VALUING HEALTH EFFECTS: THE CASE OF OZONE AND FINE PARTICLES IN SOUTHERN CALIFORNIA

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This study presents a conservative estimate of the health benefits that would result from attainment of the federal ozone and fine particle ($PM_{2.5}$) standards in the South Coast Air Basin of southern California. A three-stage approach is used that links pollution exposures to adverse health outcomes to economic values. The annual value of the aggregate health benefits approaches $500 million (with a range of $295–$646 million) for ozone and exceeds $21 billion (with a range of $12.85–$34.22 billion) for fine particles. Such results are useful to regulatory agencies and other policy makers when evaluating the merits of various air pollution reduction strategies. (*JEL* Q51, Q53)

I. INTRODUCTION

California's South Coast Air Basin (SoCAB) has air pollution levels of a severity rivaled in the United States only by the San Joaquin Valley of California and Houston, Texas. The SoCAB (consisting of Los Angeles and Orange Counties, and the nondesert portions of Riverside and San Bernardino Counties), with a population of 17.3 million, is classified by the U.S. Environmental Protection Agency (EPA) as a severe nonattainment area for fine particles ($PM_{2.5}$) and an extreme nonattainment area for ozone (SCAQMD 2007a). Both the Federal government and California have set health-based air quality standards for $PM_{2.5}$ and ozone[1] because there is extensive and convincing evidence, and wide concurrence in the medical community, that these pollutants pose a serious risk to health. Adverse effects associated with $PM_{2.5}$ exposure range from premature death and the onset of chronic bronchitis to heart attacks, work loss days (WLDs), and respiratory symptoms. Exposure to ozone is tied to premature death, hospitalizations, school absences, and symptoms that limit normal daily activity (EPA 2003).

Regulatory agencies (see, e.g., EPA 2004, 2005) commonly conduct studies to estimate the benefits of specific regulations, but less often assess the overall benefits of attaining the federal standards, also known as the National Ambient Air Quality Standards (NAAQS). Such context is useful in providing a sense of scale to decision makers and the public. Furthermore, studies carried out by the same agencies that are

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1. These are two of the six criteria pollutants specified in the Clean Air Act of 1970 for which ambient standards have been set.

ABBREVIATIONS

COI: Cost of Illness
C-R: Concentration-Response
CV: Contingent Valuation
EPA: U.S. Environmental Protection Agency
MRADs: Minor Restricted Activity Days
NAAQS: National Ambient Air Quality Standards
ppb: Parts per Billion
RR: Relative Risk
SCAQMD: South Coast Air Quality Management District
SoCAB: California's South Coast Air Basin
VSL: Value of a Statistical Life
WLDs: Work Loss Days
WTA: Willingness to Accept
WTP: Willingness to Pay

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considering adoption of a regulation, even when carefully performed and peer-reviewed, are subject to skepticism. The primary objective of this study is thus to provide a conservative estimate of the benefits that are expected to result from attainment of the $PM_{2.5}$ and ozone standards.

To determine these benefits, we use a three-stage approach. First, we establish the links between polluted air and exposure using the regional human exposure model (REHEX). REHEX was developed to estimate a population's exposure to concentrations above the air quality standards. Initially created to support assessment of pollution exposure in the SoCAB, the model has since been refined and used in multiple locations (Fruin et al. 2001; Hall, Brajer, and Lurmann 2008; Hall et al. 1992; Lurmann and Korc 1994; Lurmann, Winer, and Colome 1989; Lurmann et al. 1999).

Here, population exposure in the SoCAB is estimated relative to pollution levels averaged from 2005 to 2007. Averaging reduces the influence of weather anomalies that do not accurately represent longer term trends in air quality. REHEX generates estimates of exposure by county, age, and ethnic group as defined by the U.S. Bureau of the Census. These estimates are presented in Section II. Then in Section III, we couple the resulting exposure estimates with concentration-response (C-R) functions from the health science literature to calculate the expected number of adverse effects that would be avoided if pollution levels could be brought down to the levels of the Federal standards. In Section IV, we apply economic values to the avoided health effects to estimate, in dollar terms, the social value of meeting the federal standards. Specific values are derived from the economics literature and have all undergone peer review, both as part of that literature and as part of scientific and technical assessments of which values are most appropriate for valuing health and life in relation to air pollution exposure. In the final section, we offer some concluding thoughts about the implications of our findings.

II. THE EXPOSURE ASSESSMENT APPROACH

The exposure assessment approach used in this study represents the population and ambient concentrations on spatial grids covering California's SoCAB. For the 2005–2007 baseline period, hourly ozone data and daily $PM_{2.5}$ data were available at 24 and 14 monitoring stations in the region, respectively. These ambient air quality data were used to spatially map concentrations onto exposure grids, where each grid square is 5 km × 5 km in size.

More specifically, the ozone data were used to create maps of hourly concentrations for each day of the baseline period. The spatial mapping of daily $PM_{2.5}$ concentrations was performed using the Federal Reference Method (see EPA 1997) on days when at least 8 of the 14 stations had valid 24-h data. The REHEX model uses this spatially and temporally resolved air quality data, along with detailed population information, to quantify the frequency of population exposure to various levels of ambient particulate matter and ozone concentrations over the 3-year baseline period.

A. Population

As noted earlier, the baseline period used for exposure assessment was 2005 through 2007. Population data from 2000 were therefore projected to 2007, the most recent year in this period, to be consistent with the baseline period for air quality data and the economic parameters (2007 dollars).[2] The estimated 2007 populations in the portions of Los Angeles, Orange, Riverside, and San Bernardino Counties that lie within the SoCAB are 10.2, 3.1, 2.0, and 2.0 million, respectively, and total 17.3 million. The age distribution in the SoCAB is 28.6% children (age 17 years or less) and 71.4% adults (age 18 or older, of whom 10.1% are elderly), and the population is 40.9% Hispanic, 37.4% white non-Hispanic, 7.5% black non-Hispanic, and 14.1% other non-Hispanic.

B. Current Ambient Air Quality

This study focuses on the current 8-h ozone daily maximum standard of 75 parts per billion (ppb) and the 24-h (35 micrograms per cubic meter or $\mu g/m^3$) and annual average $PM_{2.5}$ (15 $\mu g/m^3$) standards. From 2005 to 2007, the 75 ppb 8-h ozone level was exceeded on 115–120 days/year somewhere in the SoCAB. These exceedances were more highly concentrated in Riverside and San Bernardino counties,

2. The population growth between 2000 and 2007 was determined from gridded population data for 2005 and 2010 that were used in the SCAQMD's Socioeconomic Report for the 2007 Air Quality Management Plan (SCAQMD 2007b). These projections in turn were based on the Southern California Association of Government's regional growth forecast of 1.4% per year. Hence, the population data used here are consistent with those used in the most recent agency air quality planning efforts.

with yearly average numbers of exposure-days of 48.4 and 47.5, respectively. In contrast, Los Angeles and Orange County residents only experienced 10.3 and 2.9 days of ozone exposure above 75 ppb/year. Overall, about half of the basin's populated regions exceeded the 8-h ozone standard more than 30 days/year over the 3-year period. The South Coast Air Quality Management District (SCAQMD) has adopted an air quality plan designed to reach attainment of the former NAAQS for ozone of 80 ppb by 2023 (SCAQMD 2007b), but the agency has not yet formally released plans to address compliance with the newer standard.

The frequency of exceedances of the 35 μg/m^3 daily $PM_{2.5}$ standard is somewhat lower than that for ozone, ranging from 45 to 48 days/year. Still, attainment of the daily $PM_{2.5}$ standard will require more than a 50% reduction in ambient concentrations from 2005 to 2007 levels. The SCAQMD has adopted air quality plans designed to reach attainment of the former NAAQS for $PM_{2.5}$ of 65 μg/m^3 by 2014. The agency has not yet formally released plans to address compliance with the newer and more stringent 35 μg/m^3 standard.

Annual average $PM_{2.5}$ concentrations in the SoCAB tend to increase from modest levels in the western areas of Los Angeles and Orange Counties to higher levels in the eastern areas surrounding the cities of Riverside and San Bernardino. Compliance with the annual standard requires a 24% reduction in ambient concentrations, and the SCAQMD has adopted plans to reach attainment of this standard by 2014 (SCAQMD 2007a).

C. Exposure Results

The REHEX model was applied using the population and air quality data described above to estimate the population exposure to $PM_{2.5}$ and ozone in the baseline period and in the future with attainment.

8-h Daily Maximum Ozone Exposures. Table 1 presents the estimated number of exposures to 8-h daily maximum ozone concentrations above 75 ppb for the entire air basin and for each of the four counties. The REHEX model estimates 306 million person-days of exposure per year in the SoCAB over the baseline period. On average, residents of the SoCAB are estimated to have 18 days/year with ozone exposures above 75 ppb.

The results for the individual counties reflect large differences in population and air quality. For example, the total exposures above 75 ppb are about 100 million in Los Angeles, but only 9 million in Orange County. The inland counties have much smaller populations than Los Angeles County, but a much higher frequency of high ozone concentration days. Thus, the residents of San Bernardino and Riverside Counties experience about 48 days/year with 8-h ozone levels above 75 ppb, compared to 10 days for Los Angeles County. With NAAQS attainment, REHEX estimates that SoCAB residents will have only 0.2 days/year with 8-h ozone above 75 ppb, on average. (More detailed results for the four counties, and for the various age/ethnic groups studied, can be viewed in Hall, Brajer, and Lurmann 2008).

24-h Average $PM_{2.5}$ Exposures. The estimated exposures to 24-h average $PM_{2.5}$ concentrations above 35 μg/m^3 also appear in Table 1. For

TABLE 1

The Estimated Population Exposure (in Millions per Year) to Pollutants in the 2005–2007 Baseline Period and with NAAQS Attainment, by County

	8-h Daily O_3[a]		Daily $PM_{2.5}$[b]		Annual Average $PM_{2.5}$[c]	
Region	**Baseline**	**With Attainment**	**Baseline**	**With Attainment**	**Baseline**	**With Attainment**
South Coast Air Basin	306.3	2.61	289.0	3.55	11.00	0.091
Los Angeles County	105.0	0.48	171.4	0.31	7.61	0.000
Orange County	8.86	0.00	32.16	0.00	0.475	0.000
Riverside County	97.48	0.32	39.47	1.44	1.381	0.068
San Bernardino County	94.98	1.82	45.97	1.80	1.553	0.023

[a]Exposures to concentrations above 75 ppb.
[b]Exposures to concentrations above 35 μg/m^3.
[c]Exposures to concentrations above 15 μg/m^3.

the baseline period, 289 million person-days of exposure occurred annually, with the majority occurring in Los Angeles County. With attainment of the 24-h NAAQS, population exposure above this $PM_{2.5}$ concentration is estimated to fall to 3.5 million person-days/year. SoCAB residents on average would experience only 0.2 days/year with $PM_{2.5}$ concentrations above 35 μg/m^3, whereas the range was 10–23 days in the baseline period.

Annual Average $PM_{2.5}$ Exposures. Finally, REHEX estimates annual average exposures to $PM_{2.5}$ in 2005–2007 and with attainment. Results (also in Table 1) indicate that nearly 11 million SoCAB residents (about 64% of the total population) were exposed to annual average $PM_{2.5}$ above the 15 μg/m^3 standard. With attainment of the annual NAAQS, the model predicts that only 90,000 people (1% of the SoCAB population) would be exposed to such concentrations. It is important to recognize that the 4–5 μg/m^3 reductions in annual $PM_{2.5}$ required to achieve NAAQS attainment represent a dramatic improvement in air quality relative to background levels and a dramatic reduction in population exposure to harmful levels. Furthermore, because the daily $PM_{2.5}$ standard is more stringent than the annual standard, it is quite possible that controls adopted to attain the daily $PM_{2.5}$ standard could result in greater reductions in annual $PM_{2.5}$ than estimated in this study.

III. ADVERSE OZONE AND PM-RELATED HEALTH EFFECTS

Over the past several decades, significant associations have been established between fine particle and ozone exposures and adverse health effects. A growing body of health science (epidemiological) literature now enables policy analysts to quantify how changes in air quality translate into changes in the number of adverse health effects in a population.[3] (For examples and discussion, see Pope and Dockery 2006.)

TABLE 2
Health Endpoints

Ozone	$PM_{2.5}$
School absences Age 5–17	Acute bronchitis Age 5–17
Emergency room visits All ages	Lower respiratory symptoms in children Age 5–17
Respiratory hospital admissions	Upper respiratory symptoms in children Age 5–17 asthmatic population Respiratory hospital admissions Age 65 and older
Asthma attacks All ages of the asthmatic population	Premature death (mortality) Age 30 and older
Premature death (mortality) All ages	Asthma emergency room visits Under age 18
Minor restricted activity days Age 18–64	Minor restricted activity days All ages Onset of chronic bronchitis Age 27 and older Nonfatal heart attacks Age 18 and older Cardiovascular hospital admissions Age 18 and older Neonatal mortality Under age 1 Work loss days Age 18–64

We identified 6 ozone-related and 12 $PM_{2.5}$-related effects that are appropriate for inclusion in this study. These effects are listed in Table 2.

A. Developing Health (C-R) Functions

To quantify the expected improvements in health effects associated with reduced exposure to $PM_{2.5}$ and ozone, we used the basic exponential C-R function developed in the first comprehensive analysis of the costs and benefits of the Clean Air Act (EPA 1997), and widely used in benefit assessments since.[4]

Specifically,

$$\Delta C = -C_0(e^{-\beta \Delta P} - 1)$$

where ΔC is the change in the number of cases (of a particular health outcome), C_0 the number

3. For the purposes of this study, we considered a number of factors when choosing specific studies to estimate such changes. For example, a study must be peer-reviewed, must account for potential confounders such as other pollutants and weather, must be based on a population not significantly different from the population being assessed, and must provide a basis to estimate changes in an effect that can be valued in economic terms. In addition, a health study is preferred if it uses more advanced analytical methods and reflects more recent demographics, if it covers longer periods and larger populations, and if it has been used in previous peer-reviewed benefits assessments.

4. The one exception is the case of ozone-related emergency room visits, for which we use a linear C-R function.

TABLE 3
Morbidity Health β-Values

Health Effect	β-value	Source
Chronic bronchitis	0.0137	Abbey et al. (1995)
Respiratory hospitalizations		Thurston and Ito (1999)
<64	0.001655	Schwartz (1994a, 1994b; 1995) and Moolgavkar, Luebeck, and Anderson (1997)
65+	0.004536	
Cardio hospitalizations		Moolgavkar (2000)
<64	0.000896	Moolgavkar (2003) and Ito (2003)
65+	0.0014375	
MRADs		Ostro and Rothschild (1989)
Ozone	0.0022	
PM	0.00741	
Work loss days	0.0046	Ostro (1987)
Nonfatal heart attacks	0.02412	Peters et al. (2001)
School absence days	0.004998	Chen et al. (2000) and Gilliland et al. (2001)
Upper respiratory symptoms	0.0072	Pope et al. (1991)
Lower respiratory symptoms	0.01698	Schwartz and Neas (2000)
Acute bronchitis	0.0272	Dockery et al. (1996)
Asthma attacks	0.001843	Whitemore and Korn (1980) and EPA (2003)
ER visits	0.0323	Weisel, Cody, and Lioy (1995) and Cody et al. (1992)
Children's asthma ER visits	0.0127	Norris et al. (1999)

of baseline cases (of the health outcome), ΔP the change in ambient pollution concentrations, and β an exponential "slope" factor derived from the health literature's relative risk (RR) factors pertaining to that specific health outcome.

Table 3 presents the specific β values used for each health outcome, along with the specific health studies from which they are derived.[5] These health studies, along with various Centers for Health Statistics and Hospital Discharge reports, also typically provide the number of baseline cases needed for the health improvement calculations.

Because $PM_{2.5}$-related mortality dominates the economic valuation results, we briefly describe here the derivation of specific C-R functions for this effect. More detail for all endpoints can be found in Hall, Brajer, and Lurmann (2008).

$PM_{2.5}$ Mortality. The scientific literature that assesses associations between $PM_{2.5}$ and premature mortality in adults has expanded rapidly over the past decade, with several large-scale multi-city studies that extend or reanalyze earlier studies (e.g., Krewski et al. 2000, 2009; Laden et al. 2006; Pope et al. 1995, 2002) as well as a California-specific study that focuses on the Los Angeles basin (Jerrett et al. 2005). Furthermore, in 2006, EPA sponsored an expert elicitation as part of the process of determining what risk factor(s) should be used in risk assessments conducted to inform policy decisions at the agency. Twelve experts provided responses, with a significant majority choosing an RR at or above 1.10. None recommended a value lower than 1.06 (Deck and Chestnut 2008; Roman et al. 2008).[6]

Given the differing strengths of the primary underlying health studies and the conclusions from the expert elicitation, we use a weighted average of Jerrett et al. (RR = 1.17), Laden et al. (RR = 1.16), and Pope et al. (RR = 1.06). This results in an RR factor of 1.10 and a C-R β of 0.009531. We assign greater weight (two-thirds) to Pope et al. because of the national scope of the study and the inclusion of California residents. Both the other studies include smaller samples, in one case including only

5. Although these studies are conducted both at the national level and for various cities in the United States (and not all in southern California), we follow the standard assumption that ozone and particulates cause basically the same health outcomes in southern California that they cause elsewhere in the United States At present, there is no consistent pattern of evidence to suggest otherwise. Moreover, many of the health studies we use either do include some California cities or have been conducted in California. See EPA (1997) for a more detailed explanation of how the C-R function is derived.

6. We note that this health literature has established premature mortality effects specifically for adults aged 30 and older. We therefore apply the C-R function to this cohort only.

cities outside California and in the other including only Southern California.[7,8]

IV. ECONOMIC VALUATION

Generally accepted measures of the value of changes in well-being as a result of reducing the adverse health effects include the cost of illness (COI) measure and the willingness to pay (WTP) or willingness to accept (WTA) measures. The COI method requires calculating the actual direct expenditures on medical costs, plus indirect costs (usually lost wages), incurred because of illness. In contrast, market choices that reduce risks to health or life indirectly indicate the WTP for lower risks or the WTA for higher risks. Values derived from these market-based, or hedonic, methods are based on relating differences in wages or consumer costs to differing degrees of risk. Finally, when values inferred from markets are not available, another means to estimate value is through the use of surveys—the contingent valuation (CV) method. This method has become a significant source of values over the past two decades, as the methodology has matured and become more accepted, and as policy makers (and the courts) have become more engaged with the application of economic values to decision making (see Carson, Flores, and Meade 2001).

Overall, then, the most appropriate basis for valuing reductions in adverse health effects is presently WTP values based on CV (survey) studies and WTA based on wage-risk studies (Viscusi 1993). COI measures are used when preferred measures are unavailable because a lower bound value is preferable to a zero value, which is implied when an effect is not included in the benefits assessment. The specific morbidity and mortality values we use for the SoCAB are presented in the next two sections.

A. Specific Values for Health (Morbidity) Endpoints

Generally accepted values for many endpoints have been developed and are widely used in benefit assessments and regulatory analyses by the EPA and the states. Partly based on COI calculations and partly derived from CV survey work, these values have been peer-reviewed by advisory bodies, including committees of EPA's Scientific Advisory Board, and many have also been published in the peer-reviewed literature. We follow this established protocol, adjusting specific values for inflation and California-specific incomes to reduce potential bias that could result from benefit transfer based on values for non-California populations. Where California-specific COI data are available, as for hospitalizations, we use those values. Table 4 summarizes the morbidity unit values we used and the underlying economic studies on which they are based.

B. Specific Values for Premature Death

Clearly, the most significant effect of exposure to unhealthful levels of air pollution is premature death. Determining a socially appropriate value to attach to reducing the risk of this outcome (commonly known as the value of a statistical life or VSL) is thus a crucial part of any benefit assessment. Wage-risk studies can reveal how much more compensation workers must be paid to accept jobs with higher risks of job-related death. Studies of consumer choices and product risk are based on the same approach—the small difference that each consumer pays to reduce a slight risk aggregated to the level of reducing risk enough to prevent a single death.

There is a wide range across the recent economic valuation studies that assess VSL, from \$2.5 million (Mrozek and Taylor 2002) to \$10.6 million (Kochi, Hubbell, and Kramer 2006). Given this range, it is necessary to determine how to select a single value. There is no clear theoretical or mathematical logic for accomplishing this. For example, there is little basis to give any single study greater weight than another, which argues for averaging over a group of studies. Also, it is preferable (EPA-SAB 2007; NRC 2008) to include both wage-risk and stated preference (CV) values. This is in part because the VSL used needs to reflect in some way the age distribution of the population at greatest risk (i.e., the older population). CV studies include this population, whereas wage-risk studies largely do not.

For the purposes of this study, we construct a value based on the meta-analyses of Mrozek

7. Jerrett et al. (2005) were not given greater weight because the reasons for the larger associations found in that study are not yet fully understood.

8. Because the EPA SAB-HEES (2004) now recommends that neonatal mortality be included in primary benefit analyses and that the epidemiological study by Woodruff, Grillo, and Schoendorf (1997) be used, we also include post-neonatal deaths in this benefit analysis, using a C-R β value of 0.007844 derived from the Woodruff study.

TABLE 4
Economic Unit Values

Health Effect	Unit (Dollar) Value	Source
Chronic bronchitis	$402,800	Krupnick and Cropper (1989) and Viscusi, Magat, and Huber (1991)
Respiratory hospitalizations		Chestnut et al. (2006)
<64	$39,550	
65+	$34,970	
Cardio hospitalizations		Chestnut et al. (2006)
<64	$46,610	
65+	$40,090	
MRADs	$65.70	Tolley et al. (1986)
Work loss days	$161–$188	EDD (2008)
Nonfatal heart attacks	$70,103	Eisenstein et al. (2001) and Russell et al. (1998)
School absence days	$89–$121	Smith et al. (1997)
Upper respiratory symptoms	$34.50	EPA (2005)
Lower respiratory symptoms	$21.50	EPA (2005)
Acute bronchitis	$118	Loehman et al. (1979)
Asthma attacks	$53.85	Rowe and Chestnut (1986)
ER visits	$361	EPA (2005)

and Taylor (2002), Viscusi and Aldy (2003), and Kochi, Hubbell, and Kramer (2006). Furthermore, we rely on the U.S.-only values reported by Viscusi and Aldy, and Kochi, Hubbell, and Kramer, and include the expanded revealed preference estimate (based on Kochi, Hubbell, and Kramer, developed by Deck and Chestnut 2008). The mean of the Viscusi and Aldy U.S. values is $7.6 million, which we average with $2.5 million from Mrozek and Taylor and $10.6 million from Kochi, Hubbell, and Kramer. This yields $6.9 million, based on hedonic wage-risk studies. Then we give equal weight to the average wage-risk VSL and the CV value of $6.3 million calculated by Deck and Chestnut, which they based on CV studies underlying the Kochi et al. meta-analysis, to determine a final VSL of $6.63 million. (All values are in 2007 dollars.)[9]

C. Health and Valuation Results

Failure to attain the health-based air quality standards clearly poses a pervasive and ongoing threat to public health in southern California, as represented by this assessment of the scale of illness and premature death in the SoCAB and by other recent studies (see, e.g., CARB 2006; EPA 2004, 2005; Hall, Brajer, and Lurmann 2003). Not surprisingly, given the large value that individuals, and society more broadly, place on avoiding premature deaths, the overall economic benefits of attaining the NAAQS are dominated by mortality. Across the SoCAB, it is estimated that 3,000 people would avoid premature death each year, accounting only for the effect of $PM_{2.5}$ and only for the population aged 30 and older. With a value for each statistical life of $6.63 million, this effect by itself offers an attainment benefit of nearly $20 billion each year. This consequence of elevated fine particle levels is clearly the most striking, but other health effects are also important.

For example, attainment of the $PM_{2.5}$ NAAQS could result in the avoidance of 1,590 new cases of adult-onset chronic bronchitis each year. At a value of over $400,000 for each new case—reflecting the significant costs of treatment and loss of utility—this benefit totals over $640 million. In addition, attaining the Federal fine particle standard would prevent over 3,200 nonfatal heart attacks annually, generating an economic benefit of more than $226 million, and would reduce days of lost work by nearly 400,000, worth an estimated $72 million. Days of reduced upper respiratory symptoms to the region's asthmatic children would be lessened by more than 1.6 million cases, valued at over $55 million each year.

9. Given that reductions in mortality generate the largest portion of benefits, we also conducted a sensitivity analysis for this health endpoint by estimating lower and upper bounds for the VSL. These are based on Deck and Chestnut's (2008) weighting scheme of the three recent VSL meta-analyses and on the EPA's (2005) averaging of lower and upper ends of interquartile ranges from Mrozek and Taylor (2002) and Viscusi and Aldy (2003). The resulting values (in 2007 dollars) are $5.732 million and $7.472 million, implying that our avoided mortality benefit could vary by about ±13.7%.

TABLE 5
$PM_{2.5}$-Related Health Effects in the South Coast Air Basin

	Los Angeles	Orange	Riverside	San Bernardino	All Counties	Range of Effects
Minor restricted activity days (age 18–64)	1,224,600	300,010	224,780	266,830	2,016,220	1,650,000–2,376,000
Premature mortality (age 30 and older)	1,720	410	460	410	3,000	1,840–4,880
Post-neonatal mortality	7	1	1	2	11	6–20
Work loss days (age 18–64)	241,690	59,100	44,500	52,850	398,140	337,340–458,400
Lower respiratory symptoms (age 5–17)	47,160	10,930	9,540	11,970	79,600	18,410–131,700
Upper respiratory symptoms (asthmatic children)	944,900	220,400	206,300	246,500	1,618,100	280,200–2,858,500
Acute bronchitis (age 5–17)	7,420	1,740	1,540	1,810	12,510	4,790–19,780
Chronic bronchitis (age 27 and older)	960	240	190	200	1,590	810–2,350
Children's asthma ER visits	1,175	275	255	305	2,010	1,145–2,865
Nonfatal heart attacks	1,960	485	370	415	3,230	830–5,165
Respiratory hospital admissions (age 0–64)	95	14	19	27	155	94–232
Respiratory hospital admissions (age 65+)	257	48	57	50	412	250–618
Respiratory hospital admissions (total)	352	62	76	77	567	345–850
Cardio hospital admissions (age 0–64)	121	25	26	27	199	160–250
Cardio hospital admissions (age 65+)	430	88	118	83	719	580–900
Cardio hospital admissions (total)	551	113	144	110	918	740–1,150

TABLE 6
$PM_{2.5}$-Related Economic Values in the South Coast Air Basin

	Los Angeles	Orange	Riverside	San Bernardino	All Counties	Range of Values[a]
Minor restricted activity days (millions)	$80.46	$19.71	$14.77	$17.53	$132.5	$108.4–156.1
Premature mortality (millions)	$11,397	$2,717	$3,048	$2,717	$19,878	$12,200–32,354
Post-neonatal mortality (millions)	$46.38	$6.63	$6.63	$13.25	$72.89	$39.78–132.6
Work loss days (millions)	$44.93	$11.09	$7.16	$8.50	$71.67	$60.73–82.53
Lower respiratory symptoms (millions)	$1.02	$0.24	$0.21	$0.26	$1.71	$0.396–2.83
Upper respiratory symptoms (millions)	$32.56	$7.59	$7.11	$8.49	$55.76	$9.67–98.62
Acute bronchitis (thousands)	$877.4	$205.8	$182.1	$214.0	$1,479.0	$565.2–2,334
Chronic bronchitis (millions)	$386.7	$96.7	$76.5	$80.5	$640.4	$326.3–946.6
Children's asthma ER visits (thousands)	$423.9	$99.2	$92.0	$110.0	$725.1	$413.3–1,034
Nonfatal heart attacks (millions)	$137.4	$34.0	$25.94	$29.09	$226.4	$58.18–362.1
Respiratory hospital admissions (millions)	$12.91	$2.26	$2.78	$2.86	$20.81	$12.46–30.79
Cardio hospital admissions (millions)	$22.88	$4.69	$5.94	$4.59	$38.10	$30.71–47.73
Total value in millions	$12,164	$2,900	$3,195	$2,882	$21,141	$12,847–34,218

[a]Range is based on variability in the health estimates and not the economic values.

Attaining the ozone standard offers the benefit of more than a million fewer school absence days, conservatively valued at more than $105 million/year. Minor restricted activity days (MRADs) also cost adults nearly 3 million days/year when their daily routine is limited to some degree by exposure to elevated ozone or $PM_{2.5}$. Avoiding these days of restricted activity offers an economic benefit of more than $195 million annually.

Tables 5–8 show the overall benefits in numbers of adverse health effects and annual deaths

TABLE 7
Ozone-Related Health Effects in the South Coast Air Basin

	Los Angeles	Orange	Riverside	San Bernardino	All Counties	Range of Effects
Respiratory hospital admissions (age 0–64)	333	77	117	129	656	390–906
Respiratory hospital admissions (age 65+)	47	10	68	44	169	100–234
Respiratory hospital admissions (all ages)	380	87	185	173	825	490–1,140
Asthma attacks (asthmatic population of all ages)	59,100	17,010	22,480	22,380	120,970	27,730–210,960
Emergency room visits (all ages)	150	45	55	55	305	210–400
School absences (age 5–17)	408,310	115,320	78,650	90,430	692,710	325,900–1,041,000
Days of school absences (age 5–17)	653,300	184,500	125,840	144,690	1,108,330	521,500–1,666,000
Minor restricted activity days (age 18–64)	483,840	142,380	164,470	170,720	961,410	391,200–1,517,000
Mortality	12	3	15	11	41	30–50

TABLE 8
Ozone-Related Economic Values in the South Coast Air Basin

	Los Angeles	Orange	Riverside	San Bernardino	All Counties	Range of Values[a]
Respiratory hospital admissions (millions)	\$15.40	\$3.53	\$7.21	\$6.87	\$33.0	\$18.9–44.0
Asthma attacks (millions)	\$3.183	\$0.916	\$1.21	\$1.205	\$6.514	\$1.493–11.36
Emergency room visits (thousands)	\$54.12	\$16.24	\$19.84	\$19.84	\$110.04	\$75.81–144.4
Days of school absences (millions)	\$58.63	\$22.30	\$12.17	\$12.88	\$105.97	\$50.0–159.30
Minor restricted activity days (millions)	\$31.79	\$9.35	\$10.81	\$11.22	\$63.16	\$25.70–99.67
Mortality (millions)	\$79.51	\$19.88	\$ 99.39	\$72.89	\$271.67	\$198.9–331.5
Total value in millions	\$188.6	\$56.0	\$130.8	\$105.1	\$480.5	\$295.0–646.0

[a]Range is based on variability in the health estimates and not the economic values.

avoided[10] and in dollars for both pollutants. Looking at these figures, residents of the SoCAB could expect annual benefits of \$21.23 billion (with a range of \$13.16–\$34.91 billion) if both the $PM_{2.5}$ and ozone NAAQS were attained.

The per capita benefits are also noteworthy and provide a sense of perspective. On a basin-wide average, annual benefits are over \$1,225 per person. This varies across counties with the levels of pollution and the size of the more vulnerable populations, and very slightly with income (which determines or influences the value of some effects). The county-level average benefits per resident range from \$955 in Orange County to over \$1,650 in Riverside County.[11]

10. For the health effects, we also provide a range of estimates, derived from 95% confidence intervals obtained from the original health studies.

11. Los Angeles \$1,211; Orange \$955; Riverside \$1,652; San Bernardino \$1,492; entire SOCAB \$1,226.

V. CONCLUSIONS AND IMPLICATIONS

This study has shown that most residents of the South Coast Air Basin regularly experience air pollution levels known to harm health and increase the risk of early death. This is unsurprising, given how frequently and pervasively the health-based air quality standards are violated. Finding effective policies to reduce pollution levels can therefore generate substantial health and economic gains.

For the two pollutants combined, if the NAAQS were attained more than 3,000 lives (with a range of 1,870–4,930) would be extended every year in the age 30 and over population.[12] In addition, each year 1,600 fewer adults would experience the onset of chronic

12. To place the reduction in premature deaths in perspective, attaining the $PM_{2.5}$ standard would save more lives than reducing the number of motor vehicle fatalities to zero in the counties in this study (CHP 2007).

bronchitis (with a range of 810–2,350) and children would avoid 1.1 million days of school absence (with a range of 0.52–1.67 million). Millions of fewer days of more minor effects would also be realized, including reduced activity for adults and respiratory symptoms in children. The aggregate economic value of these health effects is nearly $500 million for ozone (ranging from $295 to $646 million) and over $21 billion for fine particles (ranging from $12.85 to $34.22 billion).

Finally, because the $PM_{2.5}$ 24-h standard is typically violated more frequently in the winter months and ozone is most often elevated during the summer months, there is essentially no "clean" season in the SoCAB. As the population continues to increase, with associated increases in vehicle traffic and economic activity, the gains from attaining the health-based air quality standards will grow, but will also become more difficult to achieve. Identifying and acting on pollution reduction opportunities now will produce substantial benefits for more than 17 million Californians.

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