California's Ozone-Reduction Strategy for Light-Duty Vehicles

An Economic Assessment

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PREFACE

California has adopted an aggressive plan to bring the state into compliance with national ambient air quality standards. California's strategy includes strict emission standards on mobile and stationary sources and on area sources such as solvents, paints, and consumer products.

The cost and efficacy of California's plan have generated substantial debate. Studies by different research organizations, interest groups, and government agencies have produced widely ranging estimates of the cost and emission reductions produced by various components of the plan, and there is little commonly accepted empirical information on which to base policy decisions.

Because of the importance of this policy issue for all Californians, the Institute for Civil Justice undertook an evaluation of a key component of California's plan—the strategy for reducing emissions from light-duty vehicles. The project was funded by a grant from the California Manufacturers' Association and by the Institute's general research funds.

In light of the diverse audiences that will be interested in this subject matter, we present our findings in three separate forms. This volume summarizes our methods and findings. The details are contained in Lloyd S. Dixon and Steven Garber, *California's Ozone-Reduction Strategy for Light-Duty Vehicles: Direct Costs, Direct Emission Effects, and Market Responses,* MR-695-ICJ, 1996. Finally, some of our findings on the zero-emission vehicle mandate are presented in Lloyd S. Dixon, Steven Garber, and Mary Vaiana, *Making ZEV Policy Despite Uncertainty: An Annotated Briefing for the California Air Resources Board,* DRU-1266-2-ICJ, 1995.

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GLOSSARY

AVR	Accelerated Vehicle Retirement
Big 7	Automakers subject to the ZEV mandate in 1998: Chrysler, General Motors, Honda, Ford, Mazda, Nissan, and Toyota
California LDV Strategy	California's strategy for reducing emissions of ozone precursors from light-duty vehicles
California Strategy	California's strategy for reducing emissions of ozone precursors
CARB	California Air Resources Board
CP2G	California Phase 2 reformulated gasoline
Direct Costs	Social costs that count in evaluating narrow cost effectiveness
Direct Emission Effects	Changes in emissions of ozone precursors that count in evaluating narrow cost effectiveness
Economic Efficiency	Using resources as they are most highly valued by society as a whole
EEE Regulations	Enhanced Evaporative Emissions Regulations
Exhaust Emissions	Emissions produced during combustion and emitted in vehicle exhaust
EV	Electric Vehicle
I&M	Inspection and Maintenance program
ICEV	Internal Combustion Engine Vehicle
LDV	Light-Duty Vehicle. All passenger vehicles and trucks with a gross vehicle weight rating of 6,000 pounds or less
LEV	Low-Emission Vehicle. A vehicle that is certified to emit no more than 0.075 g/mi NMOG, 0.2 g/mi NOx, and 3.4 g/mi CO at 50,000 miles
NAAQS	National Ambient Air Quality Standards
Narrow Cost-Effectiveness Analysis	An analysis that estimates costs per unit of benefit but is too limited to provide a complete guide for policy decisions
Narrow Cost-Effectiveness Ratio	The ratio of direct costs to direct emission effects (generally measured in dollars per ton)
NCER	Narrow Cost-Effectiveness Ratio
NMOG	Non-Methane Organic Gases. ROG other than methane, which is a gas with low reactivity in the atmosphere

NOx	Oxides of nitrogen—NO and NO_2. These gases are ozone precursors
OBD II	On-Board Diagnostics II
ORVR	On-Board Refueling Vapor Recovery
Ozone precursors	Gases (ROG and NOx) that combine in the presence of sunlight to form ozone
ROG	Reactive Organic Gases. ROG consist of methane, many other hydrocarbons (compounds consisting solely of hydrogen and carbon), and oxygenated compounds such as aldehydes, alcohols, ethers, and ketones
SIP	California State Implementation Plan
Smog Check	California's inspection and maintenance program
Stage II vapor recovery nozzles	Nozzles on gasoline pumps designed to limit ROG emissions during refueling
TLEV	Transitional Low-Emission Vehicle. A vehicle that is certified to emit no more than 0.125 g/mi NMOG, 0.4 g/mi NOx, and 3.4 g/mi CO at 50,000 miles
ULEV	Ultra Low-Emission Vehicle. A vehicle that is certified to emit no more than 0.040 g/mi NMOG, 0.2 g/mi NOx, and 1.7 g/mi CO at 50,000 miles
U.S. EPA	U.S. Environmental Protection Agency
ZEV	Zero-Emission Vehicle. Vehicles that directly emit zero grams of any air pollutant into the atmosphere. Indirect emissions, such as power plant emissions, are not included

1. ISSUES, BACKGROUND, AND METHODS

POLICY ISSUES

Ozone, formed when reactive organic gases (ROG) and oxides of nitrogen (NOx) react chemically in the presence of sunlight, damages human health, vegetation, and structures. In several parts of California, ozone concentrations in the air exceed federal and state standards on many days of the year. The South Coast Air Basin, which includes all of Orange County and the non-desert portions of Los Angeles, Riverside, and San Bernardino Counties, violates these standards more often than any other area in the nation.

The Los Angeles area, which has the worst ozone problem in the nation, must meet federal air quality standards by 2010.

The federal Clean Air Act Amendments of 1990 require California to adopt a comprehensive strategy for bringing all areas of the state into compliance with the national ambient air quality standards (NAAQS). In the South Coast, plans for meeting the standards involve dramatic reductions in emissions of ozone precursors from both mobile and stationary sources. ROG emissions are targeted to fall by 79 percent and NOx emissions by 59 percent from their 1990 levels, despite increases in population, driving, and industrial activity. Compliance in Los Angeles—which is required by 2010—drives many of the policies adopted for the entire state. (Other areas of the state must reach compliance between 1999 and 2007.)

The responsibility for assuring that California has a comprehensive ozone-reduction strategy lies chiefly with the California Air Resources Board (CARB), a part of the California Environmental Protection Agency. Federal regulators—most notably, the U.S. Environmental Protection Agency (U.S. EPA)—are responsible for assuring that California complies with federal law. Federal policymakers—most notably, the U.S. Congress—face the challenge of ensuring that federal law is appropriate to California and Los Angeles, where topography and climate exacerbate ozone problems.

Policies proposed to meet the standards are costly and controversial.

Because meeting the federal regulations in the South Coast requires very aggressive policies, the policy debate has been vigorous. The stakes are enormous, for Californians and non-Californians. Reducing ozone levels would confer major health and other benefits on Californians. At the same time, reducing ozone levels will involve substantial costs both inside and outside the state.

THE PURPOSE OF THIS STUDY

California's policies to reduce emissions are at various stages of development and implementation. Some were adopted in California's 1994 State Implementation Plan (SIP)—(CARB, 1994c)—and some were adopted earlier. Overall, the strategy includes strict regulation of emissions from mobile sources, such as passenger cars and trucks; from stationary sources, such as factories and power plants; and from some consumer products. Studies by interest groups, research organizations, and government agencies have produced widely ranging estimates of the cost and emission reductions that will result from various elements of the strategy, and there is little widely accepted empirical information on which to base policy decisions.

We analyze cost and emission effects of California's light-duty vehicle strategy, focusing on the South Coast.

The purpose of this volume and its companions is to provide a firmer empirical foundation for decisionmaking. We analyze the cost and effectiveness of California' strategy for reducing emissions from light-duty vehicles (LDVs)—passenger cars and light-duty trucks—focusing, as does the SIP, on the South Coast. LDVs are believed to account for almost 40 percent of all ROG and 30 percent of all NOx emissions in the South Coast. Achieving planned overall emission reductions in the South Coast would require substantial reductions in LDV ROG emissions even if ROG emissions from all other sources were eliminated.

In the remainder of this chapter, we describe the elements of California's strategy that we analyze, discuss the types of information we develop for policymakers, and describe three key concepts used in our analyses—cost-benefit analysis, cost-effectiveness analysis, and market responses to policies.

ELEMENTS OF CALIFORNIA'S LIGHT-DUTY VEHICLE STRATEGY

California's light-duty vehicle strategy has elements aimed at diverse sources of emissions.

We analyze the following policies, referring to them jointly as California's strategy for reducing LDV emissions, or simply *the California LDV strategy*:[1]

- **Exhaust emission (NMOG) standards**. LDV manufacturers are required to meet increasingly stringent vehicle certification requirements for exhaust ROG emissions from internal combustion engine vehicles (ICEVs). The so-called NMOG standards require average tailpipe emissions of non-methane organic gases—a close cousin of ROG—of new vehicle fleets to fall by about 75 percent from 1993 to 2003. Fleet average NMOG is calculated by averaging emission certification levels for five types of vehicles (in decreasing order of ROG emission levels): California 1993 vehicles, transitional low-emission vehicles (TLEVs), low-emission vehicles (LEVs), ultra low-emission vehicles (ULEVs), and zero-emission vehicles (ZEVs). Because NOx emission limits for LEVs and ULEVs are lower than those for California 1993 vehicles and TLEVs, NOx emissions will

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[1] Some local air pollution control districts have also adopted transportation control measures, but we do not analyze them.

also fall as LEVs and ULEVs are increasingly used to meet the NMOG standard.

- **Enhanced evaporative emission (EEE) regulations.** Manufacturers are required to pass more stringent certification tests of evaporative emission control systems than currently used. The new regulations are being phased in between 1995 and 1998.
- **On-board refueling vapor recovery (ORVR) requirements.** On-board refueling vapor recovery systems use a canister on-board the vehicle to capture vapors displaced from the fuel tank during refueling. These systems are required by federal law and will be phased in between 1998 and 2000 for passenger cars and between 2001 and 2003 for light-duty trucks.
- **Enhanced emission system monitoring requirements**. A new on-board diagnostics (OBD II) regulation requires vehicles to have computerized systems that monitor the operation of all emission-related components and systems and illuminate a “check-engine” light on the dashboard if any are not working properly. OBD II is being phased in between 1994 and 1996.
- **Gasoline formulation requirements.** On June 1, 1996, all gasoline sold in California must meet CARB’s Phase 2 reformulated gasoline standards (CP2G).
- **Smog Check II.** Starting in 1996, Smog Check II will replace the current inspection and maintenance (I&M) program in the most polluted regions of the state. Among the ways Smog Check II will differ from the current program are establishment of stations that can test but not repair emission systems, higher limits on how much money owners can be required to spend to fix problems, and use of a new technology—remote sensing—to identify high emitters on the road.
- **Accelerated vehicle retirement (AVR) program**. A program adopted in the SIP and enacted by Senate Bill 501 in October 1995 will involve purchasing and scrapping up to 75,000 older, high-emitting vehicles a year in the South Coast beginning in 1999. A smaller number of vehicles will be retired in 1996, 1997, and 1998. Various aspects of the AVR program have yet to be designed.
- **Zero-emission vehicle (ZEV) mandate.** Starting in 1998 the Big 7—General Motors, Ford, Toyota, Chrysler, Honda, Nissan, and Mazda, the seven manufacturers with the highest sales levels in California—are required to produce and offer for sale zero (direct) emission vehicles or buy ZEV credits from other companies selling ZEVs. During 1998 to 2000, the required ZEV quota for each company is 2 percent of its annual sales of LDVs; the quotas rise to 5 percent in 2001 and to 10 percent in 2003. Several other manufacturers are

required to offer ZEVs for sale beginning in 2003, when they also become subject to the 10 percent mandate level.[2]

We pay particular attention to the ZEV mandate.

We pay particular attention to the ZEV mandate—the most controversial aspect of the strategy—because it is currently under review, poses particularly difficult analytic challenges, and involves very high economic and environmental stakes. However, our analysis of the ZEV mandate relies crucially on our analyses of the other elements of the California strategy.

THE TYPES OF INFORMATION WE DEVELOP FOR DECISIONMAKERS

We propose economic efficiency as the goal of California's ozone-reduction strategy.

We propose and analyze economic efficiency as the policy goal of the California strategy. Economic efficiency requires using or allocating society's limited economic resources—human time and effort, health, raw materials, clean air, knowledge, etc.—in the way most valued by members of society. Health and environmental quality are fundamental to the economic efficiency goal, since they are highly valued. But economic efficiency incorporates other concerns as well because air pollution policy affects other outcomes of major concern, such as our economic standard of living.

We develop information using a variety of methods.

Pursuing economic efficiency means trying to get the maximum social benefits for any given social costs. To provide policymakers with information about the social costs and benefits of California's LDV strategy for reducing emissions, we

- developed an economic framework for identifying costs and benefits that should be considered in evaluating components of California's LDV strategy;
- reviewed and critiqued the most informative or influential published and unpublished studies of various elements of California's LDV strategy;
- interviewed analysts and stakeholders from government, industry, environmental groups, and research organizations to locate and interpret information;
- applied standard economic principles to interpret data and estimate effects;
- characterized ranges of reasonable disagreement about key estimates;
- developed models to predict the costs, emission reductions, and market effects of various components of the strategy;

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[2] The California Air Resources Board is currently reviewing the ZEV mandate. Significant modifications appear likely, but no final decisions have been made.

- accounted for interdependencies among policies by analyzing elements under various alternative assumptions about the effectiveness of other elements;
- developed qualitative and quantitative estimates of market responses to different elements of the strategy and drew inferences about how these responses will affect costs, their distribution, and, indirectly, emissions;
- identified issues that have not been addressed and analyzed them qualitatively;
- identified other issues that may be important but about which we have essentially no information.

Table 1 provides an overview of our analyses, listing the key studies we reviewed involving costs or emission reductions, identifying sources of such information not contained in written reports, describing how we examined some interdependencies between elements, and explaining how we examined market effects.

Table 1 provides an overview of our analyses.

DEALING WITH UNCERTAINTY

The economic effects of the policies under review involve very considerable uncertainties about the costs of achieving emission reductions in various ways—emission reductions that will result from various policies, performance of machines and people, reactions of markets, and means of reducing ozone that are not part of the California LDV strategy. We deal with uncertainties as we can with the information available.

The effects of the strategy involve many economic uncertainties.

In some contexts we merely note the existence of an uncertainty that seems important and describe its apparent sources. Other times we characterize the degree of uncertainty verbally. In many cases we attempt to reduce uncertainty by developing new information or integrating old information in informative ways. Often, we attempt to quantify the degree of uncertainty; sometimes we display quantitatively the range of disagreement about various costs and benefits and analyze the sources of the disagreement.

We quantify uncertainty when we can.

When the available information enables us to do so, we develop ranges within which we are very confident a true value lies. We refer to the end points of such ranges as *lower and upper bounds*. In some cases, the quantities we bound have been estimated by others; in others, we estimate bounds on quantities not estimated in other studies, starting with ranges of estimates for underlying parameters taken directly, or adjusted, from other studies. We do not emphasize or choose particular values within such ranges; rather, we explain our methods in sufficient detail to allow readers to develop the economic implications of parameter values that *they* think are particularly plausible.

When data permit, we develop ranges about which we are confident.

Table 1

OVERVIEW OF ANALYSES PERFORMED

Element of California Strategy	(1) Studies of Costs and/or Emission Reductions Reviewed	(2) Interdependencies Examined (method)	(3) Market Effects Examined (method)
A. Policies Aimed at Next-Generation ICEVs			
TLEV, LEV, ULEV, EEE, ORVR, OBD II	CARB (1989, 1990, 1994a,b, 1995a), Sierra (1994a,b), Chrysler, Ford, GM, Honda[a]	I&M (sensitivity analysis), interaction of ORVR and Stage II vapor recovery nozzles (qualitative discussion)	Ranges of short-run effects on prices of ICEVs, losses to buyers, and lost profits (calibrated supply and demand models), effects on fleet turnover and emissions (qualitative analysis drawing on other empirical studies)
B. Policies Aimed at Existing and Future ICEVs			
CP2G	Battelle (1995), Burns et al. (1995), CARB (1991, 1995b); Sierra (1994a)	ICEV hardware costs (qualitative discussion), certification standards (review of quantitative estimates)	Effects of gasoline price increase on vehicle miles traveled (estimated gas price increases combined with estimated demand elasticities)
Smog Check II	Aroesty et al. (1994), Glazer et al. (1995), Klausmeier et al. (1995), Sommerville (1993)	OBD II (qualitative discussion)	Effects on scrapping of older vehicles and prices of newer vehicles (qualitative discussion)
AVR	Alberini et al. (1994), Sierra (1995), Hahn (1995), Engineering-Science (1994)	I&M (qualitative discussion)	In-migration and prices of older vehicles over time (qualitative supply and demand analysis)
C. The Zero-Emission Vehicle Mandate			
ZEV Mandate	Abacus (1994), Booz-Allen (1995), CARB (1994a,b), GAO (1994), Kalhammer et al. (1995), Moomaw et al. (1994), Sierra (1994a,b), Chrysler, Ford, GM[a]	Effectiveness of ICEV emission control program; NMOG standard (sensitivity analysis)	Ranges of short-run gains to EV buyers, price increases of ICEVs, losses to ICEV buyers, profit effects (calibrated supply and demand models), effects on fleet turnover and emissions (qualitative analysis drawing on other empirical studies)

[a] Interviews of motor vehicle manufacturers are listed separately because they provided estimates not reported in any written study reviewed. We also conducted interviews with authors of many studies we did review, such as CARB, Sierra Research, Inc., and GAO.

Wise policymaking also requires attention to non-economic uncertainties.

Other major uncertainties do not involve economics but are crucial to wise policymaking. These include uncertainties about factors underlying the emission reduction targets in the SIP, including: the links between emission levels and ozone levels, current levels of emissions, and the proportionate emission reductions needed to meet air quality goals. We do not analyze non-economic uncertainties; however, it is important to keep them in mind when evaluating policies designed to achieve emission reduction targets based on such estimates.

FOUR VERSIONS OF THE POLICY PROBLEM

Our analysis serves the needs of different policymakers.

The economic challenges—and consequent information needs—of policymakers differ, depending on their constituencies and on the degree of latitude they have in pursuing economic efficiency. California policymakers are concerned primarily about costs and benefits to Californians, whereas federal policymakers represent the interests of all Americans. California policymakers and federal regulators are required to achieve compliance with the NAAQS. But these standards, which are created by federal policy, can also be changed by the Congress, which has the latitude to base air quality standards on economic efficiency.

These different constituencies and degrees of latitude underlie four versions of the policy problem, described in the cells of Table 2. Our analyses provide information relevant to all four versions.

Table 2

FOUR VERSIONS OF THE POLICY PROBLEM

	Degree of Latitude in Pursuing Economic Efficiency	
Constituency	Ozone Standard Given (e.g., CARB)	Ozone Standards Can Be Changed (e.g., U.S. Congress)
California residents	NAAQS attainment in California at minimum cost to Californians	Reduce emissions in California only when extra costs to Californians are less than extra benefits to Californians
All U.S. residents	NAAQS attainment in California at minimum cost to all U.S. residents	Reduce emissions in California only when extra costs to U.S. residents are less than extra benefits to U.S. residents

CONCEPTUAL FOUNDATIONS OF OUR ANALYSIS

Current estimates suggest that the social benefits of reducing ozone emissions in the South Coast range from $5,000 to $25,000 per ton of ROG plus NOx.

The social costs of emissions are the value of the damage—to health, vegetation, etc.—they cause. The social benefits of *reducing* emissions, then, are the value of the damages thereby avoided. Existing studies suggest that the benefits of reducing emissions in the South Coast Air Basin are likely to exceed $5,000 per ton of ROG plus NOx emissions, perhaps by a substantial amount, but are probably less than $25,000. Studies also suggest that these benefits may be almost as high in Sacramento as in the South Coast but are apparently much lower, possibly less than $1,000 per ton, in San Diego, Ventura, and San Francisco. We have not examined these studies in detail and do not view them as definitive. In our discussion we use these estimates to illustrate various points, but we encourage readers to adjust these numbers as they see fit.

WHY PRIVATE BEHAVIOR OFTEN WASTES CLEAN AIR

Clean air is wasted because polluters impose costs on others without bearing those costs themselves.

Air pollution poses an economic efficiency problem because people don't have the right incentives to consider the social costs of air pollution—which depletes clean air, a valuable resource—when they make decisions affecting air quality. Drivers, auto companies, oil companies, and others are often allowed to impose pollution costs on others without bearing the costs themselves. This encourages them to give too little consideration to the costs of pollution in choosing their actions. As a result, they waste clean air—i.e., they deplete this resource in situations where the social benefits of doing so are inadequate for this depletion to be efficient.

To give an idea of the extent to which incentives are distorted, we used estimates of damage costs per ton to consider the extent to which drivers of LDVs may impose costs on others. For example, in the South Coast, drivers of vehicles with average levels of emissions impose costs on others of roughly $500 per year. However, drivers of vehicles with unusually high emissions can generate pollution costs of $10,000 or more per year. Since they don't bear these costs, we expect that they fail to take actions to reduce emissions that would be well worth the costs to society as a whole.

Correct incentives would induce efficient actions.

Correcting incentives and using market forces to spur efficient responses is one approach to encouraging people to consider the social costs of air pollution when they make decisions affecting air quality, and thereby to promote economic efficiency. For example, if we required people to pay the costs of their air pollution, would we find them scrapping vehicles with emission problems more costly to repair than the vehicles are worth, driving fewer miles, and carpooling more often? Would they be willing to pay enough to cover the costs of cleaner fuels, vehicles with more durable emission-control systems, and zero-emission vehicles?

The results of efficient regulations would mimic people's actions if they had the right incentives to reduce pollution.

California does not take this approach, possibly for good reason.[3] Rather, California directly regulates the behavior of drivers, auto and oil companies, and others. However, if they are to be economically efficient, such "command and control" policies should be designed to motivate drivers and auto and oil companies to behave the way they would if the market gave them the right incentives.

COST-BENEFIT ANALYSIS

Cost-benefit analysis is designed to evaluate whether policies promote economic efficiency.

Economics provides a widely accepted conceptual foundation for understanding the nature of social costs and benefits and, in turn, the efficiency consequences of public policies, such as those to reduce air

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[3] For example, accurately measuring emissions on a vehicle-specific basis is not feasible, and it is unclear how well feasible programs could correct incentives and how much they would cost.

pollution. Determining the efficiency of policy options involves identifying and quantifying social benefits and costs.

The *social costs* of a policy to reduce air pollution include all of its socially undesirable effects, whether or not these effects are intended. The costs include *resource costs*—the costs of resources absorbed by a policy—and *reductions in well-being* (for example, inconvenience).

The *social benefits* of a policy to reduce air pollution include any ways that members of society are made better off, whether intended or not. The policies in the California LDV strategy are intended to make people better off by reducing ozone levels. But these policies may have other important desirable effects—for example, reductions of pollutants other than ozone precursors, such as carbon monoxide. *All* socially desirable effects of these policies should be considered in an economic evaluation of them.

A policy promotes efficiency only if—and to the extent that—social benefits exceed social costs. Recognizing and considering all costs and benefits is crucial, but assigning dollar values to all costs and benefits is very difficult if not impossible. Cost-effectiveness analysis is an attempt to finesse this difficulty.

A policy is efficient if its social benefits exceed its social costs.

COST-EFFECTIVENESS ANALYSIS OF OZONE-REDUCTION POLICIES

In cost-effectiveness analysis of ozone-reduction policies, a surrogate for benefits—tons of emissions reduced—is used for actual benefits (e.g., asthma episodes avoided) and an attempt is made to compare policies in terms of costs per ton of emission reduction.

Cost-effectiveness analyses aim to compare policies in terms of costs per unit of benefit.

Virtually all of the studies we reviewed that attempt to evaluate elements of the California strategy summarize their results in cost-effectiveness terms. Usually the analysis involves four steps:

- estimating the costs per vehicle of a policy action during some time period;
- estimating the reductions in emissions of ozone precursors per vehicle affected by the policy;
- multiplying each of the per-vehicle figures by the number of vehicles projected to be affected by the policy to obtain projections of total dollar costs and tons of emission reductions;
- computing a cost-effectiveness ratio by dividing the total dollar costs by the tons of emission reductions (expressed in dollars per ton).

The *higher* this ratio, the *less* attractive a policy appears to be because it costs more per unit of benefit.

As we detail presently, the studies we reviewed generally fail to consider—and do not claim to consider—some types of costs and benefits. For example, different studies address behavioral responses of individuals to different degrees and usually ignore market responses. To remind the reader of such limitations, we refer to such studies as *narrow* cost-effectiveness analyses, and to the cost-effectiveness ratios they produce as *narrow* cost-effectiveness ratios (NCERs).

Different studies purporting to estimate cost effectiveness for California ozone-reduction policies take account of different costs and emission reductions. The nature of these costs and emission reductions differs substantially from one policy element to the next, and to a lesser, but still considerable, extent from one study of a particular element to the next. We define the terms *direct costs* and *direct emission effects,* respectively, as those costs and emission changes that the NCER for a particular element is intended to incorporate. Generally speaking, we define direct costs and direct emission reductions for a particular element to correspond to what most or all of the studies of that element that we reviewed appear to take into account in analyzing cost effectiveness. For each element, we explicitly define what we mean by direct costs and direct emission effects.

NCERs alone provide an inadequate foundation for policy choice.

Information on direct costs and emission reductions and their relative sizes can be very useful for making policy decisions, but it is important to recognize their limitations. Why do NCERs by themselves provide an inadequate foundation for policy decisionmaking? The reasons include

- Tons of emission reductions of ozone precursors is a crude surrogate for benefits of ozone reduction, such as avoided damage to health and vegetation.
- Benefits include more than ozone reduction; for example, reductions of carbon monoxide.
- Much of the analysis of cost effectiveness focuses on the year 2010. Ozone levels before 2010 are not irrelevant, and ozone levels will very likely be a policy concern in the South Coast after 2010.
- The studies generally combine costs borne by Californians with costs borne by others, but different policymakers have different constituencies.
- Analysts usually ignore how markets will respond to the policies being evaluated, look at market responses naively, or fail to consider implications of these market reactions.

Nonetheless, NCERs are important for three reasons.

Despite their limitations, we devote substantial attention to estimated NCERs, and in some cases we present our own ranges of estimates. We highlight NCERs for three reasons:

1. The concept of cost effectiveness and studies purporting to estimate cost effectiveness are very influential with policymakers.
2. Most of the quantitative information useful for our purposes is imbedded in such studies.
3. If interpreted with care, cost-effectiveness calculations can be very helpful in making policy decisions.

MARKET RESPONSES TO POLICIES

The policies we analyze will generally affect market outcomes like prices and quantities sold. Such effects include, for example, how new vehicle sales and prices will be affected by certification requirements for new vehicles and how prices and number of older vehicles on the road in the South Coast will be affected by the AVR program. Analyzing such market-mediated effects helps us understand issue like

Market responses determine actual costs, how they are shared, and indirect effects on emissions.

- overall costs of the program (e.g., by determining how many vehicles with more advanced emission control systems are produced);
- distribution of costs inside and outside California (e.g., by determining how California new car buyers and automobile manufacturers share the additional production costs); and
- actual emission benefits (e.g., by determining how policies might slow the purchase of new vehicles and retirement of older vehicles, which leads to aging of the fleet and increasing fleet emissions).

ORGANIZATION OF THIS DOCUMENT

After presenting our findings on the costs and benefits of California's LDV strategy in Chapter 2, we propose and illustrate rules of thumb for using NCERs while taking explicit account of their limitations in Chapter 3. In Chapter 4, we discuss what our analysis suggests about future directions for California's zero-emission vehicle policy.

2. COSTS AND BENEFITS OF CALIFORNIA'S LIGHT-DUTY VEHICLE STRATEGY

Emissions from internal combustion engines—from exhaust, evaporation, and refueling—depend on a variety of technological, behavioral, and climatic factors. The current California LDV strategy, responding to historical difficulties in reducing emissions from all of these sources, takes a three-pronged approach:

California's strategy for reducing light-duty vehicle emissions has three prongs.

- Many of the regulations require *improvements in next-generation ICEVs*—i.e., ICEVs that have yet to be built.
- Other policies seek to reduce emissions from existing and future ICEVs.
- *The ZEV mandate*—a major departure from the past—seeks to displace ICEVs with vehicles that can't emit directly.

We discuss our findings on the costs and benefits of each of these prongs in turn.

Tables 3 and 4 summarize our findings, which are discussed below. Table 3 collects and explains the NCERs that we derived—in various ways—from the sources indicated in Table 1. Table 3 reports ranges of NCER estimates, where they are discussed or presented in our technical report (Dixon and Garber, 1996), how they are derived, the definitions of direct cost and emission effects, key uncertainties underlying the estimates reported, and the major costs and benefits not included. Table 4 summarizes conclusions about how markets will respond to the elements of the California strategy, what these responses imply, where these effects are discussed or presented in the technical report, and what the major sources of uncertainty are.

POLICIES AIMED AT NEXT-GENERATION ICEVs: KEY FINDINGS

The elements of the California strategy designed to lower emissions from LDVs that have yet to be built are

Some elements of the strategy are designed to reduce emissions from next-generation ICEVs.

- new fleet-average NMOG standards for tailpipe emissions, involving the new vehicle certification categories of TLEVs, LEVs, and ULEVs;
- new standards for evaporative fuel emissions (EEE);
- requirements for on-board recovery of fuel vapors during refueling (ORVR); and

- new standards for on-board monitoring of emission-control systems (OBD II).

We refer to these elements as hardware-based.

The *direct costs* of these regulations are defined as the extra resources used to design, produce, and install the hardware (and computer software) to meet regulatory requirements. Like all direct cost estimates, these costs are counted without regard to who ultimately bears them. *Direct emission* reductions are decreases in ROG and NOx emissions that would result if the policy were to have no effect on the number of vehicles sold.

These hardware-based elements may increase production costs $200 to $1,000 per vehicle.

Analyses of estimates by CARB and Sierra Research, a well-known consulting firm, suggest that the hardware-based elements of the California LDV strategy taken together may increase production costs per vehicle by as little as $200 to as much as $1,000 relative to a vehicle meeting 1993 California emission standards. We view these cost estimates as lower and upper bounds.

Estimates of emission reductions vary dramatically.

The principal reasons for the discrepancy between these estimates are: whether they are based on companies with the lowest or average compliance costs; what is assumed about the extra hardware required; and what is assumed about whether hardware upgrades will be incorporated during regular vehicle redesign cycles.

CARB and Sierra estimates of emission reductions for the new tailpipe, EEE, and ORVR elements vary as much as three-fold.[4] The principal reasons for the difference are

- whether the estimates are based on the emission models developed by CARB or by U.S. EPA, which differ especially on projected rates of deterioration; this affects estimated emission effects roughly two-fold;
- whether the vehicles are assumed to last for 100,000 or 150,000 miles; this affects estimated emission effects roughly 50 percent; and
- the assumed effectiveness of Smog Check II; this interaction affects estimated emission effects of the new hardware-based elements by roughly 25 percent.

Emission effects of hardware-based elements are too uncertain to support construc–tion of upper and lower bounds.

We conclude that available estimates for emission reductions do not provide an adequate basis for constructing upper and lower bounds. This is because the studies reviewed do not account for all of the major uncertainties. Most important, there is considerable uncertainty about actual emission levels of vehicles on the road today that is not reflected

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[4] Emission reductions from OBD II are discussed below.

Table 3

NARROW COST-EFFECTIVENESS RATIOS FOR ELEMENTS OF CALIFORNIA'S LDV STRATEGY: RANGES, SOURCES, DEFINITIONS, LIMITATIONS

Element	(1) NCER ($1000s/ton of ROG+NOx)	(2) Where Discussed in Report	(3) Source	(4) Costs and Benefits Included in Definition of Narrow Cost Effectiveness[a]	(5) Key Uncertainties About NCER	(6) Key Uncounted Costs and Benefits[b]
A. Policies Aimed at Next-Generation ICEVs						
TLEV LEV ULEV	3–40 1–38 22–48	Sec. 6.3 Table 6.3-1	Derived from studies reviewed	Costs: R&D, production, and selling costs Benefits: emission reductions (costs and benefits both relative to next most stringent exhaust standard)	Accuracy of emission models, emission system deterioration rates, cost estimates	Effects on fleet turnover, location and time of emission reductions
EEE	0.5–3	Sec. 6.3 Table 6.3-1	Derived from studies reviewed	Costs: R&D, production, and selling costs Benefits: emission reductions relative to 1993 California vehicle	Accuracy of emission models, emission system deterioration rates, cost estimates	Location and time of emission reductions
ORVR	infinite	Sec. 6.3 Table 6.3-1	Derived from studies reviewed	Costs: R&D, production, and selling costs Benefits: emission reductions when Stage II vapor recovery nozzles also used	Interaction of ORVR and Stage II vapor recovery nozzles	Costs of modifications to underground storage tanks
OBD II	2–15?[c]	Sec. 8.3.2	Taken directly from studies reviewed	Costs: R&D, production, and selling costs Benefits: emission reductions with enhanced I&M	Behavioral response to check-engine light, effectiveness of Smog Check II	Repair costs, decreased time needed to diagnose malfunctions, costs and benefits of increased durability of emission-control system
B. Policies Aimed at Existing and Future ICEVs						
CP2G	9–46	Sec. 8.1.3	Derived from studies reviewed	Costs: R&D, production, and reduced fuel efficiency Benefits: emission reductions for fixed number of miles driven	Effects on vehicles certified on CP2G, change in effectiveness as vehicles age	Reduced costs of ICEV hardware, emission reductions due to reduced driving
Smog Check II	0.5–5.5?[c]	Sec. 8.2.3	Taken directly from studies reviewed	Costs: inspection, repair, driver time, administration Benefits: emission reductions of repaired vehicles	Extent of evasion, effectiveness of remote sensing, extent emission variability hinders identification of high emitters	Driver aggravation
AVR	2–10[d]	Sec. 8.4.3 Table 8.4-4	Taken directly from studies reviewed	Costs: lost transportation services, program administration Benefits: emissions avoided on scrapped vehicles net of emissions from replacement transportation	Emissions of replacement transportation, remaining lifetimes of scrapped vehicles	In-migration, responses to incentives for higher emissions, reductions in Smog Check evasion
C. The Zero-Emission Vehicle Mandate						
ZEV Mandate	5–1,197	Sec. 10.4 Table 10.4-1	Modeling and sensitivity analysis based on data derived from studies reviewed	Costs: R&D, production, and lifetime operating costs in near- and long-term Benefits: ICEV emissions directly displaced by EVs	Initial EV costs, decline in costs over time, effectiveness of ICEV emission control program, how manufacturers adjust ICEV fleet	Costs of managing reduced range, infrastructure costs, benefits of home refueling and quiet of EVs, effect on fleet turnover, ICEV mileage displaced per EV

[a] NCERs include costs borne both inside and outside California.

[b] In addition to the reductions of emissions other than ROG and NOx such as CO, air toxics, or particulates.

[c] We have very little confidence that the NCER is in or near this range.

[d] In contrast to other non-hardware elements of the California strategy, the NCER for AVR does not purport to incorporate behavioral effects.

Table 4

SUMMARY OF MARKET-MEDIATED EFFECTS, 1998 TO 2002

Element	(1) Findings on Market-Mediated Effects	(2) Where Discussed in Report	(3) Key Sources of Uncertainty
A. Policies Aimed at Next-Generation ICEVs			
ICEV hardware	ICEV prices will increase $100–$500/vehicle ICEV sales will fall 10K–60K vehicles/year ICEV buyers will lose $150M–$700M/year Manufacturers and dealers will lose $100M–$800M/year	Table 7.2-2	Effects of regulations on variable production costs
	Emissions may increase in early years due to reduced fleet turnover	Sec. 7.4	Size of price effects
B. Policies Aimed at Existing and Future ICEVs			
CP2G	Vehicle miles traveled will fall 1.5–4 percent Emissions will fall by comparable amounts or more	Sec. 9.1	Size of gasoline price increases
AVR	In-migration, price increases of older vehicles, or both will occur; lack of price increases would be a bad sign about in-migration	Sec. 9.3 Appendix 9.A	Barriers to in-migration, elasticity of demand for older vehicles
C. The Zero-Emission Vehicle Mandate			
ZEV Mandate	EV prices may be as much as $10,000 less than comparable ICEV	Table 11.5-1	Lifetime operating cost disadvantage of EVs
	EV buyers will gain $20M–$200M/year	Table 11.5-2	Willingness of EV buyers to pay premium over ICEV prices
	Producers may lose as much as $1.5B/year or profit as much as $350M/year in the EV market	Table 11.5-2	EV production costs, EV prices
	ICEV prices will increase $0–$550/vehicle	Table 11.6-1	Variable costs and prices of EVs, Big 7 pricing policies
	ICEV sales will fall 0–110K vehicles/year	Table 11.6-1	ICEV price increases, degree EV sales displace ICEV sales
	ICEV buyers will lose $0–$800M/year	Table 11.6-1	Variable costs and prices of EVs, Big 7 pricing policies
	Big 7 will lose $100M–800M/year in the ICEV market	Table 11.6-1	Degree EV sales displace ICEV sales
	Other ICEV companies may lose up to $60M/year or gain $550M/year in the ICEV market	Table 11.6-1	Big 7 price increases, whether other companies match Big 7 price increases
	California consumers may gain up to $200M/year or lose up to $750M/year	Table 11.7-1	Variable costs and prices of EVs, Big 7 pricing policies
	Emissions may increase in early years due to reduced fleet turnover	Sec. 11.8	Size of ICEV price effects

NOTE: K = thousand; M = million; B = billion.

in either emission model. We thus cannot be confident that any particular estimated emission effect is almost surely too high or too low.

Panel A of Table 3 presents and elaborates on the narrow cost-effectiveness ratios (NCERs) for the regulations aimed at next-generation vehicles. We draw the following conclusions:

Estimated NCERs for different hardware-based policies range from very low to moderate to high.

- Relative to other hardware measures, projected NCERs for EEE standards are low and do not vary a great deal across the studies reviewed ($500 to $3,000 per ton of ROG plus NOx).
- There appears to be general agreement that federal ORVR requirements are, at best, redundant given that Stage II nozzles are used to pump most gasoline in California.
- There is wide variation across the studies reviewed on the NCERs of TLEVs relative to 1993 California vehicles and LEVs relative to TLEVs. The estimated NCERs for ULEVs relative to LEVs are higher ($22,000 to $48,000 per ton of ROG plus NOx), but vary less across the studies reviewed.
- Because of the uncertainty over emission reductions, we do not think these figures represent ranges into which the NCERs will almost certainly fall.

NCERs for hardware-based policies exclude several factors.

As emphasized throughout the report, NCERs do not provide a complete basis for policy decisions, no matter how accurately they estimate what they set out to estimate. As indicated in the last column of Table 3, the NCERs for the hardware-based elements of the strategy do not account for pollutants other than ROG and NOx; the times and locations where emissions will be reduced; and the effect of increases in vehicle prices on new car sales, with consequent effects on fleet turnover and, thus, emissions. They also do not consider important factors such as the distribution of costs across stakeholders.

We estimate how the hardware-based elements will affect prices and sales of new ICEVs and costs to sellers and buyers.

As summarized in Panel A of Table 4, we analyzed the likely market reactions to the regulations aimed at next-generation vehicles to better understand the distribution of their costs inside and outside California and indirect emission effects. Using lower and upper bounds for direct variable cost estimates, we estimate that the hardware-based elements of the strategy could

- increase the average selling prices of new LDVs in California by $100 to $500 per vehicle;
- decrease new LDV sales in California by up to 4 percent;
- cost new car buyers in California somewhere between $150 million and $700 million per year; and
- cost vehicle manufacturers and California dealers between $100 million and $800 million per year in profits.

Such potential declines in new car sales and associated delays in the retirement of older vehicles due to the regulations suggest that estimates of direct emission reductions may greatly overstate actual emission reductions. We review and apply estimates of fleet-turnover effects on emission levels from other studies. We conclude that if the price increases for new ICEVs are close to $500—the high end of the range we estimate—then the new regulations could actually *increase* emissions for roughly three to five years and substantially attenuate direct emission benefits of the regulations for several years more. Available information does not allow us to gauge the effects of ICEV price increases of substantially less than $500 on fleet turnover and emissions, but the magnitude of the effects will vary directly with the size of the price increases.

The hardware-based elements may increase emissions for a few years because of market effects.

POLICIES AIMED AT EXISTING AND FUTURE ICEVs: KEY FINDINGS

Some non-hardware-based elements of the strategy are designed to reduce emissions from both existing and future ICEVs:

Other elements of the strategy are aimed at existing and future ICEVs.

- California's Phase 2 gasoline (CP2G) will be used in vehicles of all vintages and emission levels.
- Smog Check II aims to identify and repair problems in vehicles of all vintages.
- The accelerated vehicle retirement (AVR) program aims to scrap older vehicles with especially high emission levels.

We discuss the key findings for these elements in turn. They are summarized in Panels B of Tables 3 and 4. We also discuss the emission effects and NCERs for OBD II in this section because of its interdependency with Smog Check.

CALIFORNIA PHASE 2 GASOLINE

The direct costs of California's CP2G are its extra production costs and a small gas mileage penalty. These costs are likely to amount to 7 to 19 cents a gallon.

Direct costs of California's Phase 2 gasoline are likely to be between 7 and 19 cents per gallon.

We define the direct emission effects to be emission reductions in all vehicles assuming no change in vehicle miles traveled due to increased gasoline prices. The studies reviewed suggest that CP2G will reduce ROG and NOx emissions by up to 25 percent for some vehicles currently on the road, but because the percentage reductions appear to vary substantially depending on model year and accumulated mileage, the percentage reduction for the entire fleet may be significantly less. The studies also suggest that CP2G will reduce emissions by about 20 percent in new vehicles certified on CP2G.

Direct emission reductions might be as much as 20 percent.

Estimates of the NCER for California's Phase 2 gasoline range from $9,000 to $46,000 per ton.

As reported in Table 3, the studies reviewed suggest an NCER between $9,000 to $46,000 per ton of ROG plus NOx. This large range reflects variation in estimates of direct costs and variation in estimates of emission reductions that project emission effects for the whole fleet based on testing CP2G in a small number of vehicles. The $46,000 figure may be far above the actual NCER because it is based on a study that attributes no emission reductions to vehicles certified on CP2G.

Because certification tests will use CP2G, hardware costs of vehicle emission-control systems may be reduced. The narrow cost-effectiveness ratios do not count any such cost savings, and we have no basis for quantifying them.

Reduced travel could further reduce emissions by 4 percent or more.

Market effects should complement the direct emission reductions. Increases in gasoline costs will increase gasoline prices. As indicated in Table 4, vehicle miles traveled—and emissions—could fall by 4 percent or more as a result of the price increases.

SMOG CHECK II

Repair costs are likely to dominate direct costs of Smog Check II.

Direct costs of Smog Check II include inspection costs, driver time costs, net repair costs, and administrative costs. No study has estimated the direct costs of Smog Check II, but Sommerville (1993) estimates the costs of similar changes to California's current program. We conclude that there is little reason to expect large changes in direct costs other than net repair costs. Net repair costs will increase to the extent that the program succeeds in inducing more repairs, which is highly uncertain.

Smog Check II may not work much better than the current inspection and maintenance program.

Consistent with studies reviewed, we define direct emission reductions to include behavioral responses to the program. Our analysis suggests that Smog Check II may not be much more effective in reducing emissions than the current, highly criticized, program.

- Fraud may be lower in Smog Check II's test-only facilities only if they are very closely monitored.
- Gaps in the current test procedure are not remedied (e.g., emissions are still not tested when the vehicle is cold).
- The effectiveness of remote sensing in real-world situations has yet to be demonstrated.
- Higher repair limits may increase evasion.

A study by the Radian Corporation (Klausmeier et al., 1995) suggests that Smog Check II will eliminate substantially more emissions than the current program does. But assumptions about the amount of fraud in the new program, the effectiveness of remote sensing, and mechanics' performance in repairing vehicles may cause Radian to overestimate actual emission reductions.

As reported in Table 3, NCERs estimated for programs similar to Smog Check II vary from $500 to $5,500 per ton of ROG plus NOx. We are not at all confident that the actual NCER of Smog Check II will fall in or near this range. As noted in Table 3, NCERs for inspection and maintenance programs are especially unreliable because, unlike NCERs for many other policy elements, they attempt (to varying degrees) to incorporate behavioral responses, such as attempts to evade the program.

We are skeptical of the estimated NCERs for Smog Check II.

ON-BOARD DIAGNOSTICS II

Direct costs of On-Board Diagnostics II (OBD II) include the hardware and software development and production costs and the net costs of repairs resulting from information OBD II supplies. Direct emission effects of OBD II are those resulting from repairs caused or made more effective by this technology. We define direct costs and direct emission reductions of OBD II to include behavioral responses of drivers and smog-check technicians.

The studies reviewed do not provide a reliable basis for estimating NCERs for OBD II. For example, they do not appear to incorporate repair costs induced by OBD II. They also do not analyze the response of drivers or smog-check technicians to the check-engine light. They assume either that drivers will bring in vehicles for repair whenever the check-engine light illuminates or that technicians will repair whatever causes the light to illuminate.

Existing studies put the NCER for OBD II between $2,000 and $15,000 per ton of ROG plus NOx (see Table 3). However, uncertainties like those discussed above lead us to conclude that this range provides little information about what the NCER for OBD II will actually turn out to be.

Because existing studies don’t account for repair costs and behavioral responses, we are skeptical of the estimated NCERs for On-Board Diagnostics II.

Our discussions with vehicle manufacturers suggest that OBD II regulations may already be improving emission-control systems. Manufacturers want very much to keep check-engine lights off because of potential warranty costs, adverse effects on their reputations, and emission-related recalls. These are powerful incentives to design and build properly functioning and durable emission-control equipment. However, these costs and benefits are not counted in the NCERs for OBD II.

On-Board Diagnostics II may already be improving emission control systems.

ACCELERATED VEHICLE RETIREMENT

Direct costs of the scrappage program—transportation services lost from scrapped vehicles and program administration costs—are likely to be in the range of $700 to $1,000 per vehicle scrapped.

Direct costs of the scrappage program are likely to be $700 to $1,000 per vehicle scrapped.

Direct emission effects are the emissions that scrapped vehicles would have produced minus the emissions generated from replacement transportation. We are unable to gauge the reliability of existing projections of direct emission effects, partly because they depend crucially on aspects of the program that have yet to be determined—for example, program eligibility rules, how vehicles will be recruited, and rules governing offers.

Estimated NCERs of the scrappage program are relatively low, but . . .

As reported in Table 3, the NCERs for AVR programs found in the studies reviewed range from $2,000 to $10,000 per ton of ROG plus NOx. These figures may turn out to be informative, but they fail to address several key issues. For example, the AVR program might improve the effectiveness of Smog Check II by giving owners of high emitters an attractive alternative to fraud.

. . . potential in-migration of older vehicles into the South Coast and perverse incentives make program effects very uncertain.

The NCER estimates also do not attempt to account for widely recognized, but poorly understood, potential market and behavioral responses. Contrary to high hopes, the program should be expected to cause migration of older vehicles into the South Coast *and,* unless the program is ineffective, to increase the prices of older vehicles. Such price increases are generally thought of as troubling; however, if prices do not rise, this would mean that scrapped vehicles are being replaced by in-migration. Regarding individual behavior, offers to buy high emitters—if generous enough to achieve participation goals—could induce some owners to delay scrapping or emission repairs or even to tamper with their vehicles to make them dirtier. Major uncertainties about in-migration and behavioral responses—resulting partly because crucial aspects of the program have yet to be determined—leave us with little confidence about the effects of the AVR program.

DISPLACING ICEVs WITH ZERO-EMISSION VEHICLES: KEY FINDINGS

Although the ZEV mandate does not specify the technology to be used, it is widely accepted that, over the next decade or more, only electric vehicles (EVs), powered by batteries, could enable automobile manufacturers to comply with the mandate. Therefore, our analysis focuses on battery-powered EVs.

Often we distinguish between the first five years of the mandate (1998 to 2002) and the longer term because of the extreme uncertainties after 2002. Our findings on EVs are summarized in Panels C of Tables 3 and 4.

EV CHARACTERISTICS

The battery is the key source of uncertainty about EV operating cost, driving range between charges, and consumer acceptance. For the first few years of the mandate, EVs are expected to use lead-acid batteries, which will allow substantially less than 100 miles of driving range on each charge if vehicle accessories like defrosters, heaters, and air conditioners are used. These batteries are viewed as a transitional technology by almost everyone. Advanced batteries that could double or triple the range currently possible with lead-acid batteries could be available as soon as the year 2000, but only if no unforeseen technical difficulties are encountered in battery development, evaluation, or manufacturing.

In the first few years of the mandate, EVs will use lead-acid batteries—a transitional technology.

All the evidence suggests that the EVs the Big 7 will market under their own names during the early years of the mandate will be as similar as possible to their ICEVs of comparable size and body style.

Under the mandate, companies have alternatives to producing EVs and offering them for sale.

Companies subject to the mandate have alternatives to producing and selling EVs: producing and offering EVs, but not selling them; paying fines of $5,000 for each unit of the mandate not otherwise satisfied; and buying EV credits from other companies that sell EVs. Credits might be generated by companies converting ICEVs to EVs or producing niche-market vehicles with very limited speed, size, or range.

Our analysis leads us to expect that it would make little sense for companies to produce but not sell EVs and that companies will not rely heavily on paying fines. Our analysis also raises strong doubts that the firms subject to the mandate in 1998 will satisfy a substantial fraction of their mandates (more than 10 percent, say) by buying credits. A major reason is that sales of EVs by firms initially subject to the mandate will decrease the prices for EVs offered by firms not subject to the mandate and thus their incentives to produce EVs and EV credits.

A small fraction of the EVs will be produced by converters and niche-vehicle producers.

We also conclude that if the Big 7 do buy a large number of credits between 1998 and 2002, the most important source of credits is likely to be those ICEV companies that are not subject to the mandate until 2003. The characteristics of the vehicles are also expected to be similar to those produced and sold by the firms initially subject to the mandate.

Most EVs produced because of the mandate will be as similar as possible to ICEVs of comparable size and style.

EV COSTS

Direct costs include the (variable and fixed) production costs of EVs produced because of the mandate and their lifetime operating costs relative to those of the ICEVs they are assumed to displace. Costs of battery-charging infrastructure—which we do not address—are also direct resource costs of EVs.

From 1998 to 2002, EVs will cost more to produce than comparable ICEVs.

Production costs of EVs will likely be considerably more than those for comparable ICEVs during the first five years of the mandate (1998–2002). Production costs will be higher because

- EVs produced by the Big 7 will include special components such as heavy-duty suspensions and brakes and high-efficiency accessories like power steering and air conditioning;

- Many EV components are new and manufacturers have not learned how best to make them;
- EVs will involve much smaller production runs than is typical in the industry.

Additional variable production costs are likely to be between $3,300 and $15,000 per EV.

The lower and upper bounds that we develop for incremental variable production costs of a typical EV during the first five years of the mandate—excluding any batteries—are $3,300 and $15,000 per vehicle. This wide range reflects major intrinsic uncertainties and disagreements among studies. The $3,300 figure seems too optimistic because it omits the costs of several important EV components and uses optimistic assumptions about the costs of the components it does include. The $15,000 figure seems too pessimistic because manufacturers may find less costly ways to produce EVs than they have discovered to date. Moreover, if incremental costs turn out to be that high, other things equal, manufacturers can be expected to buy more credits from converters and niche-vehicle producers.

Operating costs of EVs include all batteries, fuel, repair, and maintenance.

The lifetime operating costs of an EV—relative to a comparable ICEV—depend on

- The cost of all batteries required during the life of the EV;
- The cost of electricity relative to that of gasoline over the life of the vehicle; and
- EV repair and maintenance costs relative to those of ICEVs.

EVs produced from 1998 to 2002 will likely cost $3,000 to $13,000 more to operate over their lifetimes than comparable ICEVs.

We developed a model relating the present value of incremental EV operating costs to the values of six parameters and projected incremental costs using ranges of parameter values found in the studies reviewed. We concluded that discounted lifetime EV operating costs—including all batteries—will likely exceed those of comparable ICEVs by $3,000 to $13,000 per vehicle for EVs purchased between 1998 and 2002. We ascribe roughly 90 percent confidence to this range.

ZEV mandates in three states may involve total direct costs of $2.9 billion to $12.3 billion between 1998 and 2002.

The studies reviewed suggest that incremental fixed costs of the ZEV mandate may well fall between $1.0 billion and $4.2 billion. When combined with estimates of incremental variable production costs and lifetime operating costs, these figures imply that if the mandates in California, New York, and Massachusetts remain in place, the total direct cost of the mandates is likely to be between $2.9 billion and $12.3 billion during 1998 to 2002.

EV costs should fall over time, but it's unclear how much and how quickly.

EVs are an immature technology and ICEVs are not. Given time, the production and operating costs of EVs—relative to ICEVs—are likely to decline. How quickly and how much are very uncertain. Production cost disadvantages may disappear over time. But our analysis indicates that even in the long term, EVs will continue to involve lifetime operating cost disadvantages relative to ICEVs of between $1,000 and $6,500 per vehicle. A key reason is the likelihood of substantial battery costs even in the long term.

Studies of declines in prices of new products in various industries over time suggest that EV production costs may fall 10 to 25 percent with each doubling of cumulative output. We use this range in our analysis, but further analysis is needed to better understand what rates are most relevant for EVs.

EMISSION REDUCTIONS DUE TO THE ZEV MANDATE

We consider two scenarios concerning emissions of ICEVs directly displaced by EVs.

Direct emission reductions attributable to the ZEV mandate are decreases in ROG and NOx emissions assuming that EVs produced because of the mandate displace ICEVs and their miles driven one-for-one.

Emission reductions due to EVs—which will displace ICEVs—depend on the effectiveness of the ICEV control program. We estimate the emission benefits of EVs using two scenarios for the effectiveness of the ICEV control program. In the effective scenario, the ICEVs displaced by EVs emit at the (low) rates predicted by CARB for next-generation vehicles. In the ineffective scenario, ICEV emissions are set at levels currently estimated for 1993 vehicles, which many analysts believe are too low.[5]

We also account for the interaction of ZEVs and the NMOG standard.

When EVs are introduced, manufacturers can continue to meet the NMOG standard by slightly increasing the average exhaust emissions of their remaining ICEVs. We take account of these potential adjustments, which would offset some of the emission benefits of EVs.

Each EV may reduce emissions by 51 to 579 lb of ROG plus NOx.

Different scenarios about how companies adjust their mixes of TLEVs, LEVs, and ULEVs combined with various scenarios for the effectiveness of the ICEV program lead us to use a range of direct lifetime emission reductions due to EVs of 51 to 579 pounds of ROG plus NOx for each ICEV displaced.

NARROW COST-EFFECTIVENESS RATIOS OF ELECTRIC VEHICLES

The NCER for EVs is the ratio of the present value of direct costs to direct emission reductions. In addition to the factors discussed above, the NCER for EV depends on

- The number of EVs sold. Mandated EV production tops out at 10 percent of LDV sales in 2003, but sales could be higher than that. If so, fixed costs will be spread over more units and variable costs will fall faster.

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[5] Using these estimates allows that the ICEV control program will reduce emissions somewhat if current emission estimates for California 1993 vehicles are too low.

- The time period over which costs and benefits are considered. EVs further out in time have lower production and operating costs.
- The discount rate used to express future values in present value terms. This affects the NCER because many of the costs of a vehicle occur before it produces any emission benefits.

We calculate NCERs for EVs using ranges for nine factors.

We developed a model to project future direct costs and emission reductions due to EVs. Because of uncertainty about the values of key parameters, we used the model to calculate the NCERs for different combinations of values developed from several types of information. Table 5 summarizes the ranges used in our analysis. We briefly describe the ranges not discussed above.

We use fleet penetration rates up to 40 percent to illustrate the sensitivity of NCERs to EV sales. We calculate NCERs for three time horizons: first, for all vehicles produced through 2010, because federal law requires compliance with ozone standards by 2010; second, up through 2020, because other technologies or emission-control strategies may make battery-powered EVs irrelevant at some future date such as 2020; and third, from 1998 on into the indefinite future, because this captures all potential future direct costs and emission reductions. We refer to NCERs incorporating the indefinite future as *long-term* narrow cost-effectiveness ratios. We vary the real (inflation-adjusted) discount rate between 3 and 5 percent—rates typical of those in the studies reviewed.

Table 5

RANGES OF PARAMETER VALUES USED TO CALCULATE ELECTRIC VEHICLE NARROW COST-EFFECTIVENESS RATIOS

Parameter	Range
Incremental EV variable production cost, 1998–2002 ($/vehicle)	3,300–15,000
Eventual incremental EV variable production cost ($/vehicle)	0
Incremental EV lifetime operating costs, 1998–2002 ($/vehicle)	3,000–13,000
Eventual EV incremental lifetime operating cost ($/vehicle)	1,000–6,500
Rate of decline of EV production and operating costs after 2002 (percent decline each time cumulative output doubles)	10–25
Incremental EV fixed production cost, 1998–2002 ($ billions)	1.0–4.2
Percent decline in incremental EV fixed cost in each subsequent five-year product cycle	50
ICEV emissions displaced during an EV's lifetime (pounds ROG + NOx/vehicle)	51–579
Long-term fleet penetration of EVs (percent)	10–40
Time horizon	1998–2010 1998–2020 1998–on
Real (inflation-adjusted) discount rate (percent per year)	3–5

As Table 6—which reports an illustrative selection of our NCER calculations—shows, the NCER for EVs could be very high or very low.

The NCER for EVs could be as low as $5,000 or as high as $1.2 million per ton of ROG plus NOx.

For example, as shown in the top right cell of Panel A of Table 6, we calculate a long-term NCER—i.e., based on an unlimited time horizon—of $5,000 per ton of ROG plus NOx when initial EV costs are low, costs decline quickly, emission reductions are large, fleet penetration remains at 10 percent, and the discount rate is 3 percent. In contrast, as shown in the third row of the last column in Panel B, long-term cost effectiveness is almost $850,000 per ton of ROG plus NOx when initial costs are high and decline slowly, emission reductions are low, fleet penetration remains at 10 percent, and the discount rate is 5 percent.

As can be seen from comparing the third and last columns, NCERs increase by 40 to 100 percent when the time horizon is shortened from the long-term to only 2010. The NCERs we calculate are as high as $1.2 million per ton when the costs and benefits of vehicles sold only through 2010 are considered.

Even if the true NCER of the ZEV mandate were known, the economic efficiency of the mandate depends on various factors ignored or uncounted in the definition of the NCER, including infrastructure costs, effects on ICEV fleet turnover, and ICEV mileage displaced per EV.

Table 6

SELECTED NARROW COST-EFFECTIVENESS RATIOS
FOR ELECTRIC VEHICLES

		NCER ($1000/ton ROG+NOx)		
Fleet Penetration in 2020 (percent)	Emissions Directly Displaced per Vehicle (lb ROG+NOx)	Through 2010	Through 2020	Long-Term (Unlimited Time Horizon)
A. Low Initial Cost, Fast Cost Decline[a]				
10	579	10	8	5
10	158	38	28	20
10	51	119	87	62
10	368	16	12	9
20	368	15	10	7
40	368	13	9	7
B. High Initial Cost, Slow Cost Decline[b]				
10	579	105	90	74
10	158	386	328	273
10	51	1,197	1,017	845
10	368	166	141	117
20	368	158	126	100
40	368	146	110	84

[a] Calculated using 3 percent discount rate.

[b] Calculated using 5 percent discount rate.

POTENTIAL MARKET EFFECTS OF THE ZEV MANDATE 1998 TO 2002

As summarized in Panel C of Table 4, we also performed extensive quantitative analyses of the potential effects of the ZEV mandate on California markets for EVs and ICEVs.

We quantify market-mediated effects of the ZEV mandate through 2002.

Market effects of the mandate both through 2002 and after 2002 may be very important. Because of extreme uncertainties about market developments after 2002—due to extreme uncertainties about the development of EV technology, especially battery technology—we attempt to quantify market effects only for the period 1998 to 2002. In the long term, the market effects of the ZEV mandate could fall into a very wide range.

We estimate ranges for several outcomes during 1998 to 2002 that are of considerable interest to policymakers. Key underlying factors are actual variable production costs of EVs, discussed above, and EV marketability.

To sell the mandated quantities, EVs—without any batteries—may be priced as low as $10,000 less than comparable ICEVs.

The marketability of EVs during 1998 to 2002 depends on how potential buyers evaluate EV performance and what they anticipate about the costs of owning and operating EVs relative to the costs of ICEVs. EVs have both marketing advantages and disadvantages relative to ICEVs, the most important being the convenience of home refueling and limited driving range, respectively. Studies we reviewed suggest that if EV infrastructure and range improve according to somewhat optimistic assumptions, the mandated quantities of EVs could be sold if the costs of purchasing and operating EVs are equal to those of comparable ICEVs. Taking account of the range of EV operating cost disadvantages discussed above, gasoline taxes, and a 10 percent federal tax credit for EV purchases, we conclude that during 1998 to 2002, typical EVs—not including any batteries—may sell for as much as the price of comparable ICEVs to as little as $10,000 below that price.

Several groups have much to gain or lose from the ZEV mandate.

As can be seen from Table 4, the market effects of the ZEV mandate cannot be pinned down at all precisely, but they might be very considerable for various groups, such as California EV and ICEV buyers, the Big 7 and other ICEV companies, and California light-duty vehicle dealers. We developed extensive information on the sources of uncertainties underlying the ranges reported in Table 4, and what determines the actual outcomes.

EV buyers could be big gainers. The profitability of selling EVs depends on production and operating costs.

California EV buyers can be expected to benefit by as much as $200 million per year from the mandate because it will cause high-quality EVs to be available at competitive prices. If EV production and operating costs turn out to be near the high ends of our ranges, the Big 7 could lose as much as $1.5 billion per year in the EV market. If these costs turn out to be at the low end of our ranges, the Big 7 could make profits of up to $350 million per year in the EV market, ignoring any lost profits from ICEV sales displaced by EV sales.

The ZEV mandate may have major effects on the California ICEV market.

The mandate could affect the market for ICEVs in two ways. First, EV sales will displace ICEV sales according to how many EV buyers would have bought new ICEVs if it weren't for the enhanced availability of EVs. Lost ICEV sales translate into lost profits for ICEV manufacturers and their California dealers. The second way is more subtle, but no less real. Because the mandated quantities for Big 7 companies are set as percentages of their LDV sales, whenever a Big 7 company sells additional ICEVs, it is obligated to sell additional EVs. (For example, during 2001 and 2002—when the mandate is at the 5 percent level—a Big 7 company is obligated to sell one more EV every time it sells an additional 19 EVs.) If the cost of producing and selling an additional EV is higher than the price at which it can be sold—as may or may not turn out to be the case—or if companies buy credits or pay fines to cover additional obligations under the mandate, then selling additional ICEVs involves an implicit cost due to the requirement to sell more EVs. Such an implicit cost of ICEVs may—depending on company pricing policies—lead to increases in ICEV prices.

The ZEV mandate could increase emissions in the short term.

We conclude that ICEV prices may be unaffected by the ZEV mandate, but they might increase by as much as $550 per vehicle. Potential price effects translate into losses to ICEV buyers of up to $800 million per year and sales declines of up to 110,000 ICEVs per year. As in the case of the effects of the ICEV hardware regulations, price increases of several hundred dollars per ICEV could—by reducing new ICEV sales and slowing the retirement rates of older ICEVs—increase LDV emissions for roughly three to five years and reduce the direct emission benefits of ZEVs for several more years.

The costs and benefits of the ZEV mandate are extremely uncertain.

In sum, while the stakes are high, the costs and benefits of the ZEV mandate cannot be pinned down at all precisely. Important uncertainties include the development of battery technology, EV production and operating costs, how far and how quickly costs decline, market acceptance of EVs, how well other policy elements control emissions from ICEVs, and how the mandate affects ICEV prices.

3. GUIDELINES FOR USING DISPARATE INFORMATION TO MAKE POLICY DECISIONS

We have proposed and analyzed economic efficiency as the policy goal of the California ozone-reduction strategy. As the discussion in Chapter 2 demonstrates, the efficiency consequences of the various elements depend on disparate considerations. Some of the costs and benefits have been quantified much more precisely or convincingly than others. Other costs and benefits have not been quantified at all. Costs and benefits that have been quantified seem to get predominant emphasis in policy deliberations, but they are not necessarily of paramount importance.

We propose rules of thumb for assessing policies.

We can't tell policymakers what to decide, but we do suggest a method for using the limited, disparate information available. To that end, in this chapter we propose some rough rules of thumb for using NCERs and other relevant information to decide whether a policy element promotes economic efficiency in the South Coast Air Basin.

RULES OF THUMB FOR DECIDING WHETHER POLICIES MAKE GOOD ECONOMIC SENSE

Three steps for interpreting and integrating information:

Gauging the economic efficiency of policy elements requires policymakers to interpret and combine the kinds of information summarized in Tables 3 and 4. We propose three steps for proceeding systematically. We detail these steps and suggest what we have contributed to implementing them:

Step #1: Determine your narrowest plausible range for the NCER.

> Step 1: *Use your beliefs about factors underlying the NCERs—based on information about the reliability of the data and methods used—to determine the narrowest range that you find plausible.*

We have contributed to this step by providing the kinds of information summarized in Columns (1), (4) and (5) of Table 3. Specifically, we have clarified what particular NCERs purport to measure, pointed out potential sources of inaccuracy, and analyzed what underlying conditions would be required for a true NCER to lie in a particular range.

Step #2: Assess the relative importance of uncounted costs and benefits.

> Step 2: *List the potentially important costs and benefits that are not accounted for in the NCERs you have, consider what you know about them, and form as precise a judgment as you can about the relative magnitudes of uncounted costs and uncounted benefits.*

We have contributed to this step by identifying uncounted costs and benefits (see Column (6) of Table 3) and by analyzing several of them, most notably market-mediated effects (see Table 4).

Step #3: Apply rules of thumb like those in Table 7.

Step 3: *Consult Table 7, with the dollar values modified to your liking, which provides some rough rules of thumb for the South Coast.*

The numerical values for NCERs shown in Table 7 are based on current estimates of benefits of emission reductions. As discussed in Chapter 1, we do not view these estimates as definitive and encourage policymakers to adjust them as they think appropriate.

Different policymakers should use different decision rules.

The decision rules differ depending on whether the policymaker is free to pursue economic efficiency or is legally obligated to reduce emissions by a certain number of tons. We first consider the decision rules for policymakers free to pursue economic efficiency (first column of Table 7). Current estimates for the South Coast suggest that benefits of ROG and NOx emission reductions are probably more than $5,000 per ton but below $25,000. NCERs of roughly $10,000 per ton, then, might be taken to mean that a policy is efficient as long as uncounted costs appear not to be much larger than uncounted benefits. If the NCER is considerably less than $10,000 per ton—say, $5,000—a less optimistic assessment about uncounted benefits relative to uncounted costs is required for a policy to be judged efficient. If the NCER is considerably more than

Table 7

ILLUSTRATIVE RULES OF THUMB FOR USING NARROW COST-EFFECTIVENESS RATIOS TO CHOOSE OZONE-REDUCTION POLICIES FOR THE SOUTH COAST

If you think the NCER is about:	And you are free to pursue economic efficiency, then:	And you must find more tons of reductions, then:
$5,000/ton or less	Implement the policy unless uncounted costs appear to far outweigh uncounted benefits	Implement the policy unless uncounted costs appear to far outweigh uncounted benefits
$10,000/ton	Implement the policy as long as uncounted costs appear not to much outweigh uncounted benefits	Implement the policy unless uncounted costs appear to far outweigh uncounted benefits and alternative ways to reduce tons look even less promising
$25,000/ton	Don’t implement the policy unless uncounted benefits appear to far outweigh uncounted costs	Don’t implement the policy unless uncounted benefits appear to outweigh uncounted costs or alternative ways to reduce tons look even less promising
$50,000/ton or more	Don’t implement the policy unless uncounted benefits appear to outweigh uncounted costs by tens of thousands of dollars per ton	Don’t implement the policy unless uncounted benefits appear to far outweigh uncounted costs and alternative ways to reduce tons look even less promising

$10,000 per ton—say, $25,000—a much more optimistic assessment of uncounted benefits relative to uncounted costs is required.

Rules proposed for policymakers who must find more tons of emission reductions are based on adjusting the rules for the policymakers free to pursue efficiency. Two major considerations guide the adjustments: (a) attainment of air-quality goals in the South Coast at some point may require adopting measures whose costs exceed their benefits, and (b) in such cases, it is especially important to consider alternative ways to get the same tons of reduction. Thus, compared with the rules in the first column of Table 7, the rules proposed for policymakers who must meet emission-reduction targets require less optimistic assessments of uncounted benefits relative to costs for any given NCER level, but these rules also explicitly remind the policymaker to consider alternatives when leaning toward implementing policies that appear to be inefficient.

The inevitable imprecision of rules such as those described in Table 7, while regrettable, highlights some key realities:

- Even though we'd like to know a lot more before making a decision, decisions must be made.
- Economical decisionmaking cannot be reliably reduced to precise rules in the context of the policies we are analyzing.
- NCERs contain useful information, but they often ignore important costs and benefits that are no less relevant merely because they are uncounted.
- We may know a lot or very little about costs and benefits that are uncounted in the NCERs.
- Policymakers obligated to meet emission-reduction targets (e.g., California policymakers in obeying federal law) may need to adopt measures that policymakers free to pursue economic efficiency would not.
- Even policymakers obligated to meet emission-reduction targets should strive to do so in the most efficient way.

Decisions that combine all key factors— including some requiring judgment— should be superior to decisions relying solely on numbers that ignore important factors.

We offer these rules in the belief that decisions made systematically considering all of the relevant issues—even if that requires considerable judgment about factors that are uncounted, unquantified, unquantifiable, or even effectively imponderable—will tend to turn out better than decisions based on mechanical processing of numbers that fail to account for many relevant factors.

AN EXAMPLE OF USING THE RULES OF THUMB

An example of our rules in action: comparing two types of next-generation ICEVs.

Consider how our rules of thumb might be implemented when considering the incremental costs and benefits of producing ULEVs rather than LEVs.

Step 1. As shown in Table 3, the information we adapted from other studies leads us to an NCER range of $22,000–$48,000 per ton of ROG plus NOx from reducing exhaust emissions from LEV to ULEV levels. Recall that the NCERs include costs borne both inside and outside California. Uncertainty about the range reflects disagreement between CARB and Sierra studies of the incremental production cost of additional hardware to upgrade LEVs to ULEVs and, perhaps more important, uncertainties about the deterioration rates of ULEVs relative to LEVs and the effectiveness of Smog Check II.

A policymaker who thinks that the CARB cost estimates are more reliable, that ULEV deterioration rates will be lower than LEV deterioration rates, and that Smog Check II won't be very effective might settle on an NCER near $25,000 per ton of ROG plus NOx. A policymaker who thinks the Sierra estimates are more reliable, that Smog Check II will be quite effective, and that ULEVs will deteriorate no less rapidly than LEVs might settle on a value near $50,000 per ton of ROG plus NOx as a reliable indicator of the true NCER.

Step 2. Whatever value for the NCER you think most appropriate, consider what the NCER for the ULEV standard does not include—for example, as indicated in Column (6) of Table 3, how market-mediated effects could affect fleet turnover and emissions and the extent to which emission reductions will occur in non-attainment areas during times of the day and seasons when ozone levels are unlikely to cause damage. Consider how the incremental costs of ULEVs might affect prices and sales levels of ICEVs in California and the profits of manufacturers and their dealers.

California policymakers are likely to emphasize the costs borne by Californians. Federal policymakers are likely to focus on costs to all Americans. Form a judgment about the factors that your NCER doesn't consider at all. Are the costs likely to outweigh the benefits, or vice versa? By a lot? A little?

Step 3. Suppose you are a California policymaker, needing to find tons of emissions to reduce, and you think that—after adjusting for costs borne outside California—$25,000 per ton is a reliable estimate of the NCER and that the price and fleet turnover effects of ULEVs rather than LEVs are very minor. Unless you have preferable ways to reduce the tons you think that ULEVs will provide, you may well conclude that ULEVs are an economical means of moving towards compliance. In contrast, suppose you are a federal policymaker, free to adjust the ozone standard, and you think that $50,000 per ton is a reliable estimate of the

NCER and that the price and fleet turnover effects of ULEVs rather than LEVs are quite large. You might well conclude that ULEVs are economically inefficient and that if California doesn’t have better options than ULEVs for achieving compliance with the federal ozone standards in the South Coast, then perhaps the standards should be relaxed in the South Coast.

4. WHAT DOES ECONOMIC ANALYSIS SUGGEST ABOUT ZEV POLICY?

In this final chapter, we discuss what our analysis suggests about policies regarding zero-emission vehicles. We take the perspective of policymakers who must reduce emissions in the South Coast to achieve federal ozone standards. To put ZEV policy in perspective, we begin by considering how effective the other prongs of the California strategy will be.

HOW WELL WILL THE CALIFORNIA STRATEGY CONTROL ICEV EMISSIONS?

Our analysis suggests that there is considerable justification for wondering how much the first two prongs of the California strategy will reduce emissions of ozone precursors from light-duty ICEVs. We briefly highlight some reasons for concern.

There are major pitfalls in the new certification, warranty, and recall regulations . . .

New hardware certification requirements will almost certainly reduce emissions from newer vehicles under operating conditions reflected in the driving cycle used in vehicle certification tests. California's recall and warranty programs provide powerful incentives for manufacturers to build more durable emission-control systems. But these programs do not address some important sources of emissions. Certification requirements do not address emissions that occur during operating conditions that are not part of emission-system certification tests. Recall and warranty programs do not address emissions after warranty and recall periods expire or emissions due to tampering, poor maintenance, and other damage to emission control systems. OBD II, Smog Check II, and the scrappage program target these sources of emissions, but there are major threats to their effectiveness.

. . . in on-board diagnostic systems , . . .

OBD II could pay enormous dividends, but only if behavioral pitfalls are avoided and perhaps only after the technology matures. Its effectiveness will depend on the little-understood responses of drivers and smog-check technicians to the check-engine light.

. . . in smog check , . . .

To date, California’s experience with vehicle inspection and maintenance programs—like experience elsewhere—has been very disappointing. Smog Check II could make a real difference, but past difficulties indicate that success is hardly assured. High-emitters are such a high priority that Herculean efforts to make smog check work are warranted. But we should recognize that even Herculean efforts may fail.

. . . and in the scrappage program.

The scale and duration of the South Coast scrappage program are unprecedented. Depending on design and implementation decisions yet to be made, the program could be a great success or a great failure. Achieving success will take substantial ingenuity, and efforts to achieve too much could backfire. If the scrappage program is eviscerated by perverse incentives or in-migration, NCERs of less than $10,000 per ton—which ignore behavioral and market responses—will be little consolation.

The ZEV mandate is an alternative to our historically problematic reliance on controlling emissions from ICEVs.

California policymakers who must reduce emissions face a dilemma:

- Part of the required emission reductions must come from LDVs;
- Efforts to control in-use emissions have not nearly eliminated emissions due to component aging, tampering, poor maintenance, damage, and aggressive driving;
- Dramatic future reduction in emissions from these sources is far from assured.

This dilemma suggests *consideration* of alternatives to controlling ICEV emissions. One such alternative is the third prong of the California strategy—the ZEV mandate. What does our analysis imply about ZEV policy?

PUTTING THE ZEV MANDATE IN PERSPECTIVE

The ZEV debate is often more dramatic than insightful.

Like many high-stakes, polarized policy debates, the debate over the ZEV mandate includes many rallying cries that are more dramatic than insightful. Before we consider what economic analysis of the ZEV mandate tells policymakers, we comment on some rhetoric that we think impedes useful dialogue and policy deliberation:

- **"The market has spoken."** Some argue that if EVs were economical, then they would already be marketed. This argument should not be taken seriously because current estimates of benefits of reducing emissions suggest that private incentives to reduce pollution are far below what is socially optimal.
- **"California consumers will pay the entire cost" or "Vehicle manufacturers will pay the entire cost."** Substantial portions of the costs of EVs will fall on both California consumers and vehicle manufacturers and their California dealers.
- **"We must do anything to move us toward attainment."** Some argue that we must do anything possible to meet the ozone standard in the South Coast. This argument should also not be taken seriously—attainment would not be hard to achieve if we did not care about costs.
- **"We must not do anything that is very costly."** This claim would be valid only if there are inexpensive ways to achieve air pollution goals or if there are not major benefits to improving air quality. Neither proposition has been demonstrated.

MAJOR RISKS IN ZEV POLICY

The long-term economic effects of the ZEV mandate cannot be pinned down at all precisely. As suggested by various scenarios we used to calculate NCERs, the mandate might be very beneficial or very detrimental. In short, the ZEV mandate could turn out to be a great success or a great failure.

This uncertainty does not imply, however, that California policymakers should forget about ZEVs; without ZEVs California might also face very undesirable policy choices. To highlight this possibility, consider the following pessimistic—but not inconceivable—scenario as 2010 approaches.

Both keeping the current mandate and eliminating it altogether pose major risks for California.

Suppose California were to repeal the mandate and, as a plausible—yet not inevitable—consequence, ZEV technology stagnates. Suppose further that the first two prongs of the current ozone-reduction strategy don't work very well, that new economical emission-control options have not been discovered and that, a few years before 2010, California finds itself far short of meeting federal ozone standards in the South Coast. To make matters worse, suppose also that the health effects of ozone are found to be much more deleterious than currently thought, and as a result, relaxing air quality standards appears reasonable to almost no one.

Under these circumstances, and perhaps even less extreme ones, California would find itself desperately seeking ways to reduce emissions of ozone precursors and finding only additional measures that are extremely expensive, such as very aggressive transportation control measures or even restrictions on industrial activity. In sum, there are great risks both to proceeding with the ZEV mandate in its current form and to repealing it and doing nothing else to encourage ZEV development.

Policymakers should consider alternatives.

Are there other courses of action that don't involve such big risks?

ZEV POLICYMAKING SHOULD ACCOMMODATE UNCERTAINTY, NOT DENY IT

Major uncertainties pervade the issues we have analyzed. We don't know how well the first two prongs of the strategy will work. We don't know what we will learn about health and other damage due to ozone. We don't know lots of things that would determine the outcomes of mandating commercialization of ZEVs in 1998. Battles of competing yet confident estimates—which have characterized much of the debate over the ZEV mandate—encourage policymakers to choose estimates and proceed as though the chosen estimates are reliable. For example, choosing estimates suggesting that the mandate will succeed could lead to a decision to proceed with the mandate, and estimates suggesting that it will fail could lead to a decision to repeal it and do nothing else to encourage ZEV development. However, we have seen that estimates of the costs and benefits of the ZEV mandate are subject to enormous uncertainties and that there are major risks from both proceeding with the mandate and repealing it altogether. ZEV policy is better made by facing the reality of extreme uncertainties and accommodating it rather than denying it.

We need not decide long-term ZEV policy in the short term.

It is crucial to recognize that now, in 1996, we need only decide how to proceed over the near term, until a few years into the next century, say. We need not decide whether or how California policy will address ZEVs beyond such a time horizon.

Near-term ZEV policy should promote learning, avoid the biggest risks, and allow mid-course corrections.

The uncertainties and risks involving ZEVs suggest that in considering modification to the mandate we should be searching for near-term ZEV policies with three key characteristics.

- **Learning.** Policy should be designed with learning as an interim objective. As new information becomes available, the most promising set of policies should become better defined.
- **Robustness.** Near-term policy should be formulated while recognizing that very undesirable outcomes—economic, environmental, or both—are possible. Thus, policy should be formulated with specific attention to worst-case scenarios and policy paths that avoid the worst of the worst. Such policies are often referred to as “robust” policies.
- **Adaptability.** As we learn about various factors, we want to be in a position to use this information to improve policy. Policies that can be adjusted as new information arrives are often referred to as “adaptive.” In thinking about adaptation, it is important to recognize that flexibility in future policymaking brings with it costs of uncertainty to those who must anticipate future policy when they plan and invest.

FOUR PRINCIPLES FOR FORMULATING NEAR-TERM ZEV POLICY

The ZEV mandate is currently under review and revisions seem very likely. We conclude by suggesting four principles that could help in this process.

California’s ZEV policy should promote learning about the long-run prospects of EVs, . . .

1. ZEV policy should aim to determine whether EVs are a promising cornerstone of California’s long-term ozone-control strategy. Determining this requires learning about many different things, including

- performance, cost, and availability of EV technology;
- consumer evaluation of EV performance;
- effectiveness of current ICEV emission control measures;

- cost and effectiveness of alternative LDV emission-control measures, such as new transportation control measures or taxes aimed at vehicle-specific emission levels; and
- cost and effectiveness of policies aimed at sources of emissions other than LDVs, such as heavy-duty vehicles and stationary sources.

. . . protect those prospects, . . .

2. ZEV policy should protect the long-term prospects for ZEVs. Although we are agnostic about whether EVs should be a cornerstone of California's LDV strategy, we think it very important to protect the long-run prospects for EVs. EVs may turn out to be attractive on cost and performance grounds, and for this reason it is critical to avoid near-term developments that would constrain our ability to rely on them in the long term. Both market and political factors are relevant here.

On the market side, we need to be concerned about how the mandate or its modification could affect the behavior of both consumers and innovators over the long term.

ZEV policy should consider the potential for consumer disappointment with EVs due to limited range, reliability, or infrastructure. Such disappointment could give EVs a bad name and create long-term difficulties in marketing even EVs that would not disappoint consumers. If EVs do turn out to be economical, higher market penetration rates could be the key to getting large quantities of emission reductions from them. This underscores the importance of preserving the long-run marketability of EVs and making sure they don't become the Edsel of the 1990s.

ZEV policy should also consider how revising the mandate will affect the future willingness of innovators to invest. This calls for striking a careful balance between flexibility and predictability in policy formulation. For example, whatever the outcome of the current review of the mandate, it would be helpful if CARB would announce future times at which the policy will be reviewed and indicate the major factors that will be considered.

On the political front, it is also important to consider how the mandate might affect CARB's ability to adopt innovative policies in the future. If CARB promotes a policy now that turns out to be wasteful, it may not be able, for example, to promote EVs in the future even if technological developments make EVs a good bet.

. . . give ample scope to a broad range of vehicles and innovators, . . .

i3. ZEV policy should accommodate a broad range of vehicles and innovators because the most promising path to widespread EV use is far from clear. We should be wary of policies that unduly emphasize one type of vehicle or one type of innovator. For example, some believe that the most promising path to major emission reductions from EVs involves important roles for small EVs (e.g., niche vehicles such as neighborhood electric vehicles). However, these are not the type of vehicles that will be produced by the Big 7 in the early years of the mandate. Although the ability to sell credits may encourage the production of non-Big 7 EVs, other things equal, the mandate itself may stifle consumer demand for non-Big 7 EVs by inducing the Big 7 to market very high-quality EVs at very low prices. The current mandate may thus give us little insight into what electric-drive transportation alternatives are most viable in the near term or into the long-term viability of electric-drive transportation generally.

. . . and seek lower-cost ways to meet these objectives.

4. ZEV policy should look for ways to lower the cost of achieving these objectives. For example, how can we learn more about the potential of advanced batteries while avoiding costs associated with commercialization of lead-acid batteries? What can we learn about consumer use of EVs and requirements for range without fielding a large fleet of EVs before the turn of the century? If the mandate is scaled back or delayed, are there cost-effective ways to make up any lost emission reductions? In view of potential market-mediated effects on fleet turnover and emissions, would there be any lost emission reductions?

Of course, such principles—if accepted—must be translated into policy actions. Doing so will require wisdom, energy, creativity, and cooperation.

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