7
Number in household > 15 years old	1.43	1.52	2.12	1.69
Number of income earners	.712	.981	1.62	1.12
% Household heads that are male	34.1	49.8	72.7	53.0
Age of household head	47.0	48.6	45.0	47.0
% HH heads that are white	67.2	82.9	87.5	80.2
% HH heads with educ. > high school	34.6	53.0	57.4	49.5
% HH in metro area with pop. > 4 million	23.0	11.6	10.7	14.4
% HH in Northeast	32.5	19.4	16.8	22.1
% HH in Midwest	22.1	22.6	26.6	23.8
% HH in South	30.1	35.8	35.1	34.1
% HH in West	15.2	22.1	21.5	20.1
Total quarterly expenditures (1994 $)	3725	5816	8962	6278
Bundle purchase price (1994 $)	0	5882	11630	6172
Price per mile	0	.056	.055	.041
Actual miles driven	0	2981	4943	2819

* Average values are given unless otherwise noted.

Not controlling for other variables, the number of vehicles owned increases with household size, the number of household members older than 15 (a variable meant to represent the number of drivers), the number of income earners, and total expenditures. Since all of those variables are correlated, however, Table 7-3 does not indicate which are most important. Based on the distribution of percentages across number of vehicles, the probability that a household chooses a vehicle bundle with more vehicles may increase if the head of household is male, white, has more than a high school education or lives in the Midwest. The likelihood that a household chooses bundles with more vehicles appears to decrease if the household lives in a large metropolitan area.

Statistics by engine size appear in Table 7-4.

Table 7-4: Summary Statistics by Vehicle Engine Size (Households with Vehicles)

Household and Vehicle Characteristics*	Size of Vehicles in Bundle			
	Small: All 4 cylinder	Medium: At least one 6 cylinder, no 8	Large: At least one 8 cylinder	All
Number of households	1417	1667	1115	4199
Household size	2.14	2.53	2.63	2.42
% Households with kids	29.9	37.8	36.7	34.8
Number in household > 15 years old	1.62	1.84	1.92	1.79
Number of income earners	1.21	1.33	1.25	1.27
% Household heads that are male	50.5	61.5	69.6	60.0
Age of household head	42.7	47.7	49.5	46.5
% HH heads that are white	84.3	85.6	84.8	85.0
% HH heads with educ. > high school	63.8	55.7	42.6	55.0
% HH in metro area with pop. > 4 million	9.81	12.8	10.5	11.2
% HH in Northeast	19.3	19.7	14.7	18.2
% HH in Midwest	20.9	26.0	26.5	24.4
% HH in South	35.3	34.5	37.3	35.5
% HH in West	24.6	19.9	21.5	21.9
Total quarterly expenditures (1994 $)	6470	7824	7249	7215
Bundle purchase price (1994 $)	7287	9711	7997	8438
Price per mile	.044	.057	.069	.056
Actual miles driven	3722	4078	3685	3853

* Average values are given unless otherwise noted.

The likelihood that a household chooses a vehicle with larger engine size appears to increase with household size, the number of members older than 15, and the age of the household head. More-educated household heads appear to choose smaller vehicles, and households in the Midwest and South or with male heads of household to appear to choose larger vehicles. As predicted by the fuel efficiency regression, the price per mile increases with engine size.

Finally, Table 7-5 contains summary statistics by vintage.

Table 7-5: Summary Statistics by Vehicle Age (Households with Vehicles)

Household and Vehicle Characteristics	Age of Vehicles in Bundle			
	Old: All 1979 or older	Newer: At least one 1980s, no 1990s	Newest : At least one 1990s	All
Number of households	319	2206	1674	4199
Household size	2.26	2.46	2.41	2.42
% Households with kids	27.9	35.1	35.7	34.8
Number in household > 15 years old	1.59	1.79	1.83	1.79
Number of income earners	0.92	1.24	1.37	1.27
% Household heads that are male	50.5	57.9	64.5	60.0
Age of household head	49.2	46.4	46.0	46.5
% HH heads that are white	78.7	83.0	88.8	85.0
% HH heads with educ. > high school	34.8	51.8	63.0	55.0
% HH in metro area with pop. > 4 million	6.58	11.2	12.1	11.2
% HH in Northeast	12.9	19.9	17.1	18.2
% HH in Midwest	18.2	23.9	26.2	24.4
% HH in South	34.2	34.4	37.2	35.5
% HH in West	34.8	21.8	19.5	21.9
Total quarterly expenditures	4381	6407	8819	7215
Average purchase price (1994 $)	875	3331	16609	8438
Price per mile	.078	.057	.050	.056
Actual miles driven	2106	3530	4612	3853

* Statistics are means, except where noted otherwise.

Newer and newest vehicles appear to be preferred by households with children, with more members above the age of 15, with more income earners, larger total expenditures, and with white, male, and more-educated heads. Households living in large metropolitan areas also appear more likely to choose newer vehicles, while households with older heads seem more likely to choose older vehicles. As indicated by the fuel efficiency regression, the price per mile increases with vehicle age.

These statistics provide insight into the probable determinants of bundle choice, and they inform the selection of variables to include in the vehicle-choice estimation detailed next. The reason for the estimation described below is to isolate the effect of one demographic variable controlling for the others. For example, female heads of households tend to have low income. Table 7-4 indicates that they tend to have smaller cars, but it does not indicate which variable has the stronger effect. Do they buy the smaller cars because they are female or because they have low incomes? The next section's estimation is designed to address such questions.

II. Estimation and Results

Estimation of the model described in Section I is undertaken in two stages. The first stage estimates a conditional logit specification of the discrete choice of vehicle bundle as a function of household and vehicle bundle characteristics.[51] Then, the second stage estimates the demand for *VMT* using the method described in Section I.

A. Stage 1: The Choice of Vehicle Bundle

In the first stage, we use estimate the households' choices of vehicle bundle using a "conditional logit." Such an estimation technique enables us to determine the effect of demographic and bundle characteristics on the probability that a household will choose a given bundle. Table 7-6 presents definitions of the characteristics that we include in the bundle-choice estimation.

[51] The conditional logit is estimated using full information maximum likelihood. Estimating vehicle choice using the logit specification imposes the assumption of independence of irrelevant alternatives (IIA). This assumption means that the ratio of choice probabilities between two alternatives does not depend on any alternatives other than the two. The natural solution to this problem is to use a nested logit structure, wherein households first choose the number of vehicles, the vintage, then size.

Table 7-6: Definition of Bundle-Choice Variables

Variable Name	**Variable Definition**
CAPCOST	Bundle's average purchase price
*INC*CAPCOST*	Total expenditures times average purchase price
TFCOST	Total fuel cost (price per mile times typical miles driven)
PRICE PER MILE	Price of a mile (gas price/*MPG*)
MALE	Head of household is male
EDUCATION	Head of household has more than high school education
WHITE	Head of household is white
METRO	Household lives in metro area with population>4 million
KIDS	Household has kids
FAMSIZE	Number of household members
DRIVERS	Number of household members older than 15 years
EARNERS	Number of income earners in household
AGE1	Age of household head < 25
AGE2	24 < Age of household head < 45
AGE3	44 < Age of household head < 65
AGE4	Age of household head > 64
NORTHEAST	Household lives in the Northeast
MIDWEST	Household lives in the Midwest
SOUTH	Household lives in the South
WEST	Equals one if household lives in the West

Table 7-7 presents the estimation results for the effect of vehicle price variables on the probability that a vehicle bundle is chosen.

Table 7-7: Effects of Vehicle Price Variables on Probability the Bundle is Chosen

Variable	**Increase or Decrease Probability?**
Purchase Price	Decrease
*Income*Purchase Price*	Increase
Price per Mile	Decrease

The first row of Table 7-7 means that a more-expensive vehicle makes it less likely that a household will choose it. The second row means that households with higher incomes are more likely to choose bundles that are more expensive. And, as expected, households prefer bundles with lower operating costs, those vehicles with lower price per mile.

Our results for the impact of demographic characteristics tend to confirm the apparent results of the summary statistics in Section II.C, and in some cases provide additional information not evident in the summary statistics. Table 7-8 lists the effects of these characteristics. Other characteristics that are not listed in the table cannot be said to significantly affect vehicle bundle choice. To address the question raised in the specific example above, the results in the second panel of Table 7-8 imply that females tend to buy smaller cars independent of income, and that those with less income tend to buy smaller cars (independent of gender).

Table 7-8: Effects of Demographic Characteristics on the Probability a Vehicle Bundle is Chosen

Characteristics	**Increase or Decrease Probability**
Characteristics that affect number of vehicles owned	(of owning more vehicles)
METRO	decrease
EARNERS	increase
DRIVERS	increase
KIDS	increase
MALE	increase
WHITE	increase
EDUCATION	increase
INCOME	increase
Characteristics that affect engine size	(of owning larger vehicles)
METRO	decrease
MALE	increase
AGE2	increase
AGE3	increase
AGE4	increase
EDUCATION	decrease
MIDWEST	increase
SOUTH	increase
WEST	increase
INCOME	increase
Characteristics that affect vintage	(of owning newer vehicles)
MALE	increase
WHITE	increase
EDUCATION	increase
INCOME	increase

In general, starting back at the top of Table 7-8, households that live in metropolitan areas are less likely to own cars than they are to own no cars. All else equal, households with more income earners and members over the age of 15 are more likely to own two cars than they are to own one, as are households with kids. The same is true for households with male, white, or more-educated heads.

As predicted using summary statistics, households with male, older, or less-educated heads are more likely to choose bundles with larger vehicles. Households that live in the Midwest, South, or West are more likely to own larger cars than similar households in the Northeast. Those that live in large metropolitan areas are *less* likely to own large vehicles. Once the estimation controls for income and other factors, race and family size do not appear to be an important determinant of engine size choice. In other words, if minorities tend to own older cars, it is because they tend to have lower incomes—not because they are minorities.

Households with male, white, and more-educated household heads are more likely to own newer vehicle bundles. Despite what the summary statistics indicate, age and children do not appear to affect vintage choice. In other words, Table 7-5 indicates that households with more kids and higher incomes prefer newer cars. But having children and having more income are positively correlated. Table 7-8 indicates that households with more kids and more income get newer cars because they have more income, not because they have more kids. This is what the estimation can clarify that is *not* in clarified by the summary statistics.

Households with higher incomes prefer newer and larger vehicles. These results provide preliminary information about the probable distributional effects of a size tax and newness subsidy across income, demographic characteristics, and regions. Since households that purchase larger cars have more income, a size tax would likely be progressive, and a size subsidy would likely be regressive—perhaps surprisingly. However, since households with more income also prefer newer cars, a newness subsidy would be regressive—as might be expected. Households with male, older, or less-educated heads that live in regions other than the Northeast would be hardest hit by a size tax (and would benefit the most from a size subsidy). White, more-educated, male-headed households would benefit the most from a newness subsidy.

B. Stage 2: Estimation of the Demand for Vehicle-Miles-Traveled

Table 7-9 presents the results for the estimation of the demand for *VMT*.

As expected, the demand for *VMT* decreases with the price per mile, and it increases with income. The coefficient of –469.50 on the price per mile means that if the price per mile increases by 1 cent from an average price per mile of 4 cents, households would drive, on average, 469.5 fewer miles per quarter. This figure is 17 percent of the average number of miles per household per quarter. Demand for *VMT* increases if the household lives in the South or West. Miles per household also increase if the household lives in a large metropolitan area. The number of income earners increases demand for miles per household, which emphasizes the influence of commuting. However, household miles demand decreases with the number of potential drivers, the number of household members older than 15. Those households whose heads are past retirement age also drive less. Controlling for income and other factors, miles-driven cannot be conclusively said to be affected by race, education, having children, or family size.

Table 7-9: Results from *VMT* Regressions, all Households (*VMT* minus typical miles is the dependent variable, standard errors in parentheses)

Variable	Coefficient Estimates
PRICE PER MILE (cents)	-469.50 (119.79)
(INC-TFCOST)	.10 (.030)
CAPCOST	.21 (.031)
REGION2	82.31 (175.16)
REGION3	756.73 (203.13)
REGION4	732.13 (276.46)
MALE	94.79 (158.09)
EDUC	-161.92 (237.94)
WHITE	43.17 (172.45)
NUMEARNER	-177.63 (137.15)
FAMSIZE	-41.92 (84.28)
NUMDRIVER	-406.50 (137.69)
AGE2	-307.78 (174.75)
AGE3	-421.87 (256.68)
AGE4	-708.00 (289.82)
KIDS	131.60 (175.87)
METRO	701.49 (229.89)
Adjusted R^2	.0925
Number of observations.	5740

C. Price and Income Elasticities

By controlling for other factors such as age, the number of drivers, etc., the conditional logit enables us to isolate the impacts of income on vehicle bundle choice, and thus informs us about the probable distributional effects of a size tax and newness subsidy. A second goal of this chapter is to produce reliable estimates of the degree of responsiveness in demand for *VMT* to price and income. Such degrees of responsiveness are measured using "elasticities." The price elasticity of demand for *VMT* is equal to the percentage change in vehicle-miles traveled over the percentage change in the price per mile. If households are very responsive to changes in price, then the price elasticity of demand is large in absolute value, and demand is "elastic." Under these circumstances a small increase in the gas tax would result in a proportionally larger decrease in miles-traveled. If, on the other hand, households are not very responsive to price changes, then the price elasticity of demand is closer to zero, and demand is "inelastic." If this were the case, then an increase in the gas tax would result in a proportionally smaller decrease in *VMT*.

Table 7-10: Short-run Price and Income Elasticities of Demand for Vehicle-Miles-Traveled and Gasoline

Elasticity of VMT with respect to price per mile	-.67
Elasticity of VMT with respect to net income	.23
Elasticity of gasoline with respect to price per mile	-.60
Elasticity of gasoline with respect to net income	.20

Income elasticities are defined similarly: the income elasticity of demand for *VMT* is equal to the percentage change in *VMT* divided by the percentage change in income. If the income elasticity if less than one, then on average, households with higher incomes spend lower proportions of their income on *VMT*. Wealthier households would therefore pay less in gas taxes as a proportion of their income than poorer households. A gas tax under these circumstances would be regressive. If, on the other hand, the overall income elasticity is greater than one, the gas tax overall would be progressive.[52]

The short-run elasticities[53] presented in Table 7-10 includes the effects of a change in gasoline price on net income, defined simply as the difference between

[52] Quite possibly the effect of income on gasoline purchases is not uniform across the income scale. Households with *very* low income may buy no gasoline at all. Then households with fairly low income spend a relatively high fraction of income on gasoline, so the gasoline tax is regressive beyond that point—since increases in income beyond that point tend to reduce the *fraction* spent on gasoline.

[53] Generally, because each different household in a cross-section is thought to be in long-run equilibrium after adjustments to its price and income, elasticities estimated using such data are thought to represent *long-run* elasticities. Our elasticities are therefore larger in absolute value than those obtained by estimation using time-series data. However, because the elasticities that we report here assume that households do not change vehicles in response to the gas tax, they do not incorporate the fullest possible long-run responses, and so we call them "short-run" elasticities.

income and total fuel cost. The elasticities are evaluated at the means of price per mile, income, and fuel efficiency.

The demand for *VMT* is quite inelastic. Because of how vehicle bundles are defined, these price elasticities are not strictly comparable to estimates from previous studies. However, the results presented here are generally larger in absolute value than others.[54] The income elasticity estimates are similar to those found in the two previous studies that define income as net annual income. In contrast, we use total expenditure to represent a more stable or long-run concept of permanent income.[55]

Since the estimated income elasticities are less than one, the gas tax overall appears to be regressive. However, as pointed out by Poterba (1991), a large proportion of households in the lower income deciles do not spend *any* money on gasoline. To give a more complete picture of the potential distributional effects of a gas tax in California, Table 7-11 presents average gasoline expenditures as a percent of total expenditure for the 642 Californian households in the sample, by decile.

Table 7-11: Average Share of Income Spent on Gasoline in California, by Decile

Decile	Average Gasoline Expenditure as Percent of Total Expenditures, all Households	Average Gasoline Expenditure as Percent of Total Expenditures, Vehicle Owners Only
1	2.7	5.5
2	2.9	5.6
3	4.4	4.9
4	4.7	3.2
5	3.2	4.0
6	3.4	3.7
7	3.1	3.0
8	2.9	2.8
9	2.7	2.7
10	1.9	2.0

The first column lists average total expenditure shares spent on gasoline for all California households. Decile 1 is the poorest income group, and decile 10 is the

[54] For example, Walls et al. (1994) has *VMT* price elasticity estimates that range from -0.120 to -0.583. Berkowitz et al. (1990) estimate a *VMT* price elasticity of -.21. Similarly, Mannering and Winston (1985) find a *VMT* price elasticity of -.228, and Hensher et al's (1992) results range from -.28 to -.39. Sevigny's (1998) estimates are the only ones that are larger than ours: she finds *VMT* elasticities that range from -.85 to -.94.

[55] The first, Mannering and Winston (1985) finds a *VMT* income elasticity of .04 on average. The other, Hensher et al, finds *VMT* elasticities ranging from .05 to .14. The only other study to define income as total expenditures (but not net income) is Archibald and Gillingham (1981). Their *VMT* income elasticity estimates range from .23 to .47 and their elasticities of gasoline with respect to income range from .29 to .56.

richest. These results confirm Poterba's finding that a gas tax would be regressive only across upper-income groups, in this case only in the top half of the income distribution. The second column lists average shares across deciles of only those households that own vehicles, and shows that among car-owners, a gas tax would generally be regressive.

III. Conclusion

In this chapter, we estimate a model of the choice of vehicle bundle and vehicle-miles-traveled. Since these two choices are related to each other, we use predicted probabilities of vehicle bundle-choice in addition to vehicle-bundle-choice variables in the estimation of the demand for miles. We use data on over 5000 households from the 1994 Consumer Expenditure Survey, combined with fuel efficiency numbers estimated using data from the California Air Resources Board Light-Duty Surveillance Program, and state-level gas prices from the ACCRA cost of living indexes.

By dividing vehicle choices into 19 possible bundles categorized by number of vehicles, vintage, and engine size, we can isolate the effects of income and other household characteristics on demand for these bundle attributes. However, combining the choice of the number of vehicles with choices of vehicle attributes into one decision ignores the fact that these decisions are typically made in related, but separate stages. Households may first decide how many cars to own, then vintage, and then size. If so, then a "nested logit" would be a more natural structure for sequential vehicle choice. This technique estimates each stage separately.

In addition, the first-stage estimation of vehicle bundle choice is limited by the data. While the CEX contains excellent data on expenditures and reasonably detailed information on vehicles, it does not contain information on many of the attributes that affect vehicle choice. Previous studies have found that vehicle choice is affected by shoulder room, acceleration, horsepower, luggage space, safety, and reliability. None of these variables are in the CEX. To capture the effects of these attributes on choice probabilities, and thus demand for miles, one could have to combine the CEX data with information on vehicles from other sources. On the other hand, it is not clear that this effort would much affect the estimated regressivity of a gas tax.

Results from the first-stage estimation of bundle choice indicate that households with higher incomes prefer newer, larger vehicles. Thus a newness subsidy is likely to be regressive, while a size tax (subsidy) is likely to be progressive (regressive). Households with heads who are male, older, or less-educated, or who live in regions other than the Northeast would be hardest hit by a size tax (and would benefit most from a size subsidy). White, more-educated, male-headed households would benefit the most from a newness subsidy.

Our estimate of the short-run price elasticity of demand for miles is -.67. This estimate is larger than those found in most previous studies. The gasoline price elasticity estimate is -.60. The income elasticity estimate is .23, which indicates that VMT is a necessity, and therefore that a gas tax may be regressive. However, for the lower half of the California income distribution, the average share of total expenditures on gasoline *increases* as total expenditures increase. This is because many lower income households in California do not own any vehicles. Only across upper income groups is the gasoline tax regressive.

Chapter 8

Policy Implications and Directions for Future Research

After reviewing the status of air quality in California and existing policies to deal with vehicle emissions, this monograph takes multiple approaches to analyzing those existing policies and other proposals. The goal is to control vehicle emissions in California in a way that balances competing objectives and constraints. First, the combination of vehicle emissions policies should be economically efficient. Because different households have different preferences over vehicle characteristics and mileage, an effective mix of abatement strategies will differ across households. This efficient mix of strategies is achieved by an ideal tax on emissions (Pigou, 1932), but vehicle emissions may be too difficult to measure and thus to tax. Second, therefore, environmental policy needs to balance economic efficiency with administrative complexity and feasibility. We look at incentive-based taxes and subsidies on market transactions that are easier to measure and enforce, like a tax on gasoline and a subsidy for buying a cleaner vehicle. Third, policymakers must be concerned with redistributive effects of these taxes and subsidies. Since households differ in terms of tastes and incomes, taxes and subsidies will affect them differently. Additionally, policymakers need to be concerned with political feasibility, revenue considerations, and other objectives.

Our research in this monograph takes three approaches to these problems. First, we build a theoretical model to prove mathematically the conditions under which certain combinations of available taxes and subsidies on market transactions are equivalent to the ideal-but-unavailable tax on emissions. We find that a complicated gas tax works fine, if a computer chip on the gas pump can identify the emissions characteristics of the vehicle being filled. Conversely, a tax on the vehicle characteristics can work fine, if it can be made to depend on miles driven. Even those policies may be difficult to implement, however. Assuming that those policies are also unavailable, we then turn to a set of tax rates that are uniform across consumers. We consider a gas tax that depends only on the cleanliness of the fuel and number of gallons, a size tax that depends only on the size of the engine, and a newness subsidy that depends on the age of the car. These tax and subsidy rates do not depend on characteristics of the consumer or number of miles driven. These "realistic" policies do not perform perfectly, but they can be designed to come as close as possible to the efficient outcome of the first-best emissions tax.

In our second approach, we build a numerical general-equilibrium computer model that specifies the driving behavior of 1261 different individuals, to capture heterogeneity and to calculate the effects of alternative policies. We find that the *uniform* tax rates on gas, engine size, and vehicle newness can achieve a welfare gain that is 71 percent of the full welfare gain of the ideal-but-unavailable emissions tax. The glass is more than half full, in the sense that available policies attain most of the benefits. This model is also used to evaluate subsets of tax rates. The tax on engine size turns out to be relatively unimportant, and the tax on gasoline turns out to be the single most important portion of this combined policy. The gas tax alone captures 62 percent of the full welfare gain from the emissions tax. A subsidy to buying a newer vehicle helps reduce emissions because newer cars have lower emissions rates.

In our third approach, we use econometric methods to measure statistically the parameters of demand for vehicle-miles-traveled *(VMT)* and for car characteristics like engine size and vehicle newness. Like other earlier estimates, our results suggest that a tax on gasoline is regressive, since low-income working families spend a fraction of their income on gasoline that is higher than for other families with more income. Since we simultaneously estimate demand for car characteristics, we are also able to show that a subsidy to newness might also be regressive. Higher income families tend to buy newer cars, and so they would tend to benefit from this subsidy.

The first chapter of this monograph provides a more complete summary of these results, and other chapters provide more detail. The purpose of the rest of this concluding chapter, then, is to discuss five main policy implications and to suggest directions for future research.

I. Policy Implications

A tax on gasoline is a key component of effective vehicle pollution control policy.

If policymakers wish to reduce vehicle pollution by complementing existing regulations with market-based incentives, and an emissions tax is not feasible, then a tax on gasoline can effectively encourage households to drive fewer miles and to drive more fuel-efficient vehicles. Since reduction of gasoline consumption is the most direct method of emissions reduction, a gas tax is the most powerful emissions-reducing market incentive.

A subsidy for buying a newer vehicle can play an important role in emissions reduction.

Regulations that require new vehicles to be cleaner have also increased new vehicle prices. These higher prices discourage consumers from buying newer, cleaner cars. A natural complement to vehicle regulations, then, would be a subsidy to the purchase of newer automobiles. This subsidy would counteract the effect that regulations have on new vehicle prices, and it would reward consumers for driving cars that emit lower emissions per mile. Such a subsidy could be paid upon purchase of a new vehicle, or upon retirement of an old vehicle.

A tax on engine size is not a necessary component of vehicle pollution control policy.

Cars with larger engines may be dirtier for two reasons. First, for any given level of gasoline use, they may emit more pollution per gallon. Second, they also use more gasoline per mile. It turns out that nearly all of the effect of size on emissions is due to its effect on fuel efficiency; for a given amount of gasoline, the additional impact of engine size on emissions per mile is negligible. Consumers that drive inefficient vehicles pay more in gas tax than do consumers with efficient vehicles. A gas tax alone, then, forces consumers to face the environmental costs of larger engines. A separate tax on engine size is not necessary.

Simple policies can get most of the gains of ideal but complicated policies.

To reduce vehicle emissions, policymakers must encourage consumers to change two simple behaviors: reduce miles and buy cleaner cars. The policies that encourage these behaviors can also be simple, and still get most of the gains that would be attained using more complicated policies. The glass is more than half full: A uniform gas tax and a uniform subsidy paid upon purchase of a new car or upon retirement of an old car, can attain more than half of the welfare gains of an ideal tax on emissions.

Market-based incentives that reduce car pollution will likely be regressive.

Low-income households spend a fraction of their income on gasoline that is higher than for other families with more income. Low-income families also own older cars. Because of this, market-incentives that discourage gasoline consumption and encourage the purchase of newer cars will likely be regressive.

II. Directions for Future Research

We have learned that policymakers are stuck between a rock and a hard place. To some extent, they seem forced to choose between improving air quality and protecting low-income families. A major goal of future research, then, is to find ways to avoid that conflict: can other policy combinations better achieve both goals simultaneously? Is it really necessary to raise taxes on low-income families in order to improve air quality for everyone? In general, the approaches described in this monograph can be used to answer these questions better, perhaps with additional work to improve the models.

First, the three approaches described here could be better integrated into a single comprehensive model. As a first step, the econometrically-estimated parameters of Chapter 7 could be employed in the numerical computer simulation model of Chapter 6. Then, instead of using estimated parameters of Chapter 7 to "infer" the distributive effects of each policy, we would use the estimated parameters in that model to *calculate* these effects of each policy. This step is not simple, because the specification of all consumers' demand behaviors must be consistent with utility-maximization in a way that allows us to calculate utility-based welfare measures, and it must be consistent with production and resource constraints for an overall general equilibrium in the economy. But successful implementation of this approach would provide a general-purpose model, one that would allow researchers to calculate the distributive effects of *any* specific proposal or combination of policies. We could then calculate the effects of policy combinations *designed* to improve air quality while protecting low-income families. A gas tax, with or without a newness subsidy, could be combined with a wage subsidy or other transfer to low-income working families who now spend a high fraction of their income on gasoline and other automobile expenditures. A targeted wage subsidy would encourage work effort while providing enough means to pay for transportation to work, while the other environmental components of this policy combination would encourage all workers to switch from high-emissions cars to low-emissions cars, to drive a bit less, and even to take public transportation.

Second, the model could be augmented to consider revenue implications of all these environmental taxes and subsidies. Raising new tax revenue might be politically unpopular, and so a politically-feasible combination of policies might be designed with revenue neutrality. The extra revenue from an increased gas tax could be used to pay for the newness subsidy and for the wage subsidy in a way that best meets multiple goals simultaneously without raising new revenue on the backs of low-income families. The model could be made to solve for second best tax rates that meet these revenue and distributional objectives.

Third, the model could be modified to consider other distorting taxes on labor and capital incomes that currently affect labor supply, investment, and productivity. This effort would require the model to specify labor supply functions and investment decisions in a way that is based on maximization of utility defined over leisure time at home, consumption of current market commodities, and future consumption made possible by savings. All taxes on labor and capital incomes have distorting effects on those behaviors, as do sales taxes and other taxes on consumption. Resulting excess burdens have been measured in computable general equilibrium models like the one envisaged here. Then a set of pollution-control taxes could be designed not with revenue neutrality, but with added revenue devoted to the reduction of these other distorting taxes on labor or capital incomes. Indeed, the "double-dividend hypothesis" is much discussed in the economics literature and suggests that environmentally-motivated taxes could both improve the environment and improve the workings of the tax system. The basic idea is to replace taxes on "goods" like labor and capital with taxes on "bads" – like polluting behavior. The extended model could be used to evaluate this kind of proposal as well.

Fourth, the model could be extended to include specific consideration of existing and proposed command and control (CAC) regulations. Currently the existence of those regulations is implicit in our model. Indeed, these regulations are the reason in our model for the effectiveness of the subsidy to buying a newer car, because these regulations are the reason that newer cars are cleaner. A more-general model could evaluate changes in these CAC regulations along with changes in tax or subsidy rates, perhaps to find the best overall combination of such policies. Besides certification standards, fleet composition, and reformulated gasoline policies, other possible air quality policies include accelerated vehicle retirement and other programs. In addition, all of these policies and regulations have their own distributive effects among consumers, since they affect production costs and prices paid by different consumers for different types of gasoline, cars, and other products.

Fifth, the model could be extended to consider other specific behaviors that affect vehicle emissions. The model used here captures household decisions about gas cleanliness and mileage, pollution control equipment, engine size, and vehicle newness. These are the major determinants of the emissions rate for each vehicle, but they are not the only determinants. The model could include other vehicle characteristics that affect emissions, specific fuel characteristics that affect emissions, and aspects of driving that affect emissions. As mentioned above, emissions are increased by aggressive driving and by the number of cold start-ups. Drivers could be encouraged in some fashion to modify these habits, to accelerate evenly, and to undertake more of their errands together on fewer trips.

Finally, a comprehensive evaluation of air quality policies might require a model with specified linkages between vehicle emissions and stationary or other sources of air pollution. If vehicle emission policy is to subsidize the purchase and use of zero-emission vehicles (ZEV) like electric cars, for example, then the needed electricity might well be generated using emission-producing fossil fuels such as oil or coal. It would then be important to find the effects of the ZEV policy not only on vehicle emissions in one set of locations, but also on other stationary-source emissions in other locations. And since each location has different tolerances or damages from such emissions, the model could then be used to calculate *net* effects or changes in total environmental damages – as well as revenue implications, distributional implications, and other effects of these policies.

While all of these considerations represent limitations on the current state of research presented in this monograph, they also represent productive opportunities for future research. And despite these limitations, the research presented here has provided concrete conclusions about the usefulness of incentive-based policies within a comprehensive set of air quality policies for California.

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