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An Economic Analysis of Ozone Control in California's San Joaquin Valley

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and Richard E. Howitt**

This study estimates the benefits to agriculture and human health of reducing ozone in the San Joaquin Valley of California, and the costs of ozone control. The San Joaquin Valley's highly valued crops suffer from high ozone levels. Federal and state primary ozone standards are based on health effects, not effects on other sectors, and do not consider costs of attaining the standards. The methods here allow comparison of both total and marginal benefits and costs. The results suggest that net gains can be achieved for the entire valley by reducing ozone below 1990 levels, although results vary by region.

Key words: air pollution, benefit-cost analysis, human health, ozone, San Joaquin Valley

Introduction

As urban and suburban development has extended into agricultural regions, air pollution associated with that development has begun to have significant effects on agricultural production (Adams, Hamilton, and McCarl). This problem has become acute enough in California to elicit agency attention; it foreshadows problems in other agricultural areas in which intensive agriculture is in close proximity to urban development. This case study considers the San Joaquin Valley of California, a region which produces about 60% of California's total crop production in value (California Department of Food and Agriculture). This region experienced ozone levels as high as 0.17 parts per million (ppm) in 1990, substantially exceeding the current health-based federal and state standards of 0.12 ppm and 0.09 ppm, respectively.¹ Crop damage occurs at ozone concentrations even lower than those standards; according to the California Air Resources Board (CARB 1987c), ozone-sensitive crops such as onions, lemons, beans, grapes, oranges, and cotton could experience yield losses at a 0.04 ppm

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¹ The 0.17 ppm observation is the peak concentration measured with a one-hour average. The primary federal ozone standard was amended (effective September 16, 1997) to be "an 8-hour standard at a level of 0.08 parts per million (ppm) with a form based on the 3-year average of the annual fourth-highest daily maximum 8-hour average O₃ [ozone] concentrations measured at each monitor within an area" [U.S. Environmental Protection Agency (EPA), p. 38856]. The 0.12 ppm standard, based on a one-hour average, is not directly comparable to the new 0.08 ppm standard. Because this analysis was originally conducted using the previous standard, the results obtained here do not relate directly to the new standard. For comparison, setting the standard at 0.09 with the new form of averaging "represents the continuation of the present level of protection" (EPA, p. 38858).

12-hour ozone standard (roughly equivalent to the 0.09 ppm one-hour ozone standard).² Thus, crop yields in some areas of California may be significantly affected even if the current ozone standard is attained.

Identifying the most efficient air quality standard is challenging for several reasons.³ First, measuring the benefits and costs of alternative standards with any degree of accuracy is difficult and highly controversial. Second, although the Clean Air Act sets national ambient air quality standards for major pollutants, from an efficiency perspective the optimal level of pollution is almost certain to vary across regions, due to different benefit and cost functions. Finally, how ozone is regulated (incentive approaches versus command-and-control) affects the costs of control, and thus affects the efficient standard.

A few studies in urban areas argue that the costs of achieving the federal ozone standard of 0.12 ppm may be higher than the benefits associated with that standard. Krupnick and Portney conducted a cost-benefit analysis of ozone control in the Los Angeles air quality control region. They estimated that reducing the ozone concentration to the federal standard results in annual benefits to human health and materials of about \$4 billion and annual control costs of about \$13 billion. Based on their estimates, the ozone standard may be too restrictive to maximize net benefits in that area.

These findings raise questions about the efficiency of a health-based uniform state ozone standard. In an agricultural region, a lower population density implies that the effects of ozone on human health may not be as extensive as in an urban area. On the other hand, the economic effects of ozone on agricultural production are almost certain to be larger than agricultural effects in an urban area. Whether control costs are likely to be higher or lower is an empirical matter.

This study estimates the agricultural and health benefits and control costs associated with alternative ozone standards in the San Joaquin Valley of California. The first two sections describe the estimation of benefits of ozone control on agriculture and human health. While these are not the only categories which benefit from ozone reduction, evidence suggests that other effects of ozone, such as impacts on structures and visibility, are relatively small. Next, the estimation of costs of ozone control is provided. Finally, the efficiency of alternative ozone standards as well as the distribution of costs and benefits are discussed. Unlike other benefit-cost analyses which focus on a specific standard, the development of marginal benefits and costs in this study permits an estimate of an efficient standard as well as a means to determine whether benefits outweigh costs.

The Effects of Ozone on Agriculture

The San Joaquin Valley of California, consisting of eight counties, is approximately 350 miles in length and 50 miles in width, with a climate of hot summers and rainy winters. About 3.5 million people reside in this area. Productive land allows this valley to produce about 60% of the value of total California crops, and approximately 9% of total

² The 12-hour ozone standard is the average of the peak ozone concentration per hour between 9:00 AM and 9:00 PM.

³ Whether an efficiency standard is even appropriate for setting air pollution regulations is highly controversial. Many argue that the standards should be set based purely on human health and environmental considerations, rather than on comparisons of benefits and costs. (A thorough discussion of this issue is provided in Arrow et al.)

Table 1. Ozone Standard Compliance in the San Joaquin Valley, 1990

County	Year Max. (ppm)	No. of Days Above:	
		0.09 ppm	0.12 ppm
Fresno	0.15	80	14
Kern	0.17	120	37
Kings	0.10	4	0
Madera	0.11	6	0
Merced	0.11	N/A	N/A
San Joaquin	0.13	17	1
Stanislaus	0.14	32	1
Tulare	0.17	132	5

Source: California Air Resources Board (1990a).

U.S. crops. Three counties in the San Joaquin Valley—Fresno, Tulare, and Kern—cultivate almost 30% of the total crop value produced in California.

The San Joaquin Valley is also the second worst air quality region in California. Ozone is formed in the atmosphere through a chemical reaction involving reactive organic gases (ROG), nitrogen oxides (NO_x), and sunlight. Each day, over 600 tons of ROG and 500 tons of NO_x are emitted into the air in the valley (CARB 1993). Table 1, showing ozone concentrations in the valley's eight counties in 1990, reveals that ozone concentrations in most of the counties were much higher than the state ambient standard of 0.09 ppm, and in fact were as high as 0.17 ppm (Kern and Tulare counties)—well above either the state or the national standards. These high concentrations can lead to vegetation damage because of reduced efficiency of photosynthesis. Crop losses due to high ozone levels are estimated to range from 8.4% for alfalfa hay to 32% for oranges (CARB 1987c).

Several economic analyses of air pollution's effects on crops have been conducted. Mathematical programming models of the economic effects of ozone on agriculture (Howitt 1992, 1989; Brown and Smith; Adams, Hamilton, and McCarl; Leung, Reed, and Geng) use a two-step procedure. First, the biological yield response functions, which measure the biological relationship between yields and ozone concentrations, are developed. In this study, the yield response functions summarized by CARB (1987c) are used to assess the yield losses to crops from ozone in the San Joaquin Valley (see Kim for a more detailed discussion). Then, those yield responses are included in an optimization model whose objective function is to maximize the sum of producer and consumer surplus under given physical, air pollution, and economic constraints. The increase in producer and consumer surplus with increased crop production represents the benefits of the ozone control.

The California Agriculture and Resource Model (CARM) (see Kim for a detailed description) was used in this study to predict producer and consumer surplus responses to alternative yield scenarios. CARM has been developed to predict profit-maximizing farmers' short-run acreage and production responses to changing market conditions or resource constraints (Howitt 1989; CARB 1987c; Goodman and Howitt). CARM allows

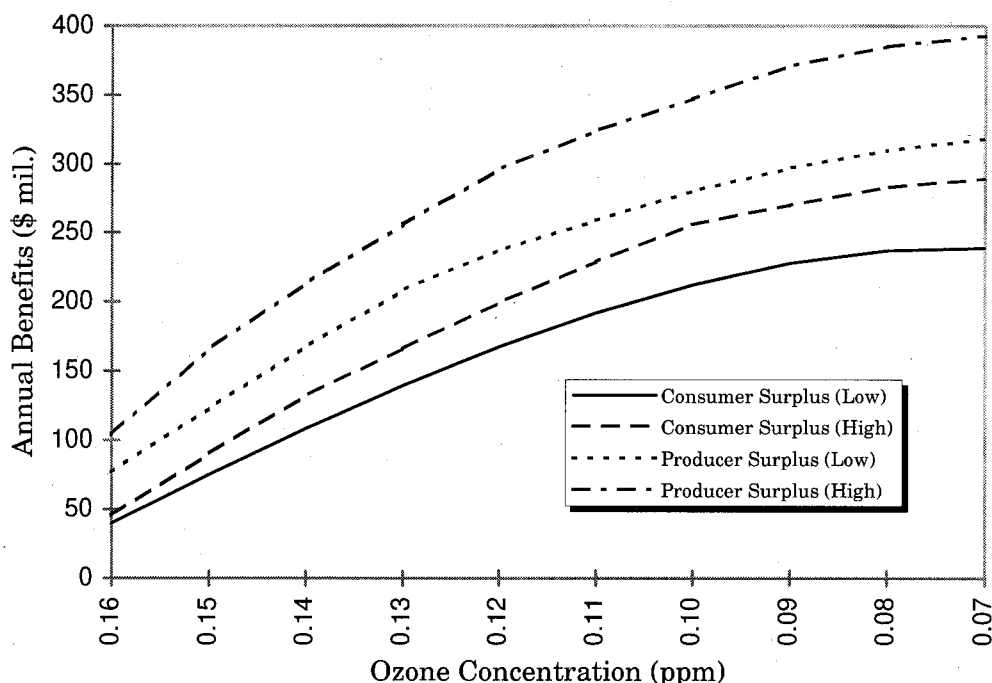


Figure 1. Annual agricultural benefits for ozone control in the San Joaquin Valley

farmers to substitute from more ozone-sensitive to less ozone-sensitive crops. The yield response functions for each crop (CARB 1987c) are used to calculate the percentage yield changes for meeting different ozone standards in the San Joaquin Valley. Because each county in the valley experiences a different level of ozone concentration, each will experience different percentage yield changes for each crop to meet a regional ozone standard.

The county yield responses are aggregated into each production region⁴ within CARM to estimate the total yield changes of each production region for different ozone standards in the valley. These percentage yield changes are used as supply shift factors⁵ in CARM to estimate changes in consumer and producer surplus.

Figure 1 presents the results of the economic analysis as changes in consumer and producer surplus. The high and low ranges are based on high and low estimates of yield responses to ozone from different studies.⁶ Increases in crop production do not always result in increased benefits to farmers, since market prices may decline due to production increases. In the San Joaquin Valley, the prices would not change significantly as a result of production increases in alfalfa hay, corn, cotton, and wheat; however, prices

⁴ CARM incorporates three San Joaquin Valley production regions: North, South, and Central San Joaquin.

⁵ This study is based on a partial-equilibrium model in which a reduction in ozone concentration proportionally shifts the agricultural supply function downward. The estimates of agricultural benefits of ozone reductions are affected by the nature of the supply shift; the assumption here of a proportional shift affects the results, leading to another source of uncertainty in the analysis.

⁶ Multiple yield-response studies are available for each crop. Each study for the same crop used a different experimental design to estimate changes in crop yields resulting from variations in ozone concentrations. The low and high bounds were considered because each study showed somewhat slightly different yield responses. (See Kim for a more detailed discussion.)

of grapes, lettuce, tomatoes, and citrus are more sensitive to production fluctuations. For example, because the San Joaquin Valley is responsible for more than 90% of total national production of all grapes, changes in production there would affect the market price of this crop.

The three major agricultural counties in the San Joaquin Valley—Fresno, Tulare, and Kern—earn about 65% of the producer surplus increase from ozone reductions. Other agricultural regions of California, such as the Sacramento Valley, experience lower market prices, and thus a reduced producer surplus, for some crops due to production increases in the San Joaquin Valley.

Our results show lower consumer surplus and higher producer surplus than found by Howitt (1992) at the California state level. Our findings are similar, however, to those of Adams, Crocker, and Thanavibulchai in their study of eliminating pollution for selected southern California crops, in that they show producer surplus gains larger than consumer surplus for this area in isolation. Howitt (1992) estimated an increase of \$274 million in consumer surplus and a \$214 million increase in producer surplus to meet a growing season 12-hour mean standard of 0.04 ppm (roughly equivalent to the 0.11 ppm standard in the current study).

It is worthwhile to describe differences in benefit estimates between this study and the two studies noted above. First, the current study arrives at the San Joaquin Valley standard by assuming that the air quality of other regions in California remains constant. The crop production increases resulting from ozone control in the valley are smaller than those that would result from controlling statewide ozone. Subsequently, the decreases in crop prices are relatively smaller in this study, which explains the smaller increases in consumer surplus. Second, the smaller decreases in crop prices provide for larger producer surpluses to farmers in the San Joaquin Valley, where the major production increases occur. This explains the larger producer surplus in the current study. Adams, Crocker, and Thanavibulchai found a similar pattern, where consumer surplus effects were larger for their entire study region than for the sum of individual regions in isolation.

Effects of Ozone on Human Health

High ozone concentrations can lead to a number of respiratory complications, including shortness of breath and coughing, and can severely affect some sensitive groups, such as asthmatics. High ozone levels also are suspected of contributing to increased mortality rates, but these effects are less understood (CARB 1987b). (An extensive review of the effects of ozone on human health is provided in McKee et al.) Willingness to pay (WTP) to avoid the adverse health effects of ozone often is approximated in two steps. First, ozone concentrations are related through epidemiological research to changes in respiratory symptom days. Next, the reduction in symptom days is multiplied by WTP to avoid symptom days. This study adapts existing studies on those data to circumstances in the San Joaquin Valley.

Several epidemiological studies (Krupnick, Harrington, and Ostro; Portney and Mullahy; Korn and Whittemore; Schwartz, Hasselbald, and Pitcher) have examined air pollution and its effects on respiratory symptom days. These studies estimated the probability that an individual would experience respiratory symptoms as a function of

a day's ozone concentration, meteorological conditions, and an individual's personal characteristics. The most useful analysis for the current study is the work of Krupnick, Harrington, and Ostro, which examined the daily health effects of excessive ozone exposure. Their study is based on a health data set collected by the California Air Resources Board and the Health Effects Research Laboratory of the U.S. EPA; it includes over 5,000 individuals' daily health status related to respiratory symptoms in the South Air Basin during the period September 1978 through March 1979. Their logit model estimates morbidity as a function of ozone level, meteorological conditions, other pollutant levels, and personal and socioeconomic characteristics of the study individuals. The authors found a significant relationship between daily respiratory symptoms in nonsmoking adults and ozone concentration for that day, but no significant relationship for children and smoking adults. They found that 3.8 million respiratory symptom days would be avoided through a 1% decrease in the nationwide average ozone concentrations in urban areas.

The health response functions estimated by Krupnick, Harrington, and Ostro were matched with the daily ozone concentrations, climatic and meteorological conditions, and personal characteristics in the San Joaquin Valley using data from several sources (U.S. Department of Commerce; California Department of Finance; and CARB 1990b). The average daily individual's health response function was estimated for each county in the San Joaquin Valley and multiplied by 365 days, and also multiplied by the adult population size of the county. The average health responses to ozone controls in the eight counties were added to produce changes in the number of respiratory symptom days due to reductions in ozone concentrations in the San Joaquin Valley.

The next step in the analysis is to value these changes in health. Contingent valuation studies (Loehman et al.; Tolley, Kenkel, and Fabian; Dickie et al.) have valued symptoms associated with ozone pollution. In these studies, individuals are asked to identify their WTP to avoid a respiratory symptom day. Contingent valuation studies are subject to a range of criticisms, including that their hypothetical questions can result in hypothetical responses (McFadden). While these weaknesses can be minimized by a well-designed questionnaire, WTP estimates from contingent valuation nevertheless may be viewed with a degree of skepticism.

Different contingent valuation studies (Loehman et al.; Tolley, Kenkel, and Fabian; Dickie et al.) for measuring WTP for avoiding one respiratory symptom day show similar magnitudes of median WTP estimates for the same symptom days, although their mean WTPs differ because of some high bids. Moreover, these contingent valuation studies have the same magnitude of WTP estimates as the cost-of-illness approach (Berger et al.), which estimates the direct monetary damage, including medical expenses and value of work loss, resulting from a respiratory symptom day associated with ozone exposure.

Median WTPs, rather than mean WTPs, are used in the valuation of respiratory symptoms in this study. Krupnick and Kopp believe that median WTPs are a better indicator of the unit value of respiratory symptoms because a range of unit WTPs for avoiding one respiratory symptom day was used to derive a range of health benefits. The lower bound is a WTP estimate of \$1.26 for coughing (drawn from Dickie et al.), while a WTP of \$25.20 for headaches (drawn from Tolley, Kenkel, and Fabian) was used as an upper bound of WTP for avoiding one respiratory symptom day. Because the Krupnick, Harrington, and Ostro health response equation does not distinguish among types of symptoms, it is more useful here to employ a range of WTPs than a single WTP.

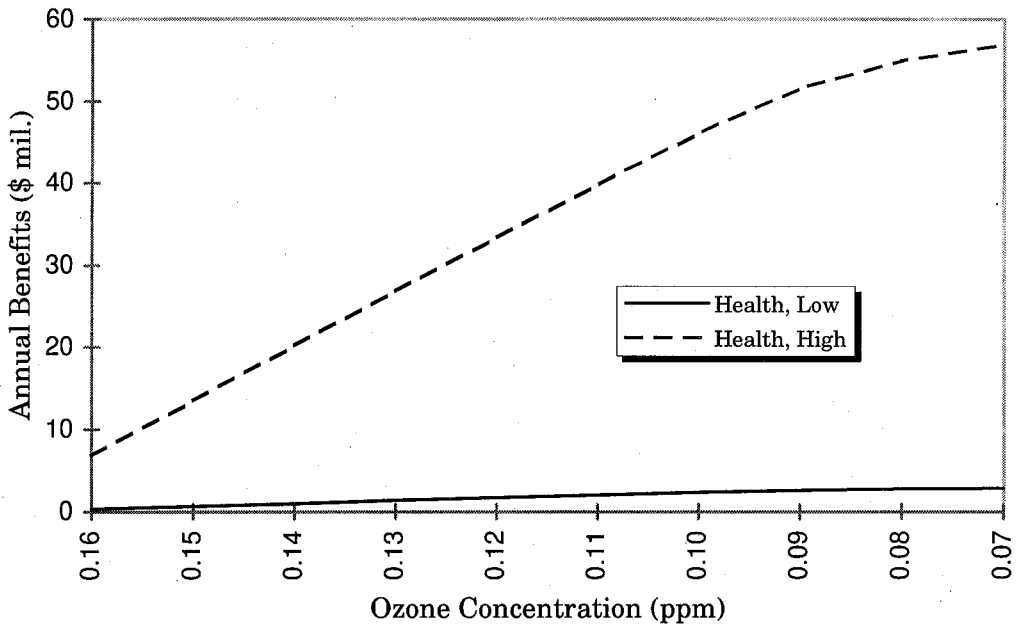


Figure 2. Annual health benefits of ozone control in the San Joaquin Valley

Figure 2 shows the estimates of health benefits associated with ozone concentrations ranging from 0.16 ppm to 0.07 ppm. The health benefits of ozone control in the San Joaquin Valley range from \$0.34 to \$6.77 million for a standard of 0.16 ppm to \$2.84 to \$56.87 million for a standard of 0.07 ppm. The health benefits of meeting the current California ozone standard of 0.09 ppm range from \$2.58 to \$51.58 million. Fresno, Kern, and Tulare counties, in which the valley's population is concentrated, realize roughly 75% of the health benefits of ozone controls. As noted above, these three counties are also the largest crop production regions, and realize most of the agricultural benefits.

The health benefits of ozone controls in the San Joaquin Valley are not as great as the agricultural benefits, due to the smaller population in this agricultural region compared to a large city, and the high value of crops grown in the area. In contrast, Krupnick and Portney estimated that the health benefits represented most of the total benefits of ozone control in the Los Angeles area, while no significant agricultural benefits were measured. This point is worth noting because the current ozone standard is based primarily on ozone's effects on human health.

The health benefit of ozone control is very sensitive to the coefficient of the ozone variable in the health response function developed by Krupnick, Harrington, and Ostro. It appears that the health benefits will be smaller than the agricultural benefits even with a high value of the coefficient on the ozone variable in the health response function, due to the low population density.

The health response function used here relates ozone concentration only to acute respiratory symptoms. Ozone also is known to affect human mortality and chronic respiratory conditions (CARB 1987c), although ozone's effects on these conditions often are complicated by other factors that act together with ozone in the long run.

Additionally, control of ozone by reducing production of nitrogen oxides can reduce particulate matter, which itself adversely affects human health. This study is likely to underestimate the health benefits of ozone control due to exclusion of these factors.

The Costs of Ozone Control

In 1990, 570 tons of ROG and 540 tons of NO_x were emitted daily into the atmosphere from stationary and mobile sources (CARB 1993). Stationary sources are responsible for approximately 69% of total ROG emissions and 39% of total NO_x emissions.⁷ Of the hundreds of plants in the San Joaquin Valley, 97 large plants account for more than 95% of total ROG emissions, while 225 large plants account for more than 95% of total NO_x emissions from stationary sources (CARB 1992). The 97 ROG-emitting plants with 250 sources, and the 225 NO_x -emitting plants with 822 sources, are included in this study [some plants have multiple emission sources (stacks)].

This study uses the linear rollback method (CARB 1990a) to calculate required ROG and NO_x reductions to meet alternative ozone standards in the San Joaquin Valley.⁸ However, the rollback model needs to be adjusted due to lack of information on some sources of ROG and NO_x emissions. This study focuses on controlling emissions from stationary sources and light-duty vehicles, which respectively comprise 82% and 58% of the total ROG and NO_x emissions in the valley. It is therefore necessary to impose more stringent emission reductions on these sources than would be applied if all sources of ROG and NO_x were controlled. With a peak ozone concentration of K ppm and a background ozone concentration⁹ of L ppm, the ROG emission reduction (X_{ROG}) necessary to meet an ozone standard of M ppm is calculated by:

$$(1) \quad X_{\text{ROG}} = \frac{(K - M)}{(K - L) * 0.82}.$$

Likewise, NO_x emission reduction (X_{NO_x}) is calculated by:

$$(2) \quad X_{\text{NO}_x} = \frac{(K - M)}{(K - L) * 0.58}.$$

⁷ Recent evidence (National Research Council, p. 7) suggests that emissions from automobiles may be understated. It could imply that greater emissions are associated with the current ozone levels, which implies that more absolute emissions will need to be reduced, although the percentage reduction may not change. Since costs of control are estimated based on absolute emissions, the estimates presented here are likely to understate costs. As will be discussed in the text, other elements of the study (exclusion of control from diesel vehicles, and use of the stacking technology for stationary sources) overstate control costs.

⁸ The linear rollback method is an approximation. Sophisticated ozone models, which replicate atmospheric chemical reactions, often are used by regulatory agencies to ensure that a given control strategy will in fact achieve the ambient ozone standard. The additional precision accompanying use of one of these models is not justified here due to the level of precision in the other empirical components.

This study assumes that air pollution in the valley is controlled by controlling sources in the valley. The San Joaquin Valley is independent from the pollution sources in the Los Angeles Basin, because wind blows in a direction from the northwest to the southeast. In addition, a mountain range blocks air pollutants in the Los Angeles Basin from the San Joaquin Valley. Transport of pollutants from the San Francisco Bay Area is potentially of greater concern, but a recent study by the California Air Resources Board found that "reducing emissions in areas upwind from the valley would not significantly alter ozone levels in the valley's central and southern portions" (Martin).

⁹ Background ozone concentration is the concentration level without any man-made air pollution. A level of 0.04 ppm was assumed to be the background ozone concentration in this study based on CARB (1990a).

Assessing the costs of ozone reduction requires knowledge of both of the types of technologies employed to control additional emissions and their associated costs. It is impossible to measure accurately the cost of controlling amounts exceeding current levels unless plants identify their choices of alternative methods with their corresponding control costs. As a result, estimating additional control costs is likely to carry with it a wide margin of variability.

Two general approaches exist for estimating further emissions reductions from stationary sources. One approach requires installation of secondary control equipment that is comparable to existing equipment, but which provides additional control (CARB 1990a). This approach would be expensive since a large part of the control cost is capital and installation cost. The other approach achieves a reduction in ROG and NO_x emissions by increasing the ROG and NO_x removal efficiencies of existing control equipment. This approach would be cheaper because it only increases operating costs; however, the benefit to be realized by this approach is limited since most sources operate their control equipment near maximum efficiencies (CARB 1991).

Maloney and Yandle used the first approach in their examination of ROG emission control cost functions for 543 sources in 52 plants of the Dupont Company. They assumed stacking technologies, in which emission control devices were applied in sequence to reduce further emissions. Marginal emission control costs were the costs incurred through the implementation of the additional control measures installed in sequence. By repeating these stacking processes, a group of emission control costs data and emission control levels were constructed. Maloney and Yandle econometrically estimated emission control cost functions for each source based on these data points.

In this study, we assume, for the stationary sources, the pollution control treatments can be applied in sequence when developing ROG and NO_x emission control costs. For example, an incinerator of any size could control inlet gases with a maximum efficiency of approximately 98% (Vaart, Vatauvuk, and Wehe). Controlling additional emissions can be achieved by sequentially installing additional incinerators to control outlet gases from the initial incinerator. If an incineration method with a 98% efficiency is applied initially, and one additional incinerator with the same efficiency is applied again, then the incinerators collectively will yield a 99.96% ($98\% + 0.02 \times 98\%$) control level. Therefore, the marginal control cost for achieving an additional 1.96% control is measured by the cost of an additional incinerator. Individual control cost functions for each source were derived through this procedure.

Because mobile sources are responsible for about half of the ozone in the San Joaquin Valley, it is necessary to control emissions from them to attain reduced ozone levels. Vehicle emission control costs as a function of emission control volumes must be estimated to assess the costs of controlling mobile sources. Wang developed vehicle emission control costs as a function of emission control volumes. Through a survey distributed to automobile dealers in the Sacramento area, Wang identified vehicles' certified emission levels of ROG and NO_x for each engine by manufacturer, and examined the emission control parts and their costs. He used these data to estimate emission control costs as a function of emissions levels of the engine families for light-duty vehicles. His regression was used in the current study to calculate the cost of controlling emissions from light-duty vehicles.

Because of lack of appropriate data, this study does not include other mobile sources, such as heavy-duty trucks, school buses, trains, airplanes, or off-road vehicles. Heavy-

duty trucks alone comprise about 50% of the total NO_x emissions from mobile sources as a whole (CARB 1993); however, no study has been identified that provides emission control costs for these sources. This study assumes that emissions from other mobile sources are constant. The results presented here are thus likely to overestimate the total control costs of emission reduction from mobile sources. It is likely to be more costly to control emissions only from light-duty vehicles, rather than controlling emissions from both light-duty vehicles and other mobile sources such as heavy-duty trucks. Moreover, by controlling only light-duty vehicles, total possible emission reductions are reduced; i.e., 0.10 ppm is the lowest ozone standard achievable through emission control from stationary sources and light-duty vehicles.

In this study, two different emission control policies were applied to stationary sources: command-and-control (CAC) and a local emission permit system (LEPS). Mobile sources are assumed to be controlled only via CAC, although control costs could be reduced by allowing trading among vehicle makers (Kling). Under CAC, uniform percentage emission reductions are imposed across stationary sources to reduce total emissions to ozone concentrations ranging from 0.16 to 0.10 ppm. Under LEPS, stationary sources within a county are allowed to trade freely their emission permits on a one-to-one basis, but trading is not permitted across counties. This is because the same amount of emissions from sources in different counties would have different air quality impacts on a specific location. An ambient permit system, which would base trades on the relative total damages of emissions at different sites, would be more cost-effective than LEPS; however, it requires information not available in this area about diffusion of emissions from different sources. The current control system uses emission trading in a limited way and thus is more cost-effective than CAC [San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD)], but it is less cost-effective than the more extensive LEPS modeled here. Because the cost savings indicated in this study represent the difference between the costs of LEPS and those of CAC, they overstate the advantages of LEPS relative to the current policy.

Controlling ROG and NO_x emissions from stationary sources and light-duty vehicles is costly. Generally, NO_x control is more expensive than ROG control, and the San Joaquin Valley has a greater number of NO_x -emitting sources (822) than ROG-emitting sources (250). The capital costs of additional NO_x control devices are responsible for most of the total cost of controlling NO_x emissions; thus, the larger number of sources significantly increases the total cost of emissions control. In contrast, the major stationary sources emitting ROG in the valley—petroleum refining and distribution firms—enjoy ROG emissions control costs that are generally lower than those of other ROG-emitting sources.

Figure 3 shows the costs of ozone control derived from this study. When LEPS is applied to the stationary sources, total control costs are lower than would be the case under CAC for both stationary sources and light-duty vehicles. Stationary sources in the San Joaquin Valley are clustered together into a few urban areas within which their emissions can be considered to have the same impact on ozone concentrations. Bakersfield and Fresno, in particular, together emit more than 80% of the total ROG and NO_x emissions from stationary sources in the valley. However, as ozone standards become stricter, the higher emissions reductions imposed on the stationary sources require greater emissions reductions by all sources, reducing flexibility in achieving the target and thus reducing the cost advantage of LEPS. Greater cost savings could be achieved

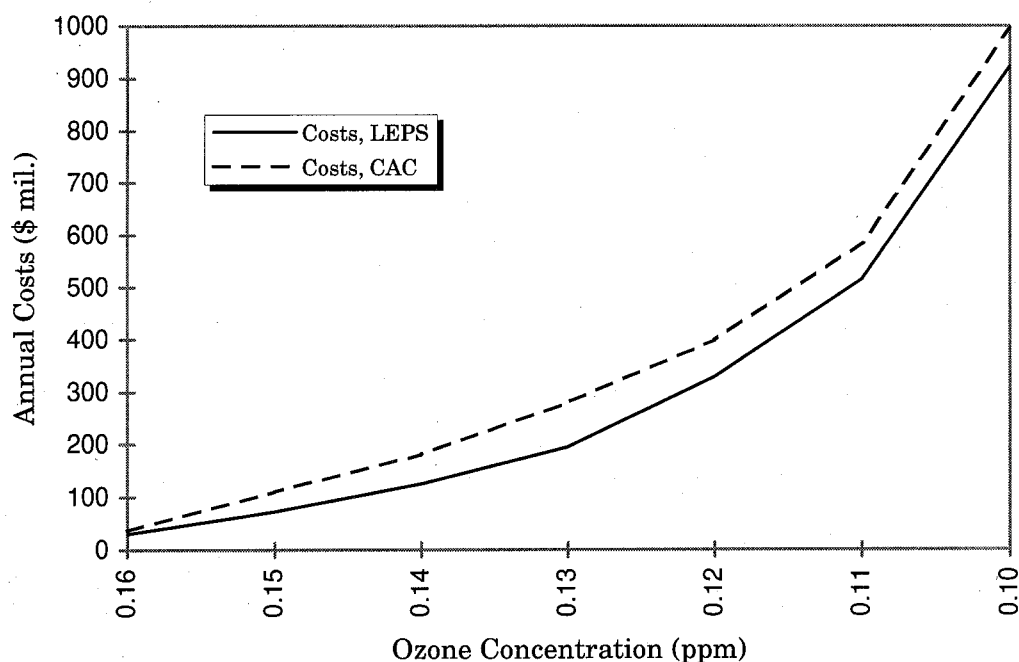


Figure 3. Annual costs of ozone control in the San Joaquin Valley

if emissions trading could take place among stationary sources and light-duty vehicles. Moreover, the inclusion of heavy-duty trucks and other mobile sources could result in even lower control costs.

Comparison of Benefits and Costs

The following discussion details the efficiency and the distribution of benefits and costs associated with two different emission control scenarios designed to meet ozone standards ranging from 0.16 ppm to 0.10 ppm in the San Joaquin Valley. Figure 4 shows the total benefits and costs of ozone control, while Figure 5 shows the marginal benefits and costs. The benefit function increases at a decreasing rate, consistent with the generally assumed form of health-response and crop yield-response functions to ozone, and control cost increases at an increasing rate. Initially, total benefits exceed total costs; as the standard becomes stricter, total costs eventually exceed total benefits associated with the same standards.

With command-and-control for stationary sources and light-duty vehicles, total costs are lower than total benefits at ozone concentrations until around 0.12 ppm to 0.10 ppm. At an ozone standard of 0.10 ppm, total costs outweigh total benefits even if the upper bound of total benefits is considered. Net benefits are maximized where marginal benefits equal marginal costs, between 0.14 and 0.13 ppm.

Using LEPS for stationary sources and CAC for light-duty vehicles, total benefits exceed total costs for ozone concentrations down to at least 0.12 ppm. Marginal benefits equal marginal costs between 0.12 and 0.13 ppm. Given that cost estimates developed

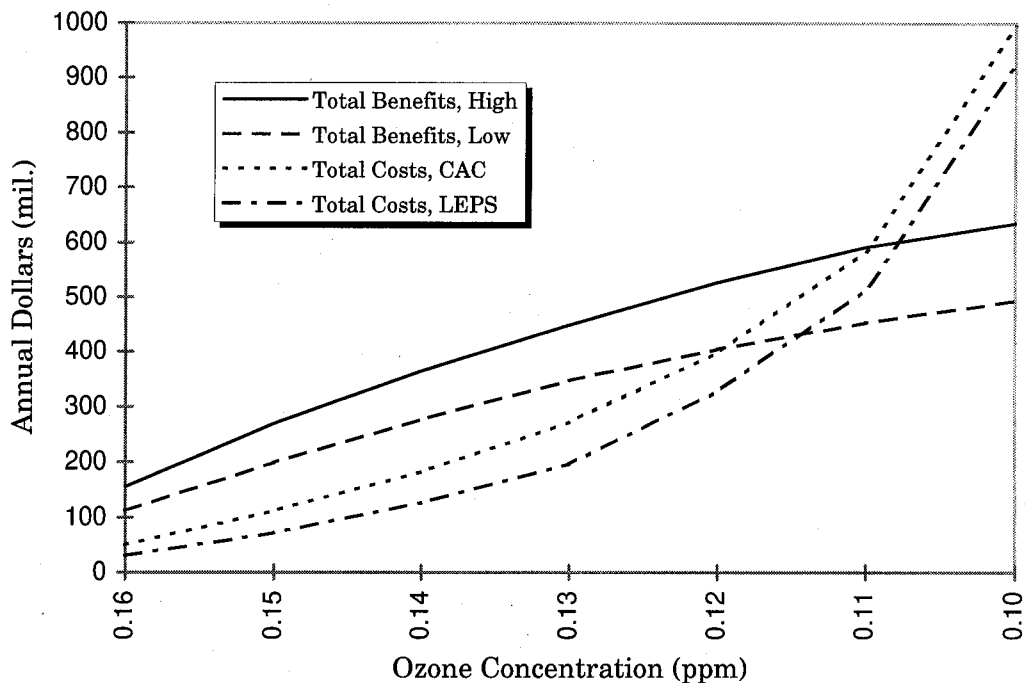


Figure 4. Total annual benefits and costs of ozone control in the San Joaquin Valley

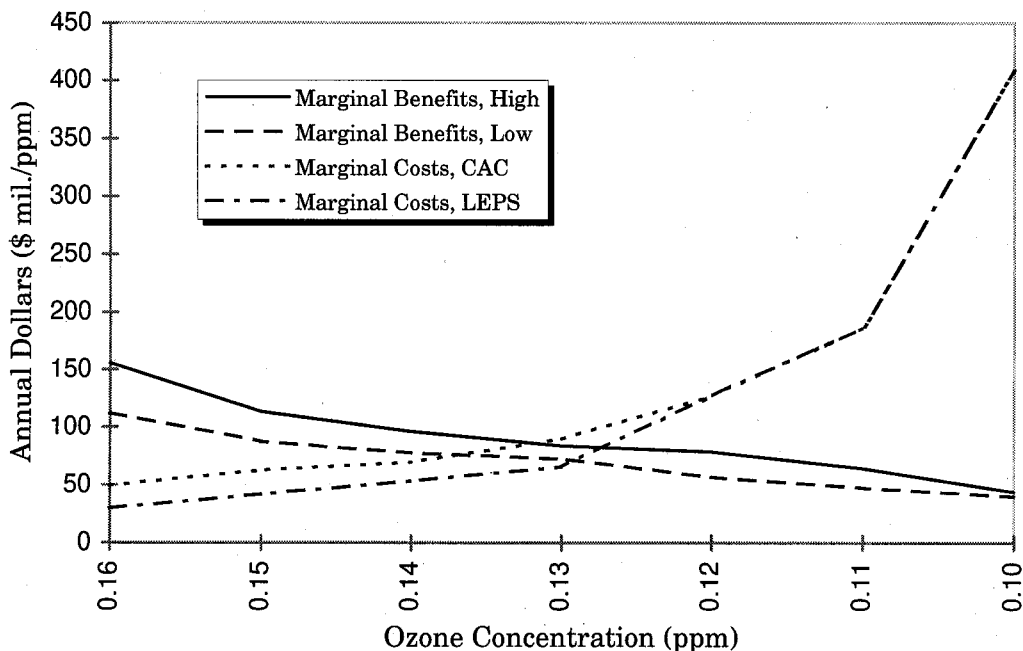


Figure 5. Marginal benefits and costs of ozone control in the San Joaquin Valley

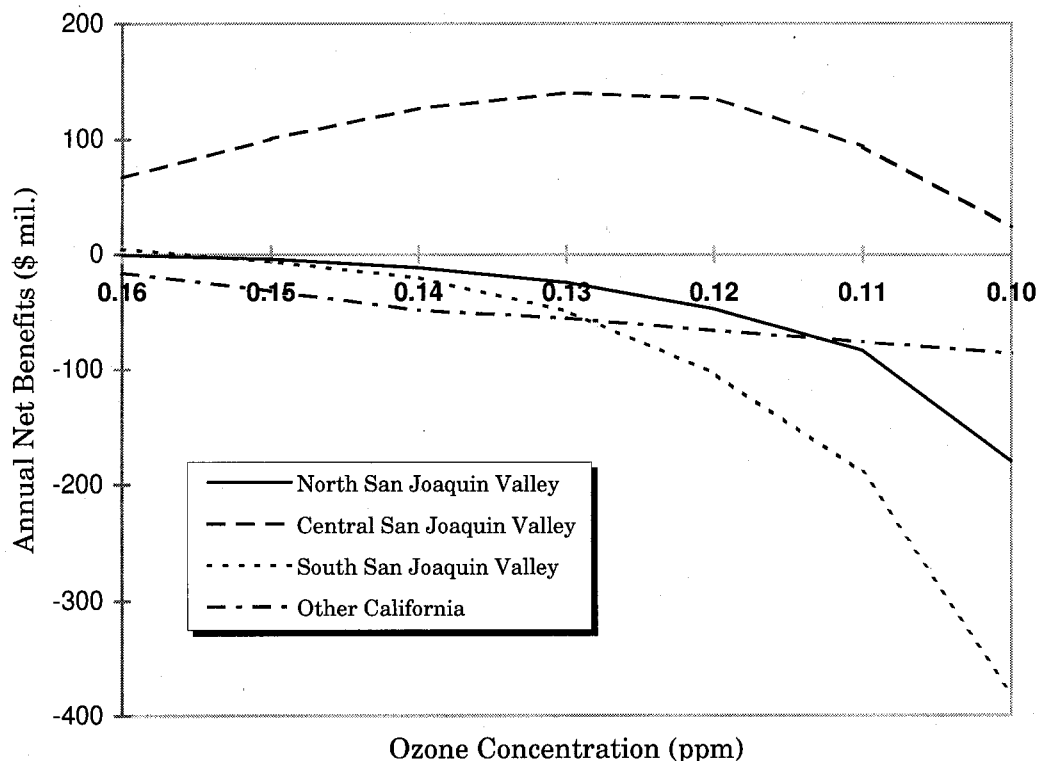


Figure 6. Distribution of net benefits by region (average of high and low)

here may be overstated, and that benefits estimates are understated due to exclusion of other factors, the current federal standard of 0.12 ppm is likely to increase net benefits. Evidence here is insufficient to make the same claim for the state standard of 0.09 ppm.

Figure 6 summarizes the distribution of the benefits and costs for three regions in the valley by averaging high and low estimates for each region. For the South San Joaquin Valley (Kern County), control costs outweigh the benefits associated with almost any reduced ozone standards. Kern County obtains relatively larger agricultural and health benefits because it is a major agricultural production region with a large population, but it is also responsible for 65% of the total ROG and 74% of the total NO_x emissions in the valley. This region is responsible for about 23% of total benefits and about 60% of total control costs associated with ozone standards in the valley as a whole. Not all individuals suffer these losses. Agricultural producers in this area would prefer tighter ozone controls, which would increase their profits by increasing crop production, while pollution sources bear the burden of controlling their emissions.

In the Central San Joaquin Valley (Fresno, Tulare, Madera, and Kings counties), control benefits exceed costs associated with the ozone standards. This area includes the two major agricultural counties of Fresno and Tulare. Its agricultural benefits represent about 80% of the benefits in the valley. At the same time, it is responsible for only about 25% of total control costs associated with ozone controls in the valley.

In the North San Joaquin Valley (San Joaquin, Stanislaus, and Merced counties), control costs outweigh benefits. The North San Joaquin Valley is responsible for about 4% of the total benefits and about 20% of the total control costs associated with ozone controls in the valley.

Other regions in California are also affected by ozone control in the valley through the effects of the increase in crop production (figure 6). For crops such as grapes (since California is the major national producer), prices are based largely on statewide production. In this case, increases in crop production in the San Joaquin Valley lead to a decrease in crop prices, which results in decreased profits for producers outside the valley. These other agricultural production regions experience losses between \$2.7 and \$47 million for ozone standards of 0.16 ppm to 0.10 ppm in the San Joaquin Valley. At the same time, consumers for crops mainly produced in the valley will benefit from the reduced prices.

These effects as described are short term. In the long run, farmers could produce new technologies to mitigate ozone's effects on crops, and polluters can find more efficient control methods. It is difficult to calculate those long-run effects of tighter air pollution restrictions; however, the long-run costs of ozone control are likely to be smaller than the short-run costs, suggesting that an even lower ozone standard might be efficient over time.

Conclusion

This study provides information about ozone control benefits on crops and human morbidity and an approximation of control costs of NO_x and ROG reductions to meet ozone standards ranging from 0.16 to 0.10 ppm in the San Joaquin Valley. With the information presented here, an ozone standard between 0.14 and 0.12 ppm appears to be the most efficient; this estimate needs to be qualified by uncertainties and omitted information. Even if it is not the optimal level of ozone control, attaining the current federal ozone standard of 0.12 ppm appears beneficial to the San Joaquin Valley. Use of incentive approaches, by lowering the costs of attaining any standard, makes a tighter ozone standard more efficient than if command-and-control is used.

The benefit and cost estimates in this study are subject to a margin of variability and uncertainties for several reasons. The agricultural benefit estimates could have large variances due to uncertainties in yield responses to ozone and elasticities of demand for crops. The health response function used in this study relates ozone concentration only to acute respiratory symptoms, although ozone also is known to affect human mortality and chronic respiratory conditions. These effects have not been documented sufficiently to be included here, leading to likely underestimation of the health benefits of ozone control. Large uncertainties surround both the health effects and the values of those effects. The cost estimates are likely to be overstated, due to lack of information on technology choices for businesses and omission of controls of some major mobile sources of pollution. Also, in the long run, new technologies are likely to reduce these costs further. Although reducing waste emissions from stationary and mobile sources in the San Joaquin Valley will likely reduce other air pollutants (such as particulates and carbon monoxide), these effects are omitted here. Finally, the analysis omits consideration of other benefits of ozone reduction, such as effects on visibility and structures. These factors will affect the efficiency of the ozone standards considered in this study.

Further research is required to provide a more complete cost-benefit assessment of regional ozone controls.

Efficiency is not the only criterion for deciding ambient air quality levels; indeed, under the Clean Air Act, consideration of costs is not permitted as a criterion. Even if efficiency were the generally accepted criterion, this analysis does not include all benefits of ozone regulation, and the costs provided are only estimates. Still, information on the benefits and costs of regulating ozone provides useful inputs into the public policy debates.

Despite these limitations, this study presents useful information on the benefits and costs associated with an environmental regulation. Through its incorporation of effects on both agriculture and health, its presentation of marginal as well as total effects, its assessment of different regulatory approaches, and its regional disaggregation of impacts, this analysis provides additional information to policy makers often absent from benefit-cost analyses of single options. As policy makers are likely to have a range of options in choosing how to control an environmental problem, this expanded information can contribute to better informed decisions.

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