Monetary Values of Air Pollutant Emissions in Various U.S. Regions

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Monetary values of emissions of criteria pollutants are needed for evaluating the costs and benefits associated with technologies that have the potential to reduce emissions. Emission values can be estimated by using either a damage value method or a control cost method. With the damage value method, emission values are estimated on the basis of estimated emissions, air quality simulation, damage identification, and valuation of damages. With the control cost method, the marginal control cost—the cost of controlling the last unit of emissions for meeting a given air quality standard—is estimated; the estimated marginal cost is treated as the value of emission reductions achieved by a given control technology. Although studies have been conducted to estimate emission values in some U.S. areas, emission values are still lacking in many others. Estimating emission values for various U.S. areas by using either method can be time-consuming and resource-intensive. Regression relationships are developed between emission values and air pollutant concentrations and population exposed with emission values already estimated for some U.S. areas. On the basis of the developed relationships, emission values have been estimated for various U.S. areas that lack them. These estimates can serve as interim values for these areas until detailed, original estimates become available.

Various measures and strategies to control air pollution are proposed for helping solve air pollution problems in U.S. cities. In determining which control measures are to be implemented, their benefits and costs must be estimated and compared. Usually, those measures with the greatest net benefits should be implemented first. Thus, the monetary value of air pollution reductions achieved by various control measures needs to be quantified.

In particular, various clean transportation technologies are being proposed for solving urban air pollution problems. These clean technologies usually bear high private costs—the costs are paid directly by private users. However, if the monetary value of emission reductions achieved by these clean technologies is taken into account, they may be cost-competitive compared with conventional transportation technologies. To evaluate various transportation technologies from the perspective of social cost accounting, society must consider both private costs and external costs attributable to environmental pollution. Estimating monetary values associated with air pollution is essential when determining the social costs of various technologies.

Studies have been conducted to estimate the monetary value of air pollutant emissions in some U.S. areas, but such values are lacking for many areas. Because air quality status and population exposed to pollution differ among areas, emission values should differ considerably. Applying emission values estimated for one area to another without any adjustment is inaccurate. Thus, area-specific emission values must be estimated.

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Two general methods have been used to estimate emission values: the damage value method and the control cost method. In this paper, using emission values for some U.S. regions already estimated with both methods, the authors estimate emission values as functions of air pollutant concentrations and total population. With the established emission-value functions, emission values are estimated for various U.S. regions.

METHODS FOR ESTIMATING EMISSION VALUES

Air pollution, created in association with the activities of industries or individuals, damages human health, agricultural crops, ecosystems, structural materials, and natural scenery. To reduce damage, emissions of air pollutants must be controlled. Monetary values of emission reductions are needed in order to evaluate the cost and benefit of a control measure. The two general methods for estimating air pollutant emission values are presented in the following.

Damage Value Method

The damage value method directly estimates monetary values of damages caused by air pollutants. The method can involve seven steps: identify emission sources, estimate emissions, simulate air pollutant concentrations in the atmosphere, estimate exposure of humans and other objects to air pollutant concentrations, identify physical effects of air pollutant concentrations on humans and other objects, valuate physical effects, and calculate emission values in dollars per ton (*1*).

Sources of emissions usually are identified by the air quality control authority in the region, mainly for preparing state implementation plans (SIPs) for meeting air quality standards. Emissions from identified sources usually are estimated through the preparation of SIPs. When the concentrations of pollutants in the atmosphere are estimated, dispersion, reaction, residence of air pollutants, meteorology, and topography are taken into account. These three steps—identifying emission sources, estimating emission inventory, and simulating air quality—can be avoided if air quality data are available. In this case, damage estimates can be based directly on measured rather than on simulated concentrations of air pollutants.

Models for simulating human exposure to air pollution are usually based on the assumption that an individual's time-integrated exposure is the product of (*a*) the air pollutant concentrations in a specific set of microenvironments, and (*b*) the time spent by the individual in those microenvironments. Most researchers use clinical studies or epidemiological studies to generate dose-response relationships. The monetary values of adverse air pollution effects can be determined through various economic valuation methods. For example, values of adverse health effects of air pollution can be related to medical expenses, loss of work, discomfort, and inconvenience that result from such effects.

The damage value method has been used in several studies (*2–10*). Among the damage-based studies, Small and Kazimi (*10*) estimated damage values for emissions from motor vehicles; others cited here estimated damage values for emissions from stationary sources. A detailed review of past studies is presented elsewhere (*11*).

The damage value method appears logical and theoretically sound. In practice, however, the necessary assumptions and simplifications as well as the tremendous uncertainties involved in each of the estimating steps diminish the method's effectiveness. The compounding effect of the uncertainty involved in each estimating step results in values that are very uncertain. Some air pollution effects are often excluded, leading to underestimated values. The principles and theories of modeling air quality and determining air pollution effects as well as their value are in dispute. Outside the discipline of economics, attempting to place dollar values on such items as human life leads to philosophical uneasiness, thus diminishing the method's credibility. Finally the complexity of the damage estimate steps makes the method time-consuming and resource-intensive.

Control Cost Method

Value estimates generated by the control cost method are based on the assumption that ideal emission or air quality standards have been established in that the marginal damage of pollution is equal to the marginal cost of controlling pollution. Supposedly, the control cost required to meet predetermined air quality standards imposed by legislators "reveals" the value that society places on the emissions being controlled [thus, the method is sometimes known as the revealed preference method (*12*)]. Therefore, the marginal control cost, as estimated to meet an emission standard, represents the marginal damage value of air pollution when the standard is met.

This method involves two major steps: determining marginal control measures and estimating dollars-per-ton control costs for identified control measures. Determining marginal control measures for a region can be difficult and subjective. Moreover, selecting one control measure over another can significantly affect the estimate of marginal control costs. Calculating control costs for a control measure requires data on costs and emission reductions associated with the control measure over its lifetime. Initial capital cost, operation cost, maintenance cost, and other cost components must be included to estimate the cost. When estimating reductions in emissions, the emission control deterioration over the lifetime of an equipment must be taken into account. To estimate the dollars-per-ton cost for a particular pollutant, the cost of a measure needs to be allocated among the pollutants reduced, if the control measure reduces emissions for more than one pollutant. Many past studies on estimating emission values used the control cost method (*6–8,13–16*). A detailed review of these studies is presented elsewhere (*11*).

Relative to the damage value method, the control cost method is easy to carry out and does not involve as many estimating steps and assumptions. However, the unrealistic assumption that legislators and regulators establish emission and air quality standards on the basis of costs alone is a weakness. In reality, emission and air quality standards are established through a highly political and scientific (but not economic) process, with scientifically identified health effects as the most dominant of the many factors considered. Although some argue that the method assumes a composite control cost to represent economic, political, and social implications, such a concept suggests that political and social implications can be interpreted in the economic sphere, which may trouble others deeply. In practice, marginal control cost is rarely equal to marginal damage. Thus, it is improper to treat the estimated marginal control cost as the value for emission damage. Nevertheless, the estimated marginal control cost represents the opportunity cost that can be avoided by implementing some control measures other than the marginal control measure in meeting standards—that is, if some other control measures are implemented, the most costly control measure can be avoided. It is this avoided opportunity cost concept that the authors prefer to adopt for interpreting the values estimated with the control cost method.

DEVELOPMENT OF EMISSION VALUES FOR VARIOUS U.S. AREAS

Approach

Estimates of emission values must be generated for societal cost-benefit analysis of the projects that cause air pollutant emissions. A proper, or societal cost-benefit analysis must place dollar values on externalities—among these are air pollutant emissions. Ideally, to generate region-specific emission values, damage models should be run for a particular region so that damage values can be estimated for the region, or emission control costs should be estimated from the control measures and their costs applied to the region. However, limited resources often prevent such detailed, accurate estimates for individual regions. In practice, emission values estimated for one region are often used for another region, without any adjustment.

Because emission values are determined by air quality status and population exposed, these values vary considerably among regions. The authors propose a simplified method to develop region-specific emission values. With the method, emission values are estimated as functions of air pollutant concentrations and total population. A regression analysis is conducted to establish emission value functions. For damage-based emission values, total population determines how many people will be exposed to air pollution, thereby determining the magnitude of health damage values attributable to air pollution—the most significant air pollution damage in most cases. For cost-based emission values, total population in a region partly determines the number of emission sources in the region. For a larger population, more human services are required and more human activities occur; both of these conditions mean more emission sources, causing a higher level of emissions. To meet given air quality standards in such regions, emissions of each source must be reduced. It is more expensive to reduce emissions to a lower percentage of the uncontrolled level. In fact, the costs to accomplish lower and lower percentages of uncontrolled emissions go up nonlinearly. It is certainly more expensive to control average emissions per source to a low value in order to reduce total emissions in a geographic area to a given target level, when the number of sources and uncontrolled emissions are high because of a need to serve a large population. Thus, meeting air quality standards is more expensive in a high-population region than in a low-population region, all else being equal.

To allow the freedom of choosing between damage-based and control-cost-based emission values, the authors establish two sets of regression relationships: one for estimating damage-based values, and the other for estimating control-cost-based values.

Data Sources

In this paper, emission values estimated in previous studies are used to establish regression relationships.

In 1987 ECO Northwest conducted a study for the Bonneville Power Authority to estimate damage-based emission values for a generic 1,300-MW coal-fired power plant presumably located in the Pacific Northwest (*2*). The study included air pollution damages to human health (mortality and morbidity), agricultural crops, materials, visibility, ecosystems (forest and lakes), livestock, and timber. On the basis of the ECO Northwest study, the Bonneville Power Authority adopted dollars-per-ton emission values for nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) for the areas east and west of the Cascade mountain range (*17*).

Since 1989 the California Energy Commission (CEC) has been estimating emission values by using both the damage value and control cost method (*6–8*). CEC has estimated damage- and control-cost-based emission values for 11 of California's air basins. With respect to control-cost-based values, CEC was concerned that taking the highest marginal control costs from any sector may not represent the public's true willingness to pay for additional emission reductions in the electricity sector. In addition, CEC maintained that the marginal control cost for a source classification may often be overestimated. For these reasons, when selecting marginal control measures, CEC decided to exclude arbitrarily the control measures with costs over $100,000/ton. With respect to damage-based values, Regional Economic Research, Inc., CEC's contractor, developed an air quality valuation model to estimate emission damage values (*1,18–20*). The model included emission estimation, air quality simulation, estimation of physical effects of air pollution, and monetary valuation of air pollution effects. Estimation of emission damage values included human health effects (mortality and morbidity), visual aesthetic effects, material effects, forest-related aesthetic effects, and agricultural effects.

In 1989 the New York State Energy Office estimated emission values for the state of New York using the control cost method (*13*). In determining costs of marginal control measures, the agency used average costs of low- and high-cost measures that were applied to a 200-MW coal-fired power plant. The agency maintained that low-cost measures reflected control in attainment areas and high-cost measures reflected control in nonattainment areas.

In 1990 the Tellus Institute of Boston conducted a study to estimate emission values by means of the control cost method (*12*). The Tellus researchers suggested that control cost estimates could be surrogates for damage values of emissions. They estimated emission values for Southern California and the northeastern United States. In determining marginal control measures, they took the measures with the highest control costs necessary for complying with emission and air quality standards.

In 1993 National Economic Research Associates completed a study to estimate emission damage values in southern Nevada (*9*). In the study, changes in air pollutant concentrations were estimated in terms of emissions from given hypothetical power plants located in and out of the Las Vegas valley. The study included effects of air pollution on human mortality and morbidity, visibility, building materials, agriculture, and ecosystems.

In 1990 the Center for Environmental Legal Studies of Pace University conducted a study to review and analyze existing studies on air pollution externalities (*4*). The Pace University study included emission values estimated on the basis of the damage value method. The study did not make its own damage value estimates; instead, it assessed values estimated in a variety of studies and proposed a "starting point" for each effect of air pollution identified.

On the basis of these studies, emission values estimated for 15 U.S. regions are used in the regression analysis (Table 1). Data on air pollutant concentrations and total population for each of the 15 regions are obtained from the Environmental Protection Agency (EPA) (*21–23*).

Resultant Regression Relationships

Various functional forms were tried in establishing the regression relationship for a particular pollutant. The most statistically significant functional form of the variables generally was chosen as the final regression relationship for the pollutant. However, in some cases, theoretical expectations for signs of coefficients made it necessary to adopt models with less goodness of fit (i.e., smaller R^2). For some pollutants, the constant term was found not to be significant. In those cases, the constant term was forced to be 0. Although some coefficients for air pollutant concentrations or population were found not to be statistically significant, these relatively insignificant coefficients occasionally were kept in the regression relationships because simple theory implies that both air pollutant concentrations and population affect the dollar emission values being estimated. The established regression relationships for damage-based and control-cost-based emission values are presented in the following (note that emission values are expressed in 1989 constant dollars):

$$NO_{x,damage} = 1{,}640 \ln(pop) + 4{,}220 \ln(O_3) \quad (1)$$

$$ROG_{damage} = 871 \ln(pop) + 2{,}310 \ln(O_3) \quad (2)$$

$$\ln(PM_{10,damage}) = 0.764 \ln(pop) + 0.685 \ln(PM_{10}) \quad (3)$$

$$\ln(SO_{x,damage}) = 5.41 + 0.325 \ln(pop) + 0.0138 \ln(SO_2) \quad (4)$$

$$NO_{x,cost} = 40{,}000 + 5.71 \ln(pop) + 15{,}100 \ln(O_3) \quad (5)$$

$$ROG_{cost} = 30{,}200 + 385 \ln(pop) + 12{,}000 \ln(O_3) \quad (6)$$

$$PM_{10,cost} = -16{,}800 + 793 \ln(pop) + 3{,}790 \ln(PM_{10}) \quad (7)$$

$$SOx,cost = -51{,}100 + 956 \ln(pop) + 13{,}500 \ln(PM_{10}) \quad (8)$$

$$CO_{cost} = -6{,}390 + 579 \ln(pop) + 2{,}110 \ln(CO) \quad (9)$$

where

$NO_{x,damage}$ = NO_x damage value ($/ton),
ROG_{damage} = reactive organic gases (ROG) damage value ($/ton),
$PM_{10,damage}$ = particulate matter less than 10 microns (PM_{10}) damage value ($/ton),
$SO_{x,damage}$ = SO_x damage value ($/ton),
$NO_{x,cost}$ = NO_x control cost ($/ton),
ROG_{cost} = ROG control cost ($/ton),
$PM_{10,cost}$ = PM_{10} control cost ($/ton),
$SO_{x,cost}$ = SO_x control cost ($/ton),
CO_{cost} = carbon monoxide (CO) control cost ($/ton),
pop = total population (in 10^3),

TABLE 1 Data for Regression Analysis Between Emission Values and Air Pollutant Concentrations and Population

Region	Emission Values Estimated with the Damage Value Method (1989 dollars, \$/ton)					Emission Values Estimated with the Control Cost Method (1989 dollars, \$/ton)					Air Pollutant Concentration[j]				Total Pop (10^3)
	NO_X	ROG	CO	PM_{10}	SO_X	NO_X	ROG	CO	PM_{10}	SO_X	O_3, 2nd 1-hr max. ppm	PM_{10}, highest µg/m^3	SO_2, highest ppm	CO, highest 2nd 8-hr ppm	
CA South Coast Basin[a]	14483	6911	3	47620	7425	26400	18900	9300	5700	18900	0.28	63	0.004	14	13183
CA San Joaquin Valley[a]	6473	3711	0	3762	1500	9100	9100	3200	5200	17800	0.14	63	0.004	9	2404
CA S.F. area[a,b]	7435	90	1	24398	3482	10400	10200	2200	2600	8900	0.11	35	0.003	8	5828
CA Sacramento Valley[a]	6089	4129	0	2178	1500	9100	9100	5000	2800	9600	0.14	39	0.006	11	1816
CA Ventura Co.[a]	1647	286	0	4108	1500	16500	21100	0	1800	6200	0.16	38	0.001	4	642
CA Santa Barbara[a,c]	1647	286	0	4108	1500	9100	9100	0	900	3000	0.13	36	0.002	6	351
CA North Central Coast[a]	1959	803	0	2876	1500	9100	9100	0	900	3000	0.09	24	0.001	2	572
CA San Diego[a]	5559	98	1	14228	2676	18300	17500	1100	1000	3600	0.18	41	0.005	9	2357
CA North Coast[a,d]	791	467	0	551	1500	6000	3500	0	900	3000	0.10	44	0.003	3	222
CA Southeast Desert[a,d]	439	157	0	680	1500	6000	3500	2900	5700	19700	0.17	76	0.003	10	225
CA O_3 att. and PM_{10} Vio.[a,e]	439	90	0	551	1500	6000	3500	0	900	3000	0.11	50	0.003	7	152
OR West of Cascade Range[f]	839	NA	NA	1950	NA	3350	NA	NA	3800	1400	0.11	31	0.006	8	1877
Eastern Massachusetts[g]	1640	NA	NA	3170	4060	6500	5300	870	5330	1500	0.12	33	0.012	6	4403
Greater New York Area[h]	1640	NA	NA	3170	4060	2460	5300	820	5330	603	0.16	45	0.017	10	11417
Las Vegas Valley[i]	210	0	NA	1350	280	6450	1120	820	5280	1480	0.10	65	NA	13	647

[a] Damage-based and control-cost-based emission values estimated for California air basins are from the CEC (*8*).
[b] The San Francisco area includes San Francisco metropolitan statistical area (MSA) and Oakland MSA.
[c] Emission values estimated by the CEC for the South Central Coast Air Basin are adopted for Santa Barbara.
[d] Two sets of air pollutant concentration measurements were available. One set was EPA's measurements presented in its air quality and emission trends report (*21-23*). EPA presents its measurements for each MSA nationwide. The other set was California Air Resources Board's (CARB's) measurements. CARB presents its measurements for each county in the state (*19*). In establishing regression relationships, we used EPA's air pollutant concentration measurements. There are no EPA measurements in the North Coast Air Basin or in the Southeast Desert Air Basin. We used EPA and CARB measurements available for other California air basins to establish regression relationships between EPA measurements and CARB measurements. We then used the established relationships to estimate EPA measurements from CARB measurements for the North Coast and Southeast Desert Air Basins.
[e] The ozone attainment and PM_{10} violation areas in California include four counties — Mendocino, Siskiyou, Modoc, and Lassen. Portions of Placer and El Dorado counties belonging to these areas were not considered here. The CEC-estimated emission values for this area with the control cost method, but not with the damage value method. We selected the lowest damage-based values among the California air basins as the damage-based values for the ozone attainment and PM_{10} violation area. EPA measurements of air pollutant concentrations for this area were estimated on the basis of the relationships between EPA measurements and CARB measurements (see footnote d).
[f] The damage-based values are from ECO Northwest's study for the Bonneville Power Authority (*2,17*). The cost-based values are from Oregon Public Utility Commission's estimates (*16*). The area includes Portland, Salem, Eugene-Springfield, and Medford. Air pollutant concentrations are population-weighted concentrations from the four MSAs.
[g] The damage-based values are from Pace University's estimates (*4*). The cost-based values are from Massachusetts Department of Public Utilities' estimates (*24*). The area includes Boston, Brockton, Fall River, Fitchburg-Leominster, Lowell, New Bedford, Salem-Gloucester, and Worcester. Air pollutant concentrations in the area are population-weighted averages among the eight MSAs.
[h] The damage-based values are from Pace University's estimates (*4*). The cost-based values are from New York State Energy Office (*12*). The area includes New York, Nassau-Suffolk, and Poughkeepsie. Air pollutant concentrations in the area are population-weighted averages among the three MSAs.
[i] The damage-based values are National Economic Research Associates' estimates (*9*). The cost-based values are based on the Public Service Commission of Nevada's estimates for the entire state (*25*).
[j] Data on air pollutant concentrations and total population for each MSA are from EPA's air quality and emission trends report (*21-23*). The values presented here are 3-year average values for the period 1989-91.

O_3 = highest second daily maximum 1-hr ozone concentration (ppm),
PM_{10} = highest arithmetic mean PM_{10} concentration (μg/m^3),
SO_2 = highest arithmetic mean SO_2 concentrations (ppm), and
CO = highest second max nonoverlapping 8-hr CO concentration (ppm).

Table 2 presents statistics for these regression relationships. For damage-based regressions, the t-values for the coefficient of the population variable always exceed those for the pollutant concentration. This result appears consistent with the damage value method, which focuses on the number of individuals exposed, using population directly in the damage function, whereas the control cost method is, in principle, affected by the size of the population exposed, but population per se does not enter into the computations of estimating control costs. For control-cost-based regressions, the t-values for the coefficient of the pollutant concentration variable always exceed those for the population variable, and the coefficient of the population variable is generally insignificant (though correct in sign). This result appears consistent with the focus of control cost on achieving reduced concentrations, regardless of the size of population exposed.

By the nature of regression analysis, these relationships are applicable only to areas in which air pollutant concentrations and population lie within the ranges of air pollutant concentrations and population used for the regression analysis (see Table 1 for the ranges). Application of air pollutant concentrations and population below the ranges to the regression relationships can result in unrealistic negative emission values.

Among the cited original studies, only the CEC study estimated CO damage values for California's air basins. CEC estimated a value of \$3/ton for the South Coast Air Basin, \$1/ton for both the San Francisco Bay Area and San Diego, and \$0/ton (i.e., zero value) for other California air basins. The CEC estimates imply virtually zero CO damage value. The CEC study estimated CO damage values on the basis of power-plant CO emissions. Generally, CO nearly is a nonreactive pollutant that disperses rapidly from its point of origin and is not a problem at great distance from the source. Although power plants and people are not close together, motor vehicles and people usually are. For example, the greatest CO concentrations are usually found near busy intersections. In addition, total CO emissions from motor vehicles are far greater than from stationary fuel combustion, leading to higher CO concentrations along roads than near stationary combustion sources. For example, nationwide, the transportation sector accounts for more than 60 percent of total CO

TABLE 2 Statistics of Emission Value Regression Relationships

Variable	Statistical parameter	NO_X	ROG	PM_{10}	SO_X	CO
Damage-Based Regressions						
Regression	Adjusted R^2	0.43	0.36	0.30	0.67	N/E
	Standard error	2775	1686	0.9785	0.3250	N/E
	F value	7.39[a]	4.93[b]	4.55[b]	12.0[a]	N/E
Constant	Standard error	N/E	N/E	N/E	1.33	N/E
	t value	N/E	N/E	N/E	4.05[b]	N/E
Population	Standard error	371	248	0.179	0.0868	N/E
	t value	4.43[b]	3.51[b]	4.27[b]	3.75[b]	N/E
Pollutant concentration	Standard error	137	881	0.353	0.148	N/E
	t value	3.09[b]	2.62[b]	1.94[b]	0.0934	N/E
Control-Cost-Based Regressions						
Regression	Adjusted R^2	0.42	0.29	0.56	0.32	0.35
	Standard error	4817	5224	1362	5658	2116
	F value	5.99[b]	3.64[c]	9.73[a]	4.33[b]	4.47[c]
Constant	Standard error	14900	16600	4800	19900	3000
	t value	2.69[b]	1.82[b]	-3.49[b]	-2.56[b]	-2.13[c]
Population	Standard error	1010	1120	254	1050	441
	t value	0.00564	0.345	3.12[b]	0.907	1.31[d]
Pollutant concentration	Standard error	4950	5540	1140	4740	1170
	t value	3.06[b]	2.61[b]	3.32[b]	2.86[b]	1.81[c]

[a] At the significance level of 99%.
[b] At the significance level of 95%.
[c] At the significance level of 90%.
[d] At the significance level of 85%.
N/E = Not estimated (see text).

emissions, whereas stationary fuel combustion accounts for only about 12 percent (*22*). In summary, CO emissions from motor vehicles are far more damaging than those from power plants. Accordingly, the authors conclude that using the available damage estimates for CO would be inappropriate and consequently do not estimate a CO damage equation.

Comparison of Emission Values Between Original Estimates and Regression Estimates

Figures 1 and 2 present comparisons between original and regression estimates for a selection of 8 of the 15 U.S. regions in which estimated emission values have been obtained for this study: Boston, Las Vegas, Los Angeles, New York, Sacramento, San Diego, San Francisco, and California's San Joaquin Valley. With respect to the damage-based emission values, regression-estimated values for SO_x and ROG are close to the original estimates in the eight areas. For NO_x, regression-estimated values in four California areas (Los Angeles, San Francisco, Sacramento, and the San Joaquin Valley) are considerably lower than the original estimates, and regression-estimated NO_x values in Boston and New York are significantly higher. The largest difference exists in PM_{10} values. Regression-estimated PM_{10} values in Los Angeles, San Francisco, and San Diego are underestimated significantly, and the value in New York is overestimated significantly. Overall, damage-based values in Los Angeles are always underestimated by the regression relationships. The variation in these estimates probably is closely tied to methods and scientific judgments used in the original studies from which the regression input data were obtained.

With respect to the control-cost-based values, the NO_x estimate is lower than the original value in Los Angeles, San Francisco, San Diego, and Las Vegas but higher in the other four areas. For ROG, the estimated value is lower than the original value in San Francisco and San Diego, but it is higher in New York, Las Vegas, and Boston. In Los Angeles, the San Joaquin Valley, and Sacramento, the regression-estimated ROG value is close to the original estimate. For PM_{10}, the regression-estimated values in New York, Los Angeles, the San Joaquin Valley, and Sacramento are close to the original estimates. The PM_{10} regression relationship underestimates the PM_{10} value in Boston and Las Vegas but overestimates it in San Diego. The SO_x regression relationship underestimates the SO_x value in Los Angeles, San Francisco, the San Joaquin Valley, and Sacramento but overestimates it in San Diego, Las Vegas, Boston, and New York. The CO regression relationship underestimates the value in Los Angeles and Sacramento but overestimates it in New York, San Diego, and Las Vegas. In San Francisco, the San Joaquin Valley, and Boston, the estimated values are close to the original values. Overall, for these eight locations, differences between regression estimates and original estimates of control-cost-based values are smaller for PM_{10} and CO than for any of the other three pollutants.

Regression-Estimated Emission Values for Various U.S. Regions

With the regression relationships established previously, the authors estimate both damage- and control-cost-based emission values for nine U.S. metropolitan areas where estimates of emission values are not available: Atlanta, Baltimore, Chicago, Denver, Houston, Milwaukee, New Orleans, Philadelphia, and Washington, D.C. Among them, Baltimore, Chicago, Houston, Milwaukee, and Philadelphia are among the nine ozone nonattainment areas specified in the 1990 Clean Air Act Amendments for introducing reformulated gasoline. Atlanta, Denver, New Orleans, and the Washington, D.C., metropolitan area are included as geographically representative of large metropolitan areas with violations of one or

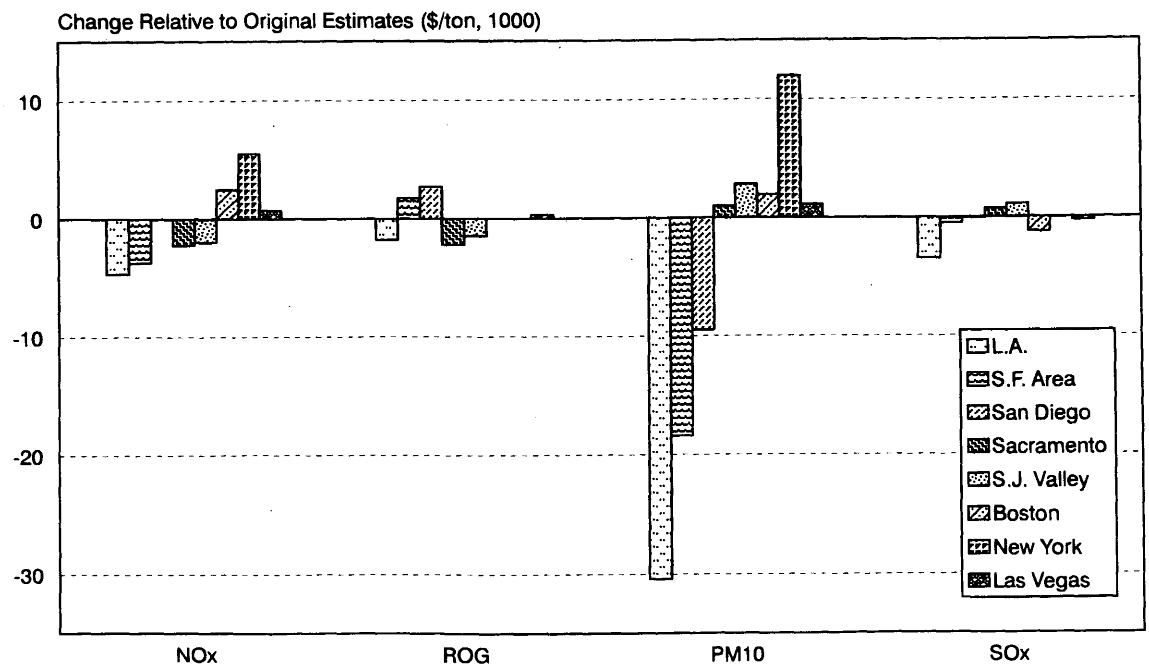

FIGURE 1 Comparison between regression estimates and original estimates, damage-based values.

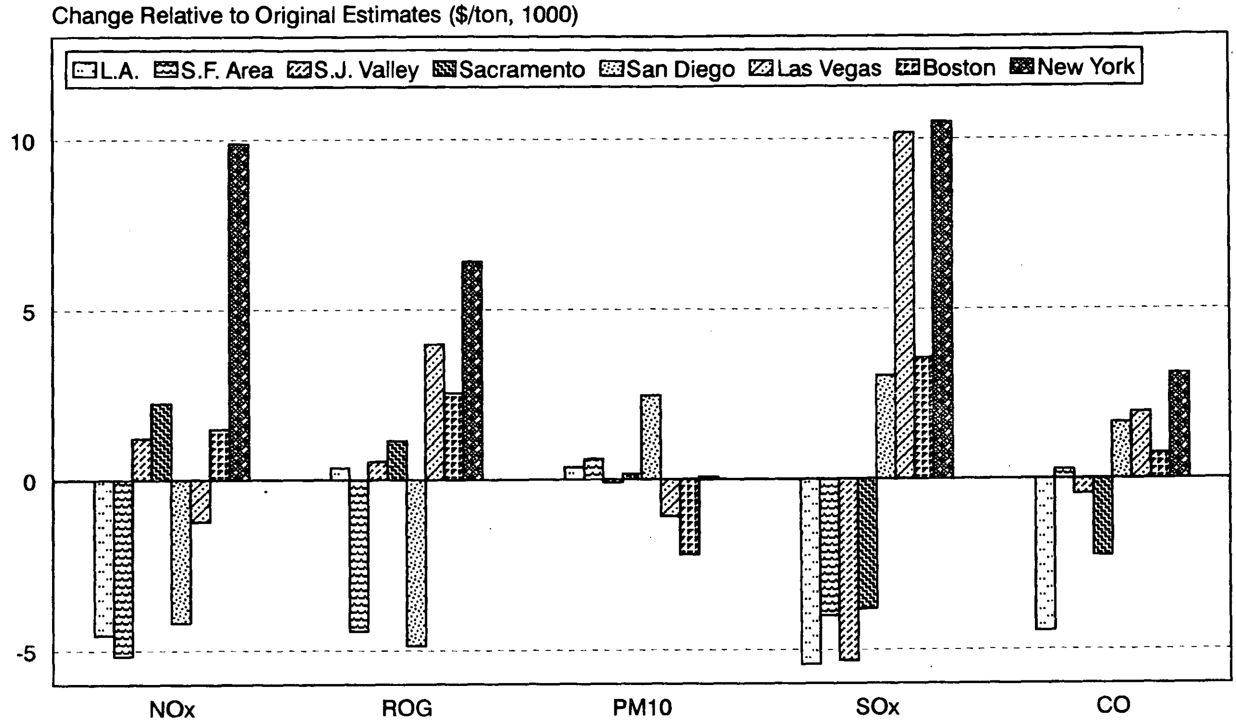

FIGURE 2 Comparison between regression estimates and original estimates, control-cost-based values.

more air quality standards. Many other areas also have air quality violations. In practice, one can select his or her own target metropolitan areas and use the preceding regression relationships to estimate emission values for the target areas.

Table 3 presents emission values estimated by using the established relationships for the nine nonattainment areas. Not surprisingly, there are significant variations in emission values across the nine areas. Damage-based emission values vary from $2,840 to $6,890 for NO_x, $1,350 to $3,540 for ROG, $2,960 to $10,840 for PM_{10}, and $2,210 to $3,600 for SO_x. Control-cost-based emission values vary from $7,990 to $17,150 for NO_x, $6,590 to $15,160 for ROG, $2,400 to $4,600 for PM_{10}, $3,130 to $9,120 for SO_x, and $1,410 to $3,160 for CO. Estimated damage-based emission values are usually lower than estimated control-cost-based values for each pollutant except PM_{10}. The underestimated damage values for PM_{10} in previous studies probably account for this outcome, because those studies did not consider all air pollution effects. For those who believe that the damage value method normally does underestimate damages, this is certainly convincing evidence that PM_{10} emissions have been undercontrolled.

QUALIFICATIONS

The regression-estimated emission values presented in this paper are based on previously estimated emission values. Compared with original estimates for a given region, regression estimates are rather rough and can only indicate the magnitude that emission values might have for the region. The regression relationships given earlier rely on original estimates, so it is recommended that original emission values, when available, be used. The authors' purpose is not to supplant a more careful study, but to provide working values that will be useful until studies are completed for the locations that lack estimates.

One can select either damage-based or control-cost-based emission values. As indicated earlier, both the damage method and the control cost method have advantages and disadvantages. One should be aware that selecting either could have significant consequences.

Past estimates of emission values were based primarily on emissions of stationary sources. Therefore, the established regression relationships, based on these past studies, rely on the estimates conducted for emissions of stationary sources. With respect to damage-based emission values, since many major stationary sources are located away from the core of a metropolitan area (while emissions from motor vehicles may occur primarily in or near the core of the metropolitan area), damage-based values for mobile-source emissions are likely to exceed those for stationary-source emissions. This phenomenon is especially true for CO emissions from motor vehicles, because CO emissions in street canyons pose a significant exposure threat to an extensive population. With respect to cost-based emission values, very few control measures for mobile-source emissions have been included in the original studies. Again, the established regression relationships are based primarily on emission control costs estimated for stationary sources. Emission values based on stationary-source control costs may be higher or lower than those based on both stationary- and mobile-source control costs.

CONCLUSIONS

Two general methods for estimating monetary values of air pollutants are presented in this paper. The damage value method directly

TABLE 3 Estimated Emission Values for Nine U.S. Regions

Area	NO_x	ROG	PM_{10}	SO_x	CO
Damage-Based Emission Values					
Atlanta	4,330	2,150	5,170	2,720	N/A
Baltimore	4,430	2,210	4,520	2,620	N/A
Chicago	5,380	2,700	10,840	3,600	N/A
Denver	2,840	1,350	3,390	2,330	N/A
Houston	6,890	3,540	5,190	2,910	N/A
Milwaukee	3,890	1,930	2,960	2,210	N/A
New Orleans	3,880	1,910	3,600	2,470	N/A
Philadelphia	5,940	3,010	8,360	3,340	N/A
Wash., D.C.	4,900	2,450	6,260	3,070	N/A
Control Cost-Based Emission Values					
Atlanta	9,190	8,780	3,460	6,420	2,280
Baltimore	10,310	9,620	3,170	5,600	2,490
Chicago	7,990	8,150	4,660	9,120	2,440
Denver	6,660	6,590	2,790	4,900	2,960
Houston	17,150	15,160	2,780	3,590	2,680
Milwaukee	11,350	10,250	2,560	4,380	1,590
New Orleans	9,190	8,670	2,400	3,130	1,410
Philadelphia	11,360	10,730	4,040	7,330	3,160
Wash., D.C.	9,190	8,910	3,340	5,320	3,010

estimates air pollutant damage values by simulating air quality, identifying health and other welfare impacts of air pollution, and valuating the identified impacts. Although the method is theoretically sound, its estimation steps involve many assumptions, and uncertainty exists in each step. The control cost method estimates the marginal emission control cost, which represents the opportunity cost offset by avoiding the need for spending on emission reductions from the most costly available emission control measures previously considered for implementation to meet regulatory requirements.

Studies conducted to estimate emission values in U.S. regions have used both methods. By taking emission values estimated for some U.S. air basins, the authors have established regression relationships between emission values and total population and air pollutant concentrations. On the basis of the established relationships, both damage-based and control-cost-based emission values have been estimated for nine major U.S. urban areas.

Although the emission values estimated by using the regression relationships may not be as accurate as the estimates obtained by applying the damage or control cost method to a region, they are superior to values adopted for the region on the basis of ad hoc selection of estimates in other regions. Ideally, emission values should be estimated for each specific region. Therefore, the authors suggest that original estimates be used for a region if they are available.

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