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IMPLICATIONS

A regression model judged to best represent mean quarterly ambient CO data indicated that sites which implemented the winter oxyfuels program in 1992 experienced a significant reduction in mean quarterly ambient CO that was sustained in subsequent years. This reduction occurred over and above the long-term trend of a decrease in ambient CO and was not observed in areas that did not implement the program.

ABSTRACT

Regression models were fit to quarterly mean ambient CO data from monitor sites which first implemented a winter oxygenated fuel program in the winter of 1992/93 and still had the program in place during the last quarter of 1994, or which had not implemented such a program through 1994. The regressions revealed a statistically significant trend of lower CO levels over time, most likely due to the effects of fleet turnover. According to the model which best represents the data based on statistical criteria, CO levels were observed to fall by 2.1 to 3.4%

per year in oxyfuel and non-oxyfuel areas combined, based on the 95% confidence interval. The analysis also revealed that ambient CO trends for the 1985/1986 winter season through the last quarter of 1994 are consistent with the hypothesis that ambient CO levels have been reduced significantly by implementation of the winter oxygenated fuels program. Ambient CO levels in areas which implemented an oxygenated fuels program in 1992 fell by 3.1 to 13.6 percent beyond what would have been expected from the long-term trend based on the 95% confidence interval. This reduction was estimated from data covering 6 months over the winter season, whereas the oxyfuel season is typically 4 months in duration for most areas. Thus, a reduction adjusted for the actual duration of the oxyfuel season, assuming in particular no spillover into the nonoxyfuel season, would be about 5 to 20%. Individual cities typically do have some spillover, and some have an oxyfuel season shorter or longer than 4 months.

INTRODUCTION

A winter oxygenated fuels program is required by Section 211(m) of the Clean Air Act Amendments of 1990 in certain areas of the country that exceed the National Ambient Air Quality Standards (NAAQS) for carbon monoxide (CO). In most areas, the program requires 2.7 weight percent oxygen on average to be present in the gasoline sold in the program areas, which is equivalent to 15 volume percent methyl tertiary butyl ether (MTBE) or 7.8 volume percent ethanol in gasoline. These two compounds are the most common oxygenates used to comply with the oxygenated fuels program requirements. The oxygenates are intended to make the combustion process more complete by providing more oxygen for combustion, thereby reducing

the rate of carbon monoxide production. As a result of this requirement, a large number of areas implemented a winter oxygenated fuels program beginning in November 1992.

Numerous dynamometer studies have demonstrated that the addition of oxygenates to gasoline reduces CO emissions substantially in both older and newer technology vehicles under a standardized driving cycle and at temperatures above 50°F.[1-4] In these studies, CO emission reductions have ranged from 2 to 10% per weight percent oxygen.[5,6] Reductions have also been found at temperatures between 20°F and 55°F, but data are lacking at temperatures below 20°F.[7] Several tunnel and remote sensing studies have confirmed that emission reductions occur under the specific real world conditions observed in those studies.[8-11] Recent studies have attempted to determine statistically whether the CO emission reductions observed under specific laboratory, tunnel, or remote sensing conditions are translated into significant reductions in ambient levels of CO in areas that have implemented a winter oxygenated fuels program. In some cities with winter oxygenated gasoline programs, a reduction in ambient CO concentrations of approximately 10% has been observed and attributed to the use of the oxygenate.[12-14] In other cases, however, a reduction either could not be quantified or was not statistically significant.[15-21]

The analyses in this study were designed to address whether ambient CO levels are consistent with a hypothesis that ambient CO levels have been reduced significantly by implementation of the winter oxygenated fuels program. This study initially grew out of an investigation into a small upturn in nationwide mean second maximum CO values and quarterly average CO levels, especially in oxyfuel areas, observed for the last quarter of 1993/first quarter

of 1994 relative to 1992/93. The 1993/94 increase in second-maximum CO levels was not found to be a statistically significant departure from the long-term downward trend seen from the 1985/86 winter season through the last quarter of 1994.

DATA

The data used in the following analyses consisted of mean ambient quarterly CO data from 310 sites in approximately 150 Metropolitan Statistical Areas over the years 1980 through 1994 (Appendix). Quarterly means values were chosen for analysis in part because they were the most readily accessible to the authors, and in part because quarterly averages would be less influenced by short-term meteorological variations ignored in the analysis. Data used in the analyses can be obtained from the authors. One-hundred seventeen (117) sites were from areas where ambient monitoring CO data were available, that had implemented the oxyfuel program in 1992/93, and still had the program in place during the fourth quarter of 1994. One-hundred and ninety-three (193) sites were from areas where ambient monitoring CO data were available and had never implemented an oxyfuel program. These data were selected so that a direct comparison could be made of changes in ambient CO from areas which had implemented an oxyfuel program with changes in ambient CO from areas which had not implemented such a program. Data from areas which had implemented an oxyfuel program prior to 1992/93 were excluded, as were data from areas which had implemented a program in 1992/93 but discontinued it. Data were analyzed on a season-by-season basis (i.e. the fourth quarter of one year and the first quarter of the following year) rather than a year-by-year basis, as is done in the U.S. EPA's National Air Quality and

Emissions Trends Report.[22,23] For the 1994/95 winter season, only data for the fourth quarter of 1994 were available.

Mean quarterly CO values are the mean of all one hour monitor values for that quarter. The minimum detectable limit for individual monitor readings is 0.5 ppm. Values below 0.5 ppm are recorded as 0.25 ppm. Readings are reported in 0.1 ppm increments as a convention. Monitors are audited by EPA for accuracy (how close measurements are to known standards) on an annual basis and precision (repeatability of measurements) on a weekly basis. Accuracy of the monitors must be within 20% for standards in the following ranges: 2-8 ppm, 15-20 ppm, 35-45 ppm, and 80-90 ppm. Precision must be within 15% for an 8-10 ppm standard.

Mean quarterly CO data were used rather than second maximum CO values because mean values are likely to be less sensitive to day to day fluctuations such as meteorology since they represent three months of measurements rather than a single measurement. Data for some sites were missing for certain quarters in certain years.

There were substantially more missing values for 1980 through the 1984/85 winter season than for later seasons. Of the 9300 potential observations for 1980 through 1994, 1261 values are missing. Only 93 sites have the full 30 observations. However, for data from 1985/86 through 1994, only 136 values are missing out of 5890 total data points, and 219 sites have the full 19 observations. Also, there was much more scatter in data for 1980 through 1984/85. Furthermore, since there is a potential non-linearity in the secular trend, using data from earlier years to

linearize the trend may increase the error in the later years. Thus, the analyses below focus on data from 1985/86 through 1994, although results from the complete data set are included as well for comparative purposes.

It should also be noted that in the analyses described below, no effort was made to estimate or interpolate missing points. Consequently, different sites and years receive slightly different weight in the various regression calculations.

Figure 1 displays box plots of the data for oxyfuel and non-oxyfuel areas by year. Higher average levels of mean ambient CO for Oxyfuel program sites are clearly shown. The plots also reveal positive skewness in the distributions, suggesting that at any time a few sites are likely to produce unusually high readings.

METHODOLOGY

These data were used to estimate a series of regression models. The following linear model forms the basis for this study:

$$\begin{aligned} Ln(CO) = B_0 + B_1{*}PROG + B_2{*}YEAR + B_3{*}POST92 \\ + B_4{*}OXPROG + B_5{*}PXYEAR + e \end{aligned} \qquad (1)$$

Where:

$$PROG = \begin{cases} 0 \text{ if non-oxyfuel program site} \\ 1 \text{ if oxyfuel program site} \end{cases}$$

YEAR = Calendar Year - 1986 (limited data set); or
Calendar Year - 1980 (complete data set)

POST92 = { 0 if pre-Quarter 4, 1992
1 if Quarter 4, 1992 or later

OXPROG = { 0 if pre-Quarter 4, 1992 or non-oxyfuel program site
1 if Quarter 4, 1992 or later <u>and</u> oxyfuel program site

PXYEAR = { 0 if non-oxyfuel program site
YEAR if oxyfuel program site

e = error term

In the model above, calendar year 1986 represents the 1985/86 oxyfuel season, 1987 represents the 1986/87 oxyfuel season, and so on. The coefficients have the following interpretation:

B_0 - Intercept for non-program sites;

B_1 - Effect (on intercept) of any time invariant factors unrelated to the oxyfuel program that nevertheless systematically differ between program sites and non-program sites variables;

B_2 - Long-term reduction trend in ambient CO levels for all sites (both oxyfuel program and non-program sites);

B_3 - Shift in Ln(CO)-intercept beginning in Winter 1992/93 for all sites (both oxyfuel program and non-program sites);

B_4 - Shift in the Ln(CO)-intercept for oxyfuel sites only, beginning in 1992/93[24];

B_5 - Difference in the slope of the regression lines between oxyfuel areas and non-oxyfuel areas.

Coefficient B_1 will reflect the fact that it was the sites with conditions leading to higher CO concentrations that were chosen by Congress to have an oxyfuel program. With the natural log transformation used in this model, the last four regression coefficients are usefully interpreted as exponential rates of decay in ambient CO over time (B_2 and B_5), incremented or decremented by the intercept shifts associated with introduction of the oxyfuels program (B_3 and B_4). The transform also can serve to stabilize the variance over time. The need for doing this is somewhat evident in Figure 1. Figure 2 demonstrates that the transformation did, in fact, stabilize the variance.

Least squares regression analyses were performed on the logarithms of the mean ambient CO data from individual sites, using the SAS PROC GLM procedure. Long-term trend (YEAR) presumably captures reductions in ambient CO resulting from mobile source control programs. The one-time shift in the intercept for all sites (POST92) captures any CO shift for 1992/93 not associated with the oxyfuel program. Possible effects of the oxyfuel program include two interaction terms -- a one-time shift in the intercept (OXPROG) of the oxyfuel program site trend lines, and the change in slope (PXYEAR) of these lines.

The purpose of this analysis is to address the primary hypothesis that the oxyfuel program has reduced CO emissions. Analyses of ambient CO data cannot prove the hypothesis, but can

determine if the data are consistent with it. In particular, after adjusting for trend (YEAR and PXYEAR) a determination can be made of whether the direction and significance of any shift in average CO in the oxyfuel program sites (OXPROG) is distinct from a general shift across all sites (POST92) following implementation. A significant negative value of B_4 and a nonsignificant value of B_3 supports the primary hypothesis that the oxyfuel program has reduced CO emissions.

The other variables potentially account for much of the variation in the data. If, as expected, the replacement of older vehicles with newer, cleaner vehicles more than offsets the yearly increase in vehicle-miles traveled (VMT) in both oxyfuel and non-oxyfuel areas, a negative value for B_2 will be observed. A difference in this trend between sites in oxyfuel areas and nonoxyfuel areas would produce a significant value for B_5, although the direction of this value was not anticipated in this research. Similarly, any general shift in the level of ambient CO coinciding with oxyfuel program implementation (B_3), possibly due to meteorology, is not predictable *a priori* but may be present.

RESULTS AND DISCUSSION

Table 1 presents regression coefficient estimates for two models using the limited data set of 1986 and later data -- one is represented by equation (1) (Model A) and one is a reduced model (Model B). Analagous regressions using the complete data set, which includes the data from 1980 through 1984/85, are included for comparative purposes (Models C and D). The R^2 values

for the Models in Table 1 are relatively low -- 0.190, 0.190, 0.186, and 0.184 for Models A, B, C, and D, respectively. These values are low because the models group many sites into two categories and do not account for the effect of each site on mean ambient CO.[25] The coefficient estimates for all models support claims about the collective efficacy of mobile source programs. The underlying trend in mean ambient CO, represented by the variable YEAR, is significant in all four models. The coefficient for this variable (B_2) ranges from -0.025 to -0.030, which suggests an average annual decrease in ambient CO of 2.5% to 3.0%. The long-term decline in ambient CO levels in both oxyfuel and non-oxyfuel areas are likely due to a combination of fleet turnover towards cars built to meet more stringent standards, improved durability of vehicle emission controls, vehicle inspection and maintenance programs in some areas, and more stringent controls on stationary sources that more than offset the effects of economic growth and increases in VMT. The step change associated with implementation of the oxyfuel program is apparent in the coefficient for the OXPROG term seen in all four models, where the estimated average effect across program sites is 11.4% in Model A, 8.3% in Model B, 14.0% in Model C, and 5.0% in Model D. This coefficient is statistically significant in all models except Model D.

As mentioned earlier, because of missing values, data scatter, and the potential non-linearity of the overall trend, use of the complete data set is likely to introduce more error into the results. Thus, Models A and B, based on the limited data set, are judged to be superior to Models C and D. Between Models A and B, B appears most satisfactory as a representation of anticipated benefits from the oxyfuel program, based on statistical criteria. As indicated above, this model includes all the terms in equation 1 except PXYEAR, the interaction term

representing the difference in the time trend between oxyfuel and nonoxyfuel areas. Where PXYEAR was included in Model A, it was the only marginal t statistic not significant at the 5% level. Since this interaction term was non-significant in Model A it was removed from the model. Although POST92 was also non-significant, it had to be retained in the model because OXPROG represents the interaction between POST92 and PROGRAM. Eliminating POST92 would bias OXPROG upward through confounding of coefficients. The significance of the OXPROG term in Model B, in contrast with the non-significance of POST92, indicates that there was a statistically significant step decrease in ambient CO for areas which implemented the oxyfuel program beginning in 1992/93, but there was not a statistically significant, corresponding decrease in nonoxyfuel areas. No mobile source program that could significantly affect ambient CO other than the oxyfuel program was implemented nationwide at this time. Many of the oxyfuel areas have vehicle emission inspection and maintenance programs, but in all or virtually all cases these began prior to 1985/86, and most have not made significant changes since (California did make changes in 1990).

Models C and D are included here to show that including the data from earlier years have a significant impact on the results of the analysis. Whereas the slope change variable (PXYEAR) was not significant in Model A, it is slightly greater than zero and significant in the analogous Model C. This would seem to indicate that the average decrease in ambient CO over time for areas which implemented the oxyfuel program is slightly lower than for nonoxyfuel areas. When this term is dropped in Model D, the coefficient for OXPROG (B_4) is still negative, but marginally insignificant. Statistically, this could be explained by collinearity of OXPROG with

PXYEAR in Model C. Because the PXYEAR term is significant when data from earlier years are included, Model C is judged to be superior to Model D.

Figure 3 depicts the regression results using Model B. In Figure 3, the individual points represent mean quarterly ambient CO for all oxyfuel areas or nonoxyfuel areas in a given season. Specifically, these points are the mean of mean CO values for each quarter at each site in that class (For oxyfuel areas, this is the mean of 236 total possible data points or fewer where there were missing values at given sites in a given season. For nonoxyfuel areas, this is the mean of 386 total possible data points or fewer where there were missing values at given sites in a given season). The regression lines for oxyfuel and non-oxyfuel areas depict the average y-intercept values across all sites.

In summary, the results of Model B are consistent with a long term CO reduction trend of 2.8%. They are also consistent with an oxyfuel program effect of about an 8% one-time step decrease in ambient CO over and above the long-term trend beginning in the winter of 1992/93, for areas which implemented an oxyfuel program at that time. The 95% confidence interval associated with the long- term trend is 2.1 to 3.4 % and for the step change coinciding with oxyfuel program implementation it is 3.1% to 13.6%. It should be mentioned that the estimate of the step change is based on data from the fourth quarter of one year and the first quarter of the next, covering a total of 6 months. However, in most oxyfuel areas, the oxyfuel season is four months in duration. Assuming no step decrease in ambient CO during the non-oxyfuel season (i.e., no spillover of oxygenated gasoline use into the non-oxyfuel season), a 5 to 20% step

decrease in ambient CO during the months the program is in effect would be expected, based on the 95% confidence interval. However, there are data from Denver indicating that the spillover effect is significant; thus, an assumption of no spillover at all is too strong. Also, some cities have oxyfuel programs of less than or more than 4 months.

One potential concern with this analysis is the possibility of correlation among errors. Errors will not be independent if seasonal deviations from the trend line are correlated among sites. Since the air quality data from both oxyfuel and non-oxyfuel sites are distributed across a wide geographic area, it is unlikely that, given the sample size, such correlation would change the statistical conclusions.

In response to reviewer comments, several modifications of these analyses which are not presented in this paper were performed. First, we observed that mean ambient CO values for the fourth quarter of one year tended to be higher than values for the first quarter of the following year. This is likely due to more inversion and less wind movement in the fourth quarter. When we added a term to the model to account for this, it did not significantly affect our results. Models were fit in which the effect of each site was included as well. Trend lines were fit to the logged time-series data for each site which were parallel to one another. The site factor captured, for example, differences among sites in traffic density and dispersion conditions. However, including a site factor in the analysis possibly confounded the program site-program implementation interaction, which is the central concern of this analysis. The potential confounding could not be avoided since every site belongs to either the non-program or program

set, but not both. To avoid this possible confounding, analyses with the site factor were also done for oxyfuel and non-oxyfuel sites separately. In addition, data were used to fit models in which a site-year interaction term was included. This effectively allowed the trend line slope to vary among sites. Finally, the models were fitted to a data set comprised of data only from those sites for which no missing values existed. In this way, all included sites had equal weight and gaps in the time series for individual sites were removed. The results from these additional analyses, not detailed here, were consistent with the hypothesis of an oxyfuel program benefit and can be obtained from the authors.

Limitations

The analyses discussed in this memo have a number of limitations. Most importantly, they do not explicitly control for meteorological factors such as temperature, wind speed, and mixing height; however, using mean ambient CO values rather than second maximum CO values for each season should make the analyses less sensitive to short-term meteorological fluctuation, since a second maximum value can reflect one severe meteorological episode within the season. Also, since the data for each oxyfuel season include means for two 3-month quarters, mean ambient CO levels will be based partly on levels outside the oxyfuel season. Moreover, these analyses include data from areas across the nation, and the results cannot be used to address whether benefits can be found in one specific region with a specific type of meteorology, such as the Northeast. In addition, the analyses do not account for differences in types of oxygenate used or levels of oxygen in the fuel among oxyfuel areas. It should also be noted that the step decrease

associated with oxyfuel program implementation cannot by this analysis alone be attributed solely to specific fuel properties such as oxygen content. Furthermore, the models assume that the decrease in ambient CO over time is log-linear. Two lines were fit to the data, one for years before 1992/93, and one for 1992/93 and later years. In the preferred Model B, these lines were forced to have the same slope; that is, we assumed that the rate of decrease over time in mean ambient CO remained the same before and after implementation of the oxyfuel program. Model B also makes an additional assumption that the slope is the same for both oxyfuel and nonoxyfuel areas. Finally, size of the estimated benefit of oxygenated fuel was sensitive to the terms and data included in the model. Thus, although the model judged to be superior based on statistical criteria is suggestive of an 8% program benefit and all models indicated a benefit, because of inherent limitations of the analysis, the quantitative results must be interpreted with caution.

Comparison to Other Studies

Ambient Air Quality Studies. A 3.1 to 13.6% step decrease (up to 5 to 20% if adjusted on the assumption of no spillover) in ambient CO is consistent with the estimates from several studies of the ambient air quality effects of oxyfuels which attempted to control for meteorological effects. For instance, CO reductions at monitoring sites in California during winter were measured at 10-35% lower for the 1992/93, 1993/94, and 1994/95 oxyfuel seasons compared to earlier years. Dolislager of the California Air Resources Board estimated that a 5-10% reduction in CO was attributable to the oxyfuel program, using NO_x and CO as independent indicators of

the effects of meteorology on air quality.[13,14] It should be pointed out, however, that California uses 2 weight percent oxygen in the fuel compared to 2.7 weight percent in most other oxyfuel areas. Assuming that the relationship between oxygen content and CO benefit is linear, Dolislager's results imply that a 2.7 weight % oxygenate program in California would result in a 6.8% to 13.5% CO benefit. A CDC study estimated CO benefits in 11 western states using 1.5-2.7 weight percent oxygen during the period 1986 through 1992.[12] The CDC researchers found that areas using oxygenates in these states had approximately 10% greater reductions in ambient CO than those that did not. Reductions of this magnitude were still found when efforts were made to account for temperature and wind speed.

However, analyses at the University of Colorado, which did not control for meteorology, generally found ambient CO reductions associated with the oxyfuel program were not statistically significant.[18-20] These studies used a regression technique known as structural time series analysis. The authors analyzed data from the Denver CO area; Albuquerque, NM; Phoenix, AZ; Las Vegas, NV; and Reno, NV. Only data from Phoenix showed a statistically significant effect of the oxyfuel program. However, depending on the sites, reductions of 7-18% were required to observe statistical significance. In a number of other studies of ambient air quality effects of oxyfuels, a reduction either could not be quantified or was not statistically significant.[15-17,21]

Emissions Studies. CO exhaust emissions from vehicles operating at temperatures of 50°F and higher are reduced by oxyfuels by about 2 to 10% per weight % oxygen, which represents a

reduction of 5 to 27% for a blend containing 2.7% oxygenate by weight.[5] A recent tunnel study in California, with a 2% oxygenate program, indicated a 21% reduction in CO emissions during the oxyfuel period relative to the non-oxyfuel season.[11] Studies by Bishop and Stedman using remote sensing found 6-16% decreases in CO emissions during the oxyfuel season.[8,9] Conversely, another remote sensing study in Raleigh, North Carolina did not find a significant reduction in CO that could be attributed to the oxyfuel program, but this study was confounded by seasonal temperature differences.[26]

Model Predictions. EPA's Complex Model for CO predicts a reduction in CO emissions with a 2.7 weight percent oxygen blend of about 9.2% for normal emitting 1990 model year vehicles and 5.0% for high-emitting vehicles.[6] EPA's MOBILE5a emission factor model predicts an average reduction in CO emissions for the on-road fleet of about 30% for a 2.7% oxygenate by weight gasoline.[5] EPA's Air Quality Trends Report indicates that on-road mobile sources account for about 60% of the nation's total annual CO emissions and 70% of total winter CO emissions.[22] Thus a 30% emission reduction in winter for motor vehicles would translate into about a 21% air quality benefit for that season, provided the on-road mobile source contribution to urban CO emissions is the same in winter as it is for the entire nation.

Potential Future Work

A potential follow-up to this study could include analyses for December and January only. All areas with an oxyfuel program are selling oxyfuel during these two months. In addition, many

CO exceedances occur during these two months. It might also be worthwhile to analyze data from the areas which initially implemented an oxyfuel program but subsequently dropped it. Another option would be to compare the ratios of mean quarterly ambient CO values in summer and winter before and after implementation of an oxyfuel program. Also, analyses could be restricted to the Northeast and North Central regions to assess the impact of the program in areas where winter temperatures are colder. Moreover, several recent studies have attempted to adjust air quality data for meteorological effects.[13,14,27-29] The applicability and reliability of these methodologies to these data should be evaluated. Yet another option for potential future work would be to perform a meta-analysis combining all sites, but allowing each to have its own unique CO trend and downward CO shift beginning in 1992/93. Similarly, a nested regression technique could be used, whereby only those sites whose trend deviated significantly from the overall trend would have a unique trend. Finally, more emission studies at low temperatures could be done to determine if CO emission benefits found at temperatures above 50°F for oxygenated fuel are also found at lower temperatures.

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23. If data were analyzed on a year-by-year basis, it would not be possible to compare ambient CO from one oxyfuel season to the next, since each season spans the latter part of one year and the first part of the next.

24. Although an observed one-time, sustained step decrease in ambient CO beginning in 1992/93 would most likely be due to the oxyfuel program, other changes could possibly contribute to such a decrease. According to the U.S. EPA's Complex Model for CO, fuel oxygen and sulfur content have the heaviest influence on exhaust CO emissions, with very little influence from such parameters as RVP, distillation characteristics and olefins. However, there were no mandated changes in sulfur content or other fuel parameters in this time period, and the lower cost of higher sulfur crude oils would be expected to discourage significant sulfur reductions in 1992 and later years.

25. Analyses which included a site factor were performed but are not included here. In these analyses, trend lines were fit to the logged time-series data for each site which were parallel to one another. Adding this site factor increased R^2 values to about 0.8 but did not affect the conclusions made in this paper.

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Table 1. Estimates and T-values (in Parentheses) for Variables Used in Regressions of Log Mean Ambient CO data.

Model	INTERCEPT	YEAR	PROGRAM	POST92	OXPROG	PXYEAR
A	0.176 (11.515*)	-0.030 (-7.248*)	0.349 (5.582*)	-0.004 (-0.149)	-0.114 (-2.741*)	0.006 (0.966)
B	0.168 (12.856*)	-0.028 (-8.453*)	0.408 (29.827*)	-0.008 (-0.347)	-0.083 (-3.104*)	---
C	0.358 (22.835*)	-0.030 (-14.771*)	0.285 (11.278*)	0.002 (0.084)	-0.140 (-3.988*)	0.013 (3.948*)
D	0.324 (24.770*)	-0.025 (-15.676*)	0.375 (32.871*)	-0.032 (-1.639)	-0.050 (-1.870)	---

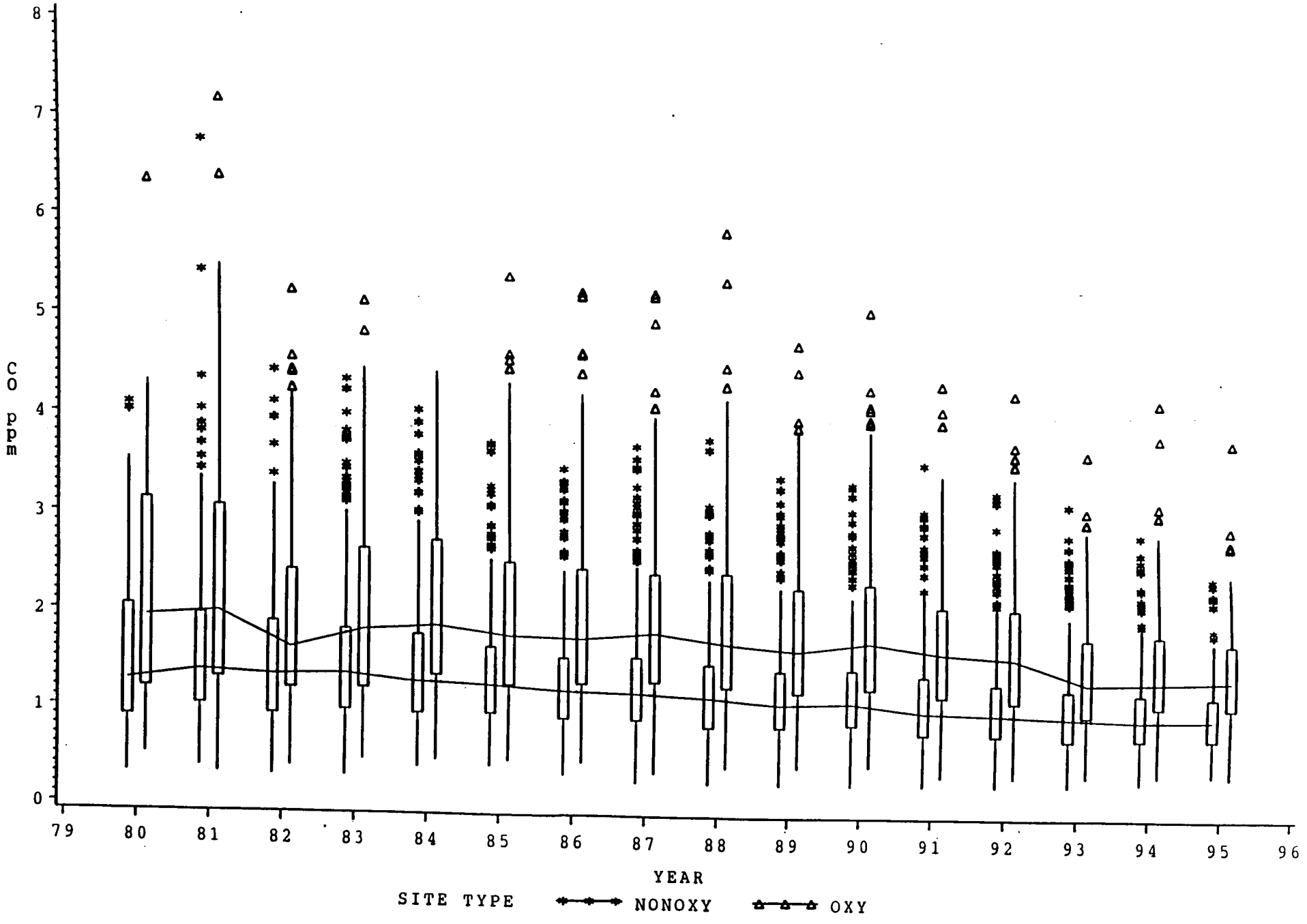
*Significant at the $p<0.05$ level

Figure 1. Box Plots of Oxyfuel and Nonoxyfuel areas by year (non-transformed data).

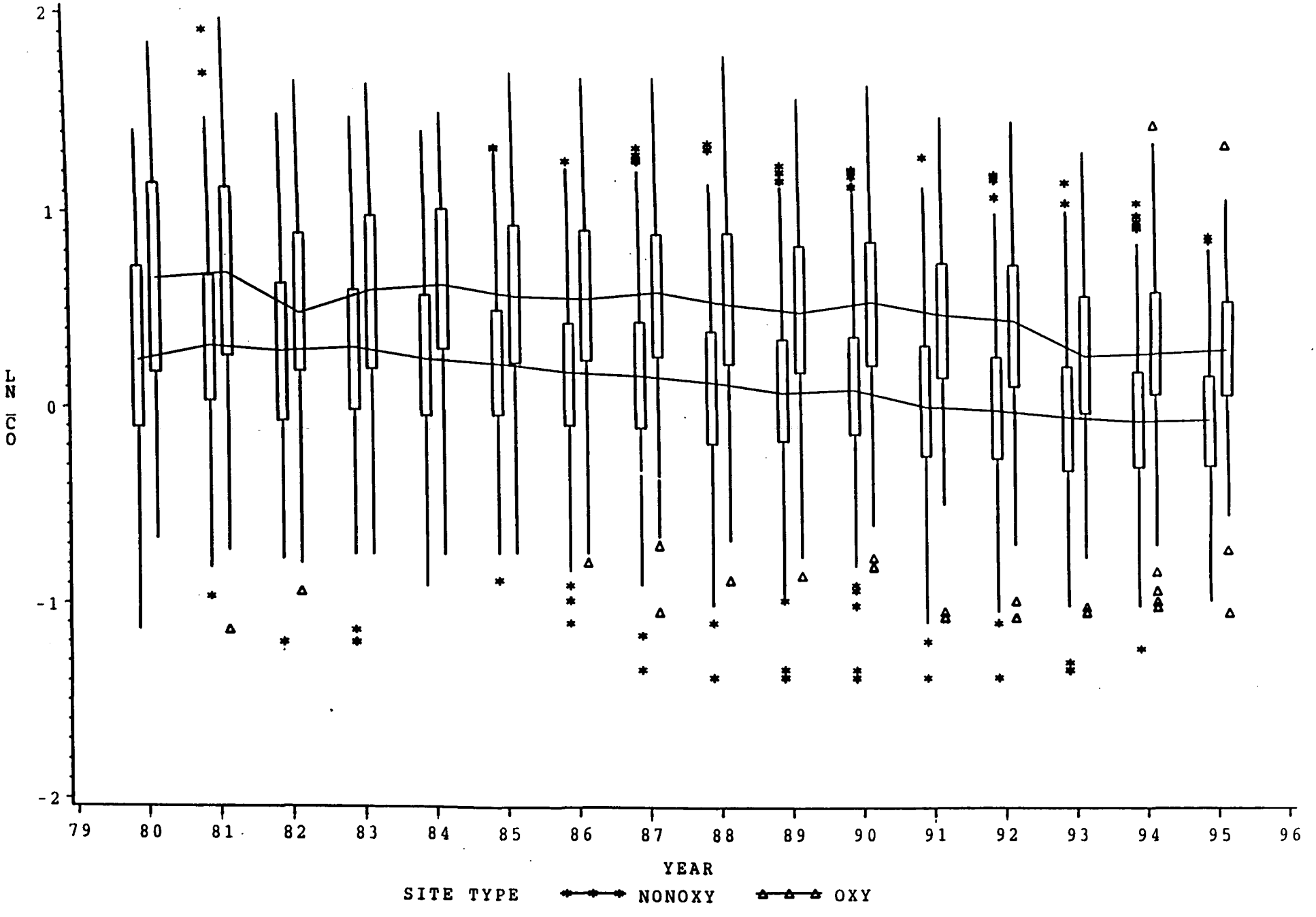
Figure 2. Box Plots of Oxyfuel and Nonoxyfuel areas by year (natural log transformed data).

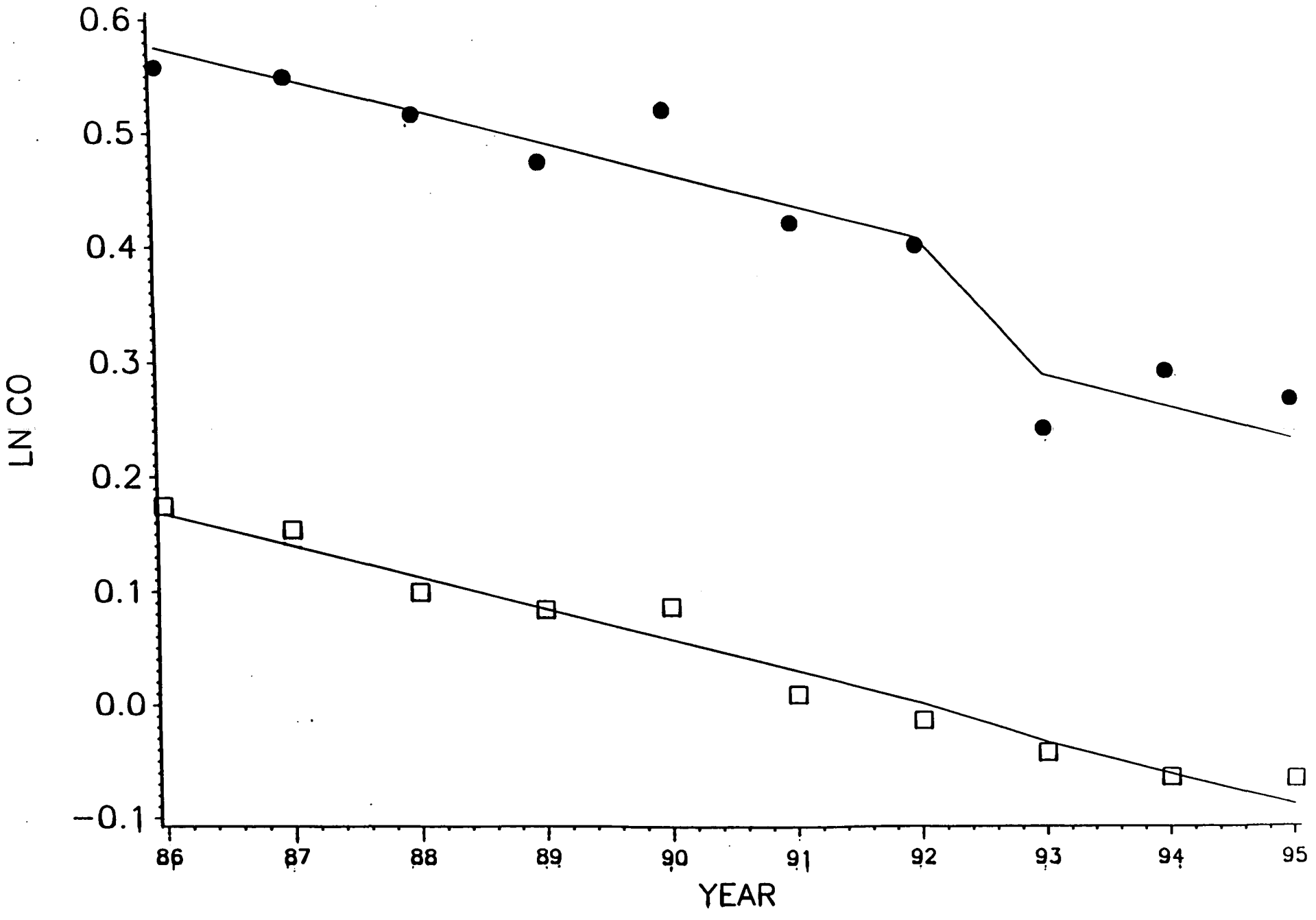
Figure 3. Regression of Log Mean Ambient CO Air Quality Data Using Model B (described in text).

BOX PLOTS OF CO BY YEAR AND SITE TYPE



BOX PLOTS OF LN_CO BY YEAR AND SITE TYPE




0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
LN CO
86
87
88
89
90
91
92
93
94
95
YEAR

APPENDIX

Metropolitan Statistical Areas (MSAs) or Counties and Number of Monitor Sites Included in Analyses

MSA or County	Number of monitor sites
Nonoxyfuel Areas:	
Birmingham, AL	5
Tuscon, AZ	3
Bakersfield, CA	2
Mono County, CA	1
Salinas, CA	1
Vallejo-Fairfield-Napa, CA	2
Orange County, CA	3
San Luis Obispo-Atascadero-Paso Robles, CA	1
Santa Barbara-Santa Maria-Lompoc, CA	2
Santa Cruz-Watsonville, CA	1
Santa Rosa, CA	1
Visalia-Tulare-Porterville, CA	1
Ventura, CA	2
Greeley, CO	1
Fort Lauderdale, FL	4
Miami, FL	2
Jacksonville, FL	4
Tampa-St. Petersburg-Clearwater, FL	7

MSA or County	Number of monitor sites
Orlando, FL	2
West Palm Beach-Boca Raton, FL	1
Atlanta, GA	1
Honolulu, HI	2
Boise City, ID	1
Chicago, IL	4
St. Louis, MO-IL	6
Peoria-Pekin, IL	1
Springfield, IL	1
Rockford, IL	1
Fort Wayne, IN	1
Gary, IN	1
Cedar Rapids, IA	1
Des Moines, IA	3
Wichita, KS	3
Kansas City, MO-KS	5
Owensboro, KY	1
Lexington, KY	1
Evansville-Henderson, IN-KY	1
Louisville, KY-IN	3
Cincinnati, OH-KY-IN	3
McCracken County, KY	1
New Orleans, LA	2
Cumberland, MD-WV	1

MSA or County	Number of monitor sites
Springfield, MA	1
Lowell, MA-NH	1
Boston, MA-NH	2
Grand Rapids-Muskegon-Holland, MI	1
Detroit, MI	5
Rochester, MN	1
Springfield, MO	1
Missoula County, KY	1
Omaha, NE-IA	2
Lincoln, NE	1
Douglas County, NV	1
Nashua, NH	1
Middlesex-Somerset, Hunterdon, NJ	1
Las Cruces, NM	2
San Juan County, NM	1
Santa Fe, NM	1
Buffalo-Niagara Falls, NY	3
Rochester, NY	2
Albany-Schenectady-Troy, NY	1
Charlotte-Gastonia-Rock Hill, NC-SC	3
Columbus, OH	3
Stuebenville-Weirton, OH-WV	1
Toledo, OH	1
Dayton-Springfield, OH	2

MSA or County	Number of monitor sites
Canton-Massilon, OH	1
Oklahoma City, OK	2
Tulsa, OK	2
Josephine County, OR	1
Eugene-Springfield, OR	1
Pittsburgh, PA	5
Reading, PA	1
Johnstown, PA	1
Harrisburg-Lebanon-Carlisle, PA	1
Erie, PA	1
Scranton-Wilkes-Barre-Hazelton, PA	2
Allentown-Bethlehem-Easton, PA	2
York, PA	1
Providence-Fall River-Warwick, RI-MA	2
Charleston-North Charleston, SC	1
Columbia, SC	1
Nasheville, TN	3
Johnson City-Kingsport-Bristol, TN-VA	1
San Antonio, TX	2
Dallas, TX	2
Houston, TX	5
Beaumont-Port Arthur, TX	1
Fort Worth-Arlington, TX	2
Salt Lake City-Ogden, UT	4

MSA or County	Number of monitor sites
Burlington, VT	1
Norfolk-Virginia Beach-Newport News, VA-NC	2
Richmond-Petersburg, VA	2
Yakima, WA	1
Charleston, WV	1
Wheeling, WV-OH	1
Madison, WI	1
Milwaukee-Waukesha, WI	5
Racine, WI	1
San Juan-Bayamon, PR	2
Oxyfuel Areas	
Oakland, CA	6
Chico-Paradise, CA	2
Sacramento, CA	6
Fresno, CA	3
Los Angeles-Long Beach, CA	12
San Francisco, CA	4
Riverside-San Bernardino, CA	6
San Diego, CA	6
Stockton-Lodi, CA	2
San Jose, CA	3
Modesto, CA	1
Bridgeport, CT	1
Stamford-Norwalk, CT	1

MSA or County	Number of monitor sites
Hartford, CT	2
New Haven-Meriden, CT	1
Wilmington-Newark, DE-MD	2
Washington, DC-MD-VA-WV	9
Baltimore, MD	4
Worcester, MA-CT	1
Minneapolis-St. Paul, MN-WI	3
Bergen-Passaic, NJ	2
Philadelphia, PA-NJ	10
Newark, NJ	3
Jersey City, NJ	1
Monmouth-Ocean, NJ	2
New York, NY	4
Nassau-Suffolk, NY	1
Raleigh-Durham-Chapel Hill, NC	1
Akron, OH	2
Medford-Ashland, OR	1
Portland-Vancouver, OR-WA	3
El Paso, TX	4
Provo-Orem, UT	2
Seattle-Bellevue-Everett, WA	5
Tacoma, WA	1
Spokane, WA	1