A Spatial Econometric Approach to Measuring Air Pollution Externalities

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Abstract

This paper uses spatial exploratory data analysis and spatial econometrics to analyze the regional transport of air pollution. According to my results, precursor emissions from up to 1000 km away from a variety of directions can have significant effects on ozone air quality, though the effect is not always negative, and although neither the sign nor the significance of the effect is constant over time. NO_x emissions from West Virginia and Ohio appear to increase the 90[th] percentile ozone concentration in a number of other states. Non-monotonicities in ozone production may be a reason why the transport of NO_x can sometimes be a positive externality rather than a negative one, and why a cap-and-trade program that reduces aggregate NO_x emissions may not always reduce ozone.

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1 Introduction

In 1997, eight states in the northeastern United States filed petitions under Section 126 of the Clear Air Act, claiming that emissions from upwind states were affecting their ability to attain and maintain the national ambient air quality standard for ozone smog. These petitions identified 31 states plus the District of Columbia as containing sources that significantly contribute to the regional transport of ozone (EPA, 1999b; Helms, 2002).[2] All the petitions target sources in the Midwest; some of the petitions also target sources in the south, southeast, and northeast (EPA, 1999a). Were these petitions justified? Is it indeed the case that emissions from one state may affect the air quality in another state?

The principal ingredient of smog, tropospheric ozone is the most difficult to control of the six criteria pollutants for which United States Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS) have been established (Chang & Suzio, 1995). Among ozone's adverse effects on humans are labored breathing, impaired lung functions, increased hospital admissions and emergency room visits for respiratory causes, and possible long-term lung damage. Ozone exposures have also been associated with a wide range of vegetation effects, including visible foliar injury, growth reductions and yield loss in agricultural crops; growth reductions in seedlings and mature trees; and impacts at forest stand and ecosystem levels (EPA, 1997b; Sillman, 1995a).

A secondary pollutant, ozone is not emitted directly but is formed in ambient air by chemical reactions involving nitrogen oxides (NO_x), which consist of nitrogen oxide (NO) and nitrogen dioxide (NO_2), and volatile organic compounds (VOCs). NO_x is emitted from fossil fuel combustion, biomass burning, lightning, stratospheric flux, and microbial activity in soils (Carroll & Thompson, 1995), while VOCs are emitted from combustion, industry and vegetation (NRC, 1992). Cities with high emission rates, warm temperatures, frequent inversions, and stagnant meteorology are most vulnerable to high levels of ozone smog (Sillman, 1993).

[2] According to the EPA (1999b), only 30 states plus DC were identified.

The rate of ozone production shows a nonlinear and non-monotonic dependence on precursor concentrations. There are two different photochemical regimes: a NO_x-limited regime, in which the rate of ozone formation increases with increasing NO_x and is insensitive to changes in VOC; and a VOC-limited regime, in which the rate of ozone formation increases with increasing VOC and may even decrease with increasing NO_x (Sillman, 1999). Thus, higher emissions of NO_x do not always result in higher levels of ozone pollution; in some cases, higher NO_x emissions may actually *decrease* ozone.[3]

Both ozone and its precursors are transboundary pollutants. Since the lifetime of ozone is several days long, enabling transport of up to 2000 km (Daniel Jacob, personal communication, 18 March 2000), peak ozone associated with an individual city is the sum of the city's local production contribution plus the regional baseline ozone imported by that city. When regional baseline concentrations are already high, individual cities do not always have direct control of their own attainment of the ozone standard. For instance, according to the EPA: "a reduction in transport into the New York area associated with upwind emissions reductions on the order of 75 percent for NO_x and 25 percent for VOC along with local VOC and NO_x reductions may be needed for attainment in New York" (EPA, 1997a, II.B.4).

To assess the extent of regional transport, the EPA has relied primarily from the simulation results of atmospheric chemistry models (Tracey Holloway, personal communication, 25 March 2003).[4] For example, the 1990 Clean Air Act Amendments require the use of 3-D Eulerian photochemical modeling for planning ozone attainments in many nonattainment areas (Chang & Suzio, 1995; Sistla et al., 1996).

While these models incorporate natural phenomena such as wind patterns, seasonal cycles, chemical processes, and biological emissions, they have several drawbacks. First, the models make many functional form and parameter assumptions in order to specify the equations governing chemical processes and transport. For example, rate constants are assumed to be a given function of temperature

[3] This phenomenon is known as NO_x titration; for a scientific explanation, see Lin (2000).
[4] The majority of models are Eulerian models, which simulate the concentration and transport of air pollution at every grid point and time step. Another type of model is a Lagrangian model, which follows a given air parcel, but must make the assumption that each air parcel is independent and therefore that there are no interactions between air parcels (Tracey Holloway, personal communication, 25 March 2003).

and other factors, and natural emissions of isoprene are assumed to be a parametric function of a given set of base emissions. While many of these functional form and parameter assumptions may have been estimated off of actual data or experiments, and therefore should have confidence intervals associated with them, they are instead treated as if they were known with certainty and constant over time (Arlene Fiore, personal communication, 25 October 2002).

A second drawback with using models to measure transport is that the models are deterministic. In contrast, ozone smog is in part a function of stochastic factors such as weather (Arlene Fiore, personal communication, 25 October 2002). It is unclear whether these model simulations appropriately handle the stochastic component to ozone formation.

A third problem with the photochemical models is that their accuracy is limited. For example, uncertainties in boundary conditions (Winner et al., 1995) and in meteorological parameters such as wind fields and mixing heights (Sistla et al., 1996) cast doubt on the accuracy of VOC-NO_x sensitivity predictions (Chang & Suzio, 1995; Sillman, 1995b). Models can also err in their prediction of sensitivity because similar ozone concentrations can be produced in either VOC- or NO_x-sensitive environments (Sillman, 1995b).

A fourth problem with the atmospheric chemistry models is that supporting data for input and diagnostic evaluations are sparse or lacking for most regions (Blanchard et al., 1999). A fifth problem is that models are costly in terms of both time and money (Blanchard et al., 1999; Winner et al., 1995).

The purpose of this paper is to measure regional transport using a different approach: that of spatial exploratory data analysis and spatial econometrics. I hope to tease out, statistically, the extent to which emissions at one location impose an externality on air quality at another state.

A spatial econometric approach to measuring air pollution externalities has several advantages over the conventional modeling approach. First, by estimating reduced-form relationships between emissions and air quality at neighboring sites, I avoid having to make any of the parametric, structural or functional form assumptions that are needed for an atmospheric chemistry model—assumptions that can sometimes be ad hoc. Second, the use of econometrics enables me to form confidence intervals around my estimates, and therefore provide a more informative measure of the externality. Third, an alternative means of measuring air pollution externalities enables us to compare the validity of the modeling and econometric approaches.

The research questions I hope to answer are thus the following. First, *What is the effect of air quality and emissions at one site on air quality at another site?* And second, *What is the optimal geographical range for regional coordination?*

My paper is important for several reasons. First, methods that account for the spatial dimension of social, economic and environmental processes are of statistical and econometric interest. Second, externalities are an important concept in economics and especially in environmental economics; in this paper I quantify air pollution externalities. Third, my results have important implications for policy, especially those involving the regional transport of ozone and the design of regional coordination.

According to my results, both ozone and NO_x air pollution exhibit spatial correlation, and this correlation is in many cases due to transport rather simply to spatially correlated omitted variables. Emissions from up to 1000 km away from a variety of directions can have significant effects on air quality, though the effect is not always negative, and although neither the sign nor the significance of the effect is constant over time. In the Eastern United States, emissions from EPA Regions 2 to 5 may affect air quality in EPA Regions 2 to 5, but not in Region 1. NO_x emissions from West Virginia and Ohio appear to increase the 90^{th} percentile ozone concentration in a number of other states in the Eastern United States. A cap-and-trade program for the states in the NO_x SIP call may be appropriate for reducing ambient NO_x, but not for reducing ambient ozone. Non-monotonicities in ozone production may be a reason why the transport of NO_x can sometimes be a positive externality rather than a negative one, and why a cap-and-trade program that reduces aggregate NO_x emissions may not always reduce ozone.

The balance of this paper proceeds as follows. In Section 2, I describe my data set. Section 3 presents summary statistics. Section 4 presents maps of my data. Section 5 analyzes the spatial autocorrelation structure of my data, and Section 6 analyzes whether the spatial autocorrelation arises from true or spurious state dependence. In Section 7, I examine the geographical extent of transport. In

Section 8, I examine whether transport across political boundaries matters. In Section 9, I examine a model that incorporates both spatial distances and time lags. Section 10 concludes.

2 Data

2.1 Annual data

Annual summary data of ozone (mean 1-hour O3, 10th percentile 1-hour 03, 90th percentile 1-hour O3) and NO_x (mean 1-hour NO_x), all in parts per billion (ppb), were obtained via monitor data queries of the EPA's Air Quality System (AQS) database (http://www.epa.gov/aqspubl1/annual_summary.html).

Annual county-level NO_x and VOC emissions estimates data for 1990, 1996-1999 and 2001 were obtained from Tom McMullen of the EPA, and were converted from tons per year to tons per square mile per year using county area data from the EPA.[5]

The annual county-level population and per capita personal income (nominal $) variables are taken from the Bureau of Economic Analysis (BEA)'s County Summary CA1-3 1969-2001 (BEA, 2003a).[6] Per capita income data were deflated to 1982-1984 U.S. dollars using the consumer price index (CPI). County population data were converted to population per square mile using county area data from the EPA.

[5] According to McMullen (personal communication, 23 December 2003): "The process of estimating emissions is continually under scrutiny and refinement. At the following web page http://www.epa.gov/ttn/chief/publications.html#reports you will find six bulleted links; choose the second: Emission Inventory Trends Documents and then the first listed document – PROCEDURES DOCUMENT FOR NATIONAL EMISSION INVENTORY, CRITERIA AIR POLLUTANTS 1985-1999 (EPA-454/R-01-006) describes the processes for each major source category (409 pages, enjoy!). It is the on-going refinement and correction process that has rendered the '91-'95 data inconsistent. We had funds only to update the base year, 1990, and the years 1996 forward.

"Basically, demographic data (census data, economic data, etc.) are multiplied by empirical emissions factors (tons of NOx per million BTUs of fuel burned), summed over all known sources of NOx. Electric generating plants are a special case; most have sensors installed in their stacks monitoring actual emission amounts."

[6] According to BEA (2003b), "**Personal income** is the income received by all persons from participation in production, from government and business transfer payments, and from government interest. Personal income is the sum of net earnings by place of residence, rental income of persons, personal dividend income, personal interest income, and transfer payments. **Net earnings** is earnings by place of work (the sum of wage and salary disbursements, other labor income, and proprietors' income) less personal contributions for social insurance, plus an adjustment to convert earnings by place of work to a place-of-residence basis. Personal income is measured before the deduction of personal income taxes and other personal taxes and is reported in current dollars (no adjustment is made for price changes).... Per capita personal income is the annual total personal income of residents divided by resident population as of July 1."

2.2 Daily data

Hourly ozone concentration data from 1980 to 1998 were extracted from the EPA's Aerometric Information Retrieval System (AIRS). Data for the first 16 years were extracted by Fiore et al. (1998), while data for the last 3 years were obtained via a Freedom of Information Act Request.[7]

I chose to begin the data set in 1980, a year after the EPA used an ultraviolet photometric method to uniformly calibrate all ozone measurements (Chock, 1989). Most ozone instruments at AIRS sites measure within 5-6% of the true value most of the time for ozone concentrations in the range of 30-80 ppb, with the accuracy somewhat higher for ozone concentrations in higher ranges (Fairley, 1999).

Over 2000 sites across the United States have monitored ozone at one time or another over the 19 years of my data set. I segregated the sites into grid squares 4° latitude by 5° longitude (approximately 400 km by 500 km) in size, each named by the coordinates of the point at its center. For some analyses, the grid squares are grouped by quadrant; the boundaries for these quadrants are 97.5°W in longitude and 36°N in latitude. Figure 1.1 in Lin (2000) shows the boundaries of the grid squares and quadrants.

For cases in which data for sequential years were available from sites a few kilometers apart, usually because the ozone monitoring station had moved, the ozone data were merged. In accordance with the protocol for the new NAAQS, running 8-hour averages, indexed by the first hour, were calculated for each 8-hour interval with at least 6 hours of data, and the daily maximum 8-hour average was stored for each day for each site.

Daily maximum temperature data were extracted from National Climatic Data Center (NCDC) Summary of the Day First Order data files. These files contain daily selected elements of observations taken by certified stations operated by the National Weather Service, United States Air Force, United

[7] At each AIRS monitoring site, ozone is measured by Advanced Pollution Instrumentation (API) 400 ozone analyzers which are subject to frequent calibration and consistency checks. Automated zero (0 ppb), precision (100 ppb) and level 1 (400 ppb) checks are performed at least every three days, level checks are performed twice a month, and full calibration occurs every three months (D. Flynn, personal communication, Sept. 9, 1999). For photographs of the air monitoring station at Waltham, MA, see Appendix A of Lin (2000).

States Navy, and the Federal Aviation Administration (NCDC, 1998). Following Fiore et al. (1998), the NCDC sites were selected for the length of their records and their proximity to AIRS sites. One NCDC site was selected for each 4° by 5° grid square. See Figure 1.2 in Lin (2004). A finer resolution is unnecessary because the lifetime of ozone is long enough for ozone and temperature to be correlated throughout the same grid square, and because small-scale variations in temperature and ozone are not necessarily correlated. These assumptions are verified in Lin (2000).

For my daily data, I restrict my data to the month of July for each year.

3 Summary Statistics

Table 1 presents summary statistics for my data.

As a point of reference, the original primary and secondary National Ambient Air Quality Standards (NAAQS) for ozone established in 1979 were each a 1-hour average of 120 ppb, not to be exceeded more than three times in three years. In July 1997, based on its review of the available scientific evidence linking ozone exposures to adverse health and welfare effects at levels allowed by the 1-hour standards, the EPA revised both ozone standards to 8-hour standards at levels of 80 ppb, with forms based on the three-year average of the annual fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area (EPA, 1998). The NAAQS for NOx is 53 ppb for an annual (arithmetic) mean (EPA, 2004a).

According to Table 1, while both the annual mean and the annual 10^{th} percentile values for ozone have trended upwards over the period 1990-2001, there is no significant trend in the annual 90^{th} percentile value for ozone. The upward trend in the 10^{th} percentile ozone concentrations is consistent with an increase in the background level of ozone, perhaps due to transport from outside the United States (Lin, Jacob, Munger & Fiore, 2000). The insignificant trend in the 90^{th} percentile value for ozone is consistent with a study by Lin, Jacob and Fiore (2001) demonstrating that while air quality improved from the 1980s to the 1990s, the improvements leveled off during the 1990s. There is a downward trend in the daily maximum 8-hour average ozone.

As for the ambient NO_x concentration, while the annual mean NO_x has increased over time, both the annual 10th percentile and the annual 90th percentile NO_x have decreased over the period of study.

There are significant downward trends in both NO_x and VOC emissions per square mile, which is evidence for the effectiveness of pollution control measures on net.

4 Maps

As an initial overview of the spatial features of my data set, I first present maps of the spatial means and the quartile values of my variables.

4.1 Spatial mean

The spatial mean $(\bar{x}, \bar{y})$ of a set of observations $\{z_1, ..., z_n\}$ of spatial variable Z, where each z_i is located at coordinates (x_i, y_i), is given by (Arlinghaus, 1996; Griffith & Amrhein, 1991):

$$(\bar{x}, \bar{y}) = \left(\frac{\sum_i z_i x_i}{\sum_i z_i}, \frac{\sum_i z_i y_i}{\sum_i z_i} \right)$$

and the standard distance SD is given by:

$$SD = \left(\frac{\sum_i z_i (x_i - \bar{x})^2}{\sum_i z_i} + \frac{\sum_i z_i (y_i - \bar{y})^2}{\sum_i z_i} \right)^{1/2} .$$

In Figures 1a-c, I plot the spatial mean and standard distance for each of the variables in my annual data set, for each year separately and also for all years pooled together.

For ozone, the spatial means of the annual mean, 10th percentile and 90th percentile all coincide. Per capita county income lies to the West of county NO_x and VOC emissions and county population density. For the NO_x data set, the NO_x mean and county per capita income lie to the West of the county NO_x emissions and county population density. All the spatial means appear roughly constant over time.

4.2 Quartile maps

To better grasp the spatial distribution of my data, each of the maps in Figures 2 and 3 plots, for a given variable in my data set, the location of each of the observations for a given year and color codes the points by quartile.[8] Dotted lines indicate quadrant boundaries (36ºN, 97.5ºW); I use these quadrants as a grouping variable for the mixed effects analyses in Section 7.

In my annual data set, there are three measures of ambient ozone (mean, 10^{th} percentile and 90^{th} percentile), one measure of NO_x (mean), two types of county emissions (NO_x and VOC), and two county controls (population density and per capita income). Figure 2 presents maps of these variables for the years 1990, 1996 and 2001.

There are several key features of these maps. First, it seems that many of the variables have a spatial component; for ozone, for example, high values tend to be clustered in the Midwest, along the East coast, and in California. Second, the spatial patterns for precursor emissions are not identical to the ones for ozone air quality. For example, in the eastern half of the US, high values of NO_x emissions extend further West than high values of 90^{th} percentile ozone do, suggesting that emissions of NO_x might be transported eastward.

Figure 2 plots, for the two daily variables (daily maximum 8-hour average ozone and daily maximum temperature), the values on July 15^{th} for 1980, for 1990 and for 1998.[9] Once again, ozone appears to exhibit a high degree of spatial autocorrelation, as does temperature.

Having presented graphical evidence for possible spatial autocorrelation, I now test whether spatial autocorrelation is indeed present.

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[8] I need to show each year separately because the "geoR" package does not easily handle multiple observations at the same site.

[9] I choose the years 1980 and 1998 because they are the end points of my daily data set; I choose 1990 as well because it is the date closest to the midpoint during which I also have annual emissions data.

5 Spatial Autocorrelation

I use two tests for spatial autocorrelation: the Moran's *I* test and the Geary's *c* test. For both tests, I test the null hypothesis H_0 of no spatial autocorrelation against the two-sided alternative hypothesis H_1 that the data are spatially autocorrelated. Two versions of the null hypothesis H_0 are used: one under a normality assumption and the other under a randomization assumption. Under the normality assumption for H_0, the observed map is assumed to be the result of *n* independent draws from a normal population, and is therefore one possible realization of an underlying normal probability model. Under the randomization assumption for H_0, the observed map is one possible arrangement of the set of *n* values (Haining, 1990).

For both tests, I define a spatial neighborhood using distance (Bivand & Portnov, 2002). In particular, the first-order "neighbors" of any particular site *i* consist of all other sites with data in the given year located between 1 km and 500 km (in Great Circle distance) from site *i*.

According to my results, for nearly all variables and for both types of tests, and for both distributional assumptions, the null hypothesis of no spatial autocorrelation can be rejected at a 5% significance level.[10] Thus, nearly all my annual variables (mean 1-hour O3, 10th percentile 1-hour 03, 90th percentile 1-hour O3, mean 1-hour NO_x, county-level estimated NO_x emissions per square mile, county-level estimated VOC emissions per square mile, annual county-level population per square mile, and annual county-level per capita income) exhibit spatial autocorrelation.

Having confirmed that air quality is indeed spatially autocorrelated, I now test to see if the autocorrelation is due to transport.

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[10] All the p-values are < 2.2E-16, with the exception of VOC emissions for Geary's *c* under randomization (p-value = 0.119); NO_x emissions for Geary's *c* under randomization (p-value =0.0051); and population for Geary's *c* under both normality (p-value = 4.076E-10) and randomization (p-value = 0.3054).

6 Spurious or true state dependence?

In this section, I examine whether the spatial autocorrelation in ambient air quality is due to transport or merely to omitted variables.[11]

In the unrestricted version of the model, which I call the *spatial distance model*, air quality z is given by:

$$z = \rho Wz + X\beta_1 + WX\beta_2 + \varepsilon, \qquad (1)$$

where W is a weight matrix, X is a matrix of explanatory variables including emissions, and ε is i.i.d. normal. The weight matrix W is derived from assuming, as I did above, that the first-order "neighbors" of any particular site i consist of all other sites located between 1 km and 500 km from site i, and from requiring the weights to all of site i's neighbors sum to 1 for each site i. I call Wz the "distanced" value of z, as it represents the value of z at neighboring sites, subject to distance decay. The parameter ρ indicates the extent of spatial interaction between neighboring observations.

As seen from its reduced-form version,

$$z = (I - \rho W)^{-1}(X\beta_1 + WX\beta_2 + \varepsilon), \qquad (2)$$

the spatial distance model implies that the air quality z at any one site depends on the distanced values of the explanatory variables X. In particular, if X includes emissions, then this means that air quality at one site depends on the emissions from a neighboring site. If the autocorrelation in z does indeed arise from a dependence on distanced X's, then, following the terminology used by Heckman (1978) in an analogous time series context, there is true state dependence.

However, if the following restriction holds:

$$\beta_2 = -\rho\beta_1 \qquad (3)$$

then the model collapses to:

$$z = X\beta_1 + \mu, \qquad (4)$$

[11] The exposition in this section is guided in part by Abreu, de Groot and Florax (2004) and by Heckman (1978).

where μ exhibits spatial autocorrelation, since

$$\mu = (I - \rho W)^{-1}\varepsilon, \qquad (5)$$

where ε is i.i.d. normal. In this restricted version of the model, which I call the *spatial error model*, the spatial dependence comes from autocorrelation in the error term, and not from dependence of *z*'s on distanced *X*'s. The spatial autocorrelation in the error term may arise through omitted variables that have a spatial dimension, such as climate, industrial patterns, or exogenous shocks (Abreu et al., 2004).[12] If the underlying model is the spatial error model, then, to borrow Heckman's (1978) terminology, there is spurious, not true, state dependence.

Thus, if the autocorrelation is in the error term, then there is spurious state dependence; if there is dependence of z's on distanced *X*'s, then there is true state dependence. I now test whether the spatial dependence comes from autocorrelation in the error term, or from dependence of *z*'s on distanced *X*'s.

In order to test for true versus spurious state dependence, I estimate the parameters in each of the two models—the unrestricted spatial distance model and the restricted spatial error model—via a 2-step procedure. In the first step, for each value of ρ over a grid of possible values, the coefficients $\beta_1^c(\rho)$, $\beta_2^c(\rho)$, the sum of squared residuals $SSR(\rho)$, and the concentrated log likelihood

$$\mathrm{L}^c(\rho) = -n\ln\left(\frac{SSR(\rho)}{n}\right) + \ln(\det(\mathrm{I} - \rho W)) - \frac{n}{2}$$

are estimated via OLS. In the second step, the concentrated log likelihood $L^c(\rho)$ is maximized over ρ.

For the unrestricted spatial distance model, the concentrated log likelihood is obtained by running OLS of $(z - \rho Wz)$ on $[X \;\; WX]$. For the restricted spatial error model, the concentrated log likelihood is obtained by running OLS of $(z - \rho Wz)$ on $(X - \rho WX)$.

12 Owing to spatial autocorrelation in the error term, estimation of the spatial error model via OLS results in unbiased but inefficient estimates (Abreu et al., 2004).

I conduct the 2-step procedure twice: first optimizing over ρ from a coarse grid over the range $[-4\rho_{lagsarlm}, 6\rho_{lagsarlm}]$, where $\rho_{lagsarlm}$ is the estimate of ρ obtained from an initial estimation of the spatial distance model (1).[13] I then use the optimum ρ_{coarse} of the coarse grid to form a fine grid $[-\rho_{coarse}, 2\rho_{coarse}]$ over which to obtain the estimated optimum $\hat{\rho}_{opt} \equiv \rho_{fine}$. Both grids consist of 100 points each. Estimates of the remaining coefficients are then obtained by re-running OLS with $\hat{\rho}_{opt}$ to obtain $\hat{\beta}_1 \equiv \beta_1^c(\hat{\rho}_{opt})$ and $\hat{\beta}_2 \equiv \beta_2^c(\hat{\rho}_{opt})$.[14]

The 95% confidence interval $[\rho_{low}, \rho_{high}]$ for $\hat{\rho}_{opt}$ is obtained from using the inverse log likelihood ratio test to find ρ_{low} and ρ_{high} that satisfy:

$$2\left(L^c(\hat{\rho}_{opt}) - L^c(\rho_{low})\right) = \chi_{crit}$$

and

$$2\left(L^c(\hat{\rho}_{opt}) - L^c(\rho_{high})\right) = \chi_{crit}$$

respectively, where χ_{crit} is the critical value of the chi-squared distribution at 95% and with 1 degree of freedom.

I test for true versus spurious state dependence using a likelihood ratio test. If the null hypothesis that the restrictions hold is rejected, this means that the spatial autocorrelation is from dependence of *z*'s on distanced *X*'s rather than from spatial autocorrelation in the error term, i.e., that we have true, not spurious, state dependence. Otherwise, the dependence is merely spurious.

Table 2.1 presents the results for the regressions using the annual mean O3, annual 10th percentile O3, annual 90th percentile ozone, and the daily maximum 8-hour average O3 as the dependent variable *z*. For the dependent variables *X*, I use county estimated annual NO_x emissions (in tons per square mile), county estimated annual VOC emissions (in tons per square mile), county population per square mile, and county per capita personal income (in 1000 1982-1984 $). For the regression of daily maximum 8-hour

[13] I do so using the "lagsarlm" function in the "spdep" package in R.
[14] Standard errors under this OLS would be wrong; need to calculate derivatives of $\det(I - \rho W)$.

average O3, the dependent variables also include daily maximum temperature and time lagged daily maximum 8-hour average O3. Owing to memory limitations, only observations from July 5, 10, 15, 20, 25, and 30 are used for the daily regressions.

There are several key features of my results for the annual O3 statistics. First, for the regressions of ozone, the estimated $\hat{\rho}$ is significant and positive for all regions and years. For mean ozone, there is true state dependence in each year in the Southeast and for most years in the Southwest. For 90th percentile ozone, there is true state dependence in the Northeast and the Southwest, and spurious state dependence over the entire US. For 10th percentile ozone, there is true state dependence in the Southeast and spurious state dependence in the US. For all other cases, there is a roughly even mix between years for which the data exhibits true state dependence and years for which the data exhibits spurious state dependence. Thus, while spatial autocorrelation over the entire US may be due to spatial autocorrelation in the error term, high (90th percentile) levels of ozone in both the Northeast and in the Southwest—two areas of non-attainment—depend on emissions from other states. Transport thus does appear to matter in areas in which high levels of ozone are a problem.

For daily maximum 8-hour average ozone in 1990, air quality exhibits true state dependence in all quadrants except the Southwest.[15]

Is the spatial correlation in ambient NO_x concentrations due to spatial autocorrelation in the error term, or to neighboring NO_x emissions? Table 2.2 presents the results for the regressions using annual mean NO_x, where the controls now no longer include county VOC emissions. Spurious state dependence appears to be the case in the Northeast, while true state dependence is the case for the Southeast and the Southwest. The results for the Northwest are mixed. Thus, NO_x transport appears to matter in the South, but not in the North.

Now that I have determined that, in some cases, the spatial autocorrelation in air quality is due to transport and not to omitted variables, I now estimate the extent of transport.

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[15] I am in the process of running the spurious vs. true test on the daily data for other years

7 Regressions based on distance

I first examine transport based on geographical distance. Is air quality at one site affected from emissions hundreds of kilometers away? Does the extent of transport depend on the region of the United States, and does the direction whence the pollutant was emitted matter?

7.1 Multiple spatial distances and spatially autocorrelated errors

In order to determine the geographical extent of transport, I run spatial simultaneous distance linear mixed effects models with multiple spatial distances using my annual data set. The different spatial distances are neighbors of different distances and direction. The first-order spatial distances of any particular site *i* consist of all other sites from the same year located between 1 km and 100 km from site *i*, the second-order spatial distances consist of sites located between 100 km and 500 km from site *i*, and the third-order spatial distances consist of sites located between 500 km and 1000 km from site *i*.

I first run a fixed effects model with quadrant fixed effects in both the intercept and in the emissions and distanced emissions, and test whether fixed effects in the coefficients on emissions and on distanced emissions are needed in addition to fixed effects in the intercept (i.e., if the slopes can be considered constant (or the same) across all quadrants).[16]

I then run a linear mixed effects model (grouped by quadrant) with random effect in the intercept. I test whether the random effect is needed. I also consider various models for spatial autocorrelation in within-group errors, and test the various models (exponential, Gaussian, linear, rational quadratic, and spherical). I can test a linear mixed effects model without spatial autocorrelation against a linear mixed effects model with any of the various spatial autocorrelation structures using a likelihood ratio test because the former is nested in the latter. However, because I cannot conduct likelihood ratio tests among

[16] As mentioned earlier, quadrant boundaries are 36ºN, 97.5ºW.

different spatial correlation models, I compare them instead based on the information criteria AIC and BIC (Pinheiro and Bates, 2000).[17]

My results for mean ozone, 90th percentile ozone and mean NO_x for the years 1990, 1996 and 2001 are presented in Tables 3.[18] According to my results, transport up to 1000 km does seem to matter, as even the 3rd distanced value of county NO_x and VOC emissions often have significant coefficients. However, both the sign and the significance of the various distanced emissions vary by year. Emissions can cause a decrease in ambient ozone, perhaps owing to the non-monotonic nature of ozone production. For many of the cases in which spatial autocorrelation in the error term is the favored random effects model, transport is no longer significant once the spatial autocorrelation in the error term is accounted for.

7.2 Multiple spatial directional distances and spatially autocorrelated errors

Having established that regional transport does affect ozone air quality, I now examine whether the direction of transport matters. To do so, I run spatial simultaneous distance linear mixed effects models with multiple spatial distances of different directions using my annual data set. As before, the different spatial distances are neighbors of different distances and direction. The first-order spatial distances of any particular site *i* consist of all other sites from the same year located between 1 km and 100 km from site *i*, the second-order spatial distances consist of sites located between 100 km and 500 km from site *i*, and the third-order spatial distances consist of sites located between 500 km and 1000 km from site *i*.

For each order of spatial distance, I also use spatial distances of five different directions: North (“N”), West ("W"), South ("S"), Northwest ("NW"), and Southwest ("SW"). For example, the first-order spatial distances to the West of any particular site *i* consist of all other sites located both between 1 km

[17] I also attempted to run models of random effects in both the intercept and in the coefficients on emissions and distanced emissions, and to test whether these additional random effects are needed, but often my computer did not have sufficient memory to run these programs.

[18] Because the “nlme” programs do not handle zero distances, I average the values for all sites located at the same latitude-longitude coordinates in any particular year. I cannot pool data over all years because the programs do not handle zero distances.

and 100 km from site *i* and also to the West of site *i* (e.g., have a longitude less than or equal to that of site *i*).The directions were chosen to match wind flows. Trade winds between 0ºN and 30ºN blow from the Northeast; prevailing winds between 30ºN and 50ºN blow from the Southwest (Jacob, 1999).

I first run a fixed effects model with quadrant fixed effects in both the intercept and in the emissions and distanced emissions, and test whether fixed effects in the coefficients on emissions and on distanced emissions are needed in addition to fixed effects in the intercept (i.e., if the slopes can be considered constant (or the same) across all quadrants).

I then run a linear mixed effects model (grouped by quadrant) with random effect in the intercept. I test whether the random effect is needed. I also consider various models for spatial autocorrelation in within-group errors, and test the various models (exponential, Gaussian, linear, rational quadratic, and spherical).

My results for ozone for 1990 are presented in Tables 4.1 and 4.2.[19] The tables present the estimates from the fixed effects specification, the random effects specification, and the random effects specification with the best-fit spatial autocorrelation error structure (which in both cases is rational quadratic).

There are two key features of my results to note. First, in 1990, transport appeared to matter in the Northwest and in the Southwest, but not in either the Northeast or in the Southeast. Second, once a spatial autocorrelation structure was imposed on the error term, transport no longer became significant.

The results for ambient mean NO_x are presented in Table 4.3. In 1990, transport only mattered in the Southwest. In 1996, transport mattered in all quadrants except the Northeast. In 2001, transport only mattered in the Northeast and in the Southwest, the two quadrants in which ozone non-attainment is most problematic.

[19] I am in the process of obtaining results for 1996 and 2001.

8 Regressions based on political boundaries

The transport of air pollution over long distances and from different directions becomes even more important if the pollutant crosses the borders between different air quality management jurisdications, since then the pollution control policy in one jurisdiction imposes externalities on another jurisdiction. I now examine whether emissions does affect air quality across political boundaries.

8.1 EPA regions

I first examine the source-receptor transport coefficients among EPA regions in the Eastern United States. The states in the continental US that fall into the 5 EPA regions considered are:

EPA Region	States
1	CT, ME, MA, NH, RI, VT
2	NJ, NY
3	DE, DC, MD, PA, VA, WV
4	AL, FL, GA, KY, MS, NC, SC, TN
5	IL, IN, MI, MN, OH, WI

Source: EPA (http://www.epa.gov/epahome/locate2.htm).

To estimate the region-by-region source-receptor transport coefficients, I run a region fixed effects model on the total NO_x emissions from each of the regions. I control for county VOC emissions, county population density, county per capita income, and region fixed effects in the constant. Results from analogous random effects specifications were not included because tests of the null hypothesis that random effects are not needed over a fixed effects model were not rejected at a 5% level.

My results for the mean, 10^{th} percentile, and 90^{th} percentile ozone are presented in Tables 5.1 to 5.3, respectively. There are two main features of my results to note. First, emissions in one region may have either a positive or negative, or no effect on air quality on another region. The significant negative coefficients may be due to the non-monotonic nature of ozone formation. Second, Region 1 does *not* appear to be affected by transport.

According to my results for mean NO_x (Table 5.4), NO_x does not appear to travel across regional boundaries; NO_x emissions in one EPA region has no significant effect on the ambient NO_x concentration in any of the other EPA regions considered.

8.2 Ozone Transport Commission (OTC)

The Ozone Transport Commission (OTC) is comprised of the following states: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, the northern counties of Virginia, and the District of Columbia.

In 1994, the OTC adopted a memorandum of understanding (MOU) to achieve regional emission reductions of NO_x. States signing the MOU were committed to developing and adopting regulations that would reduce region-wide NO_x emissions in 1999 and further reduce emissions in 2003 (EPA, 2004b).[20]

I now examine state-by-state source-receptor transport coefficients for the states comprising the OTC.

To estimate the state-by-state source-receptor transport coefficients, I run a state fixed effects model on the total NO_x emissions from each of the states. Owing to singularities, emissions from only 4 states could be included; I thus used the 4 states with the highest total NOx emissions in 1996: NJ, NY, PA, and VA. I control for county VOC emissions, county population density, county per capita income, and state fixed effects in the constant. Results from analogous random effects specifications were not included because tests of the null hypothesis that random effects are not needed over a fixed effects model were not rejected at a 5% level.

My results are presented in Tables 6. Connecticut's air quality is negatively affected by emission from Pennsylvania and Virginia; Massachusetts' air quality is negatively affected by emissions from New

[20] Virginia was not a signatory of the MOU. The OTC NO_x Budget Program ran from 1999 to 2002 and is now replaced by the NO_x SIP call (EPA, 2004b).

York and Virginia, but benefits from emissions from New Jersey; and Rhode Island's air quality is negatively affected by emissions from Pennsylvania.[21]

To examine if the effects of NO_x emissions on all states in the OTC is uniform, and therefore whether a cap-and-trade program is appropriate, I conduct a joint test to see of all the coefficients on the state NO_x emissions are equal and all the coefficients on the state VOC emissions are equal. The null hypothesis that the coefficients were equal could not be rejected at a 5% level for either the ozone mean or the NO_x mean, but was rejected for both the 10^{th} and 90^{th} percentile ozone. Thus, for the mean concentration of both ozone and NO_x, a cap-and-trade program is appropriate, but perhaps not for either high or low levels of ozone.

8.3 Section 126

I now examine the effects on air quality in states that filed petitions under Section 126 of the Clean Air Act of emissions from the states that were filed against. States that filed under Section 126 are: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, and the District of Columbia. The 32 states that were filed against are in EPA regions 1 to 5, plus Iowa, Missouri, Arkansas, and Louisiana (Helms, 2002).

To estimate the state-by-state source-receptor transport coefficients, I run a state fixed effects model on the total NO_x emissions from each of the states being filed against. Owing to singularities, emissions from only 4 states could be included; I thus used 4 states against which multiple petitions were filed: NC, OH, VA, and WV. I control for county VOC emissions, county population density, county per capita income, and state fixed effects in the constant. Results from analogous random effects specifications were not included because tests of the null hypothesis that random effects are not needed over a fixed effects model were not rejected at a 5% level.

According to my results (Tables 7.1-7.3), emissions from West Virginia increase the 90^{th} percentile ozone concentration in Connecticut, DC, and Maryland, while emissions from Ohio increases

[21] Emissions have a negative effect on air quality when its coefficient in the regression of ozone is positive.

the 90th percentile ozone in Pennsylvania. Emissions from North Carolina and Virginia decrease the 90th percentile ozone in Pennsylvania. None of the other source-receptor coefficients are significant at a 5% level.

8.4 NO_x SIP call

In September 1998, in effort to mitigate the regional transport of ground-level ozone in the eastern half of the United States, the EPA finalized a rule, known as the NOx SIP call, that required 22 States and the District of Columbia to submit state implementation plans (SIPs) to reduce NO_x emissions EPA, 2002). These states are: Alabama, Connecticut, Delaware, District of Columbia, Georgia, Illinois, Indiana, Kentucky, Maryland, Massachusetts, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, and West Virginia.[22] I now examine the state-to-state source-receptor coefficients for states covered by the NO_x SIP call.

To estimate the state-by-state source-receptor transport coefficients, I run a state fixed effects model on the total NO_x emissions from each of the states. Owing to singularities, emissions from only 4 states could be included; I thus used the 4 states against which multiple petitions were filed under Section 126: NC, OH, VA, and WV. I control for county VOC emissions, county population density, county per capita income, and state fixed effects in the constant. Results from analogous random effects specifications were not included because tests of the null hypothesis that random effects are not needed over a fixed effects model were not rejected at a 5% level.

According to my results (Tables 8.1-8.3), emissions from Ohio appear to increase the 90th percentile ozone in most of the states in the NO_x SIP call.

To examine if the effects of NO_x emissions on all states in the NO_x SIP call is uniform, and therefore whether a cap-and-trade program is appropriate, I conduct a joint test to see of all the coefficients on the state NO_x emissions are equal and all the coefficients on the state VOC emissions are

[22] Wisconsin was removed via court order. Georgia is not listed on: http://www.dep.state.wv.us/item.cfm?ssid=8&ss1id=295 but Georgia's website does mention NOx SIP call: http://www.air.dnr.state.ga.us/sspp/noxsipcall/

equal. The null hypothesis that the coefficients were equal was rejected at a 5% level for all statistics of ozone (mean, 10th percentile, 90th percentile), but could not be rejected for mean NO_x. Thus, a cap-and-trade program may be appropriate for reducing ambient mean NO_x, but perhaps not for reducing ambient ozone. The latter result may be due to non-monotonicities in ozone formation.

9 Regressions using time lags and multiple spatial distances on July daily data

In this section, I run spatial non-simultaneous autoregressive lag models with multiple spatial distances on the July daily panel data. The different spatial distances are neighbors of different distances. The first-order spatial distances of any particular site *i* consist of all other sites from the same year located between 1 km and 500 km from site *i*, and the second-order spatial distances consist of sites from the same year located between 500 km and 1000 km from site *i*.[23]

According to my results, distanced emissions do matter, even after accounting for time lagged air quality, but the signs of the dependence are not always the same for the 2 years considered.

10 Conclusion

This paper uses spatial exploratory data analysis and spatial econometrics to analyze the regional transport of air pollution.

According to my results, both ozone and NO_x air pollution exhibit spatial correlation, and this correlation is in many cases due to transport rather simply to spatially correlated omitted variables. Emissions from up to 1000 km away from a variety of directions can have significant effects on air quality, though the effect is not always negative, and although neither the sign nor the significance of the effect is constant over time. In the Eastern United States, emissions from EPA Regions 2 to 5 may affect air quality in EPA Regions 2 to 5, but not in Region 1. NO_x emissions from West Virginia and Ohio

[23] I was unable to use time lagged emissions because my emissions data are at an annual frequency.

appear to increase the 90th percentile ozone concentration in a number of other states in the Eastern United States. A cap-and-trade program for the states in the NO_x SIP call may be appropriate for reducing ambient NO_x, but not for reducing ambient ozone. Non-monotonicities in ozone production may be a reason why the transport of NO_x can sometimes be a positive externality rather than a negative one, and why a cap-and-trade program that reduces aggregate NO_x emissions may not always reduce ozone.

References

Abreu, M., de Groot, H.L.F., & Florax, R.J.G.M. (2004). Spatial patterns of technology diffusion: An empirical analysis using TFP. Tinbergen Institute Discussion Paper (Paper No. TI 2004-079/3). Amsterdam.

Arlinghaus, S.L. (1996). The practical handbook of spatial statistics. New York: CRC Press.

Bivand, R.S., & Portnov, B.A. (2002). Exploring spatial data analysis techniques using R: the case of observations with no neighbours. Mimeo. Norwegian School of Economics and Business Administration.

Blanchard, C.L., Lurmann, F.W., Roth, P.M., Jeffries, H.E., & Korc, M. (1999). The use of ambient data to corroborate analyses of ozone control strategies. Atmos. Environ., 33, 369-381.

Carroll, M.A., & Thompson, A. (1995). NO_X in the non-urban troposphere. In J. Barker (Ed.), Progress and problems in atmospheric chemistry (pp. 198-255). New Jersey: World Scientific.

Chang, T., & Suzio, M. (1995). Assessing ozone precursor relationships based on a smog production model and ambient data. J. Air Waste Manage. Assoc., 45, 20-28.

Chock, D.P. (1989). The need for a more robust ozone air quality standard. Journal of Air Pollution Control Association, 39, 1063-1072.

Environmental Protection Agency [EPA]. (1997a). Finding of significant contribution and rulemaking for certain states in the Ozone Transport Assessment Group region for purposes of reducing regional transport of ozone (40 CFR Part 52). Federal Register.

Environmental Protection Agency [EPA]. (1997b). National ambient air quality standards for ozone; final rule (40 CFR Part 50). Federal Register, 62 (138).

Environmental Protection Agency [EPA]. (1998). National Air Quality and Emission Trends Report, 1997 (EPA Report No. EPA 454/R-98-016). Research Triangle Park, NC.

Environmental Protection Agency [EPA]. (1999a). Fact sheet: Findings of significant contribution and rulemaking on Section 126 petitions for purposes of reducing interstate ozone transport – Final Rule

4/30/99. [Online: web]. Cited 24 August 2004. URL: http://www.epa.gov/ttn/oarpg/t1/fact_sheets/126ffs.pdf

Environmental Protection Agency [EPA]. (1999b). Findings of significant contribution and rulemaking on Section 126 petitions: Fact sheet 12/17/99. [Online: web]. Cited 24 August 2004. URL: http://www.epa.gov/ttn/oarpg/t1/fact_sheets/126fs.pdf

Environmental Protection Agency [EPA]. (2002). Finding of significant contribution and rulemakings for certain states in the Ozone Transport Assessment Group region for purposes of reducing regional transport of ozone ("NOx SIP Call "). [Online: web]. Cited 25 August 2004. URL: http://www.epa.gov/ttn/naaqs/ozone/rto/sip/index.html

Environmental Protection Agency [EPA]. (2004a). National Ambient Air Quality Standards. [Online: web]. Cited 20 July 2004. URL: http://epa.gov/air/criteria.html

Environmental Protection Agency [EPA]. (2004b). Ozone Transport Commission (OTC) NOx Budget Program. [Online: web]. Cited 24 August 2004. URL: http://www.epa.gov/airmarkets/otc/overview.html

Fairley, D. (1999). Overshoot bias and the national ozone standard. J. Air Waste Manage. Assoc., 49, 370-385.

Fiore, A.M, Jacob, D.J., Logan, J.A., & Yin, J.H. (1998). Long-term trends in ground level ozone over the contiguous United States, 1980-1995. J. Geophys. Res., 103(D1), 1471-1480.

Griffith, D.A., & Amrhein, C.G. (1991). Statistical analysis for geographers. New Jersey: Prentice Hall.

Haining, R. (1990). Spatial data in the social and environmental sciences. Cambridge: Cambridge University Press.

Heckman, J.J. (1978). Simple statistical models for discrete panel data developed and applied to test the hypothesis of true state dependence against the hypothesis of spurious state dependence. Annales de l'insee, 30-31, 227-269.

Helms, G.T. (2002, July). Update...Q & As on the NOx SIP Call and related actions. [Powerpoint presentation]. Sent via email, 8 Dec. 2003.

Jacob, D.J. (1999). Introduction to atmospheric chemistry. Princeton: Princeton University Press.

Lin, C.-Y.C. (2000). Trends in ozone smog. Senior thesis, Harvard University.

Lin, C.-Y.C., Jacob, D.J., & Fiore, A.M. (2001). Trends in exceedances of the ozone air quality standard in the continental United States, 1980-1998. Atmospheric Environment, 35, 3217-3228.

Lin, C.-Y.C., Jacob, D.J., Munger, J.W., & Fiore, A.M. (2000). Increasing background ozone in surface air over the United States. Geophysical Research Letters, 27 (21), 3465-3468.

National Research Council [NRC]. (1992). Rethinking the ozone problem in urban and regional air pollution. Washington, DC: National Academy Press.

Pinheiro, J.C., & Bates, D.M. Mixed-effects models in S and S-Plus. New York: Springer.

R Development Core Team. (2004). R: A language and environment for statistical computing [Computer programming software]. Vienna, Austria: R Foundation for Statistical Computing. URL: http://www.R-project.org.

Ribeiro Jr., P.J., & Diggle, P.J. (2001). geoR: A package for geostatistical analysis. R-NEWS, 1 (2), 15-18.

Ribeiro Jr., P.J., & Diggle, P.J. (2003). geoR: A package for geostatistical analysis: An illustrative session. [Online: web]. Cited 27 May 2004. URL: http://www.est.ufpr.br/geoR/geoRdoc/geoRintro.html

Sillman, S. (1993). Tropospheric ozone: the debate over control strategies. Annu. Rev. Energy Environ., 18, 31-56.

Sillman, S. (1995a). New developments in understanding the relation between ozone, NO_x and hydrocarbons in urban atmospheres. In J. Barker (Ed.), Progress and problems in atmospheric chemistry (pp. 145-171). New Jersey: World Scientific.

Sillman, S. (1995b). The use of NO_y, H_20_2, and HNO_3 as indicators for ozone-NO_x-hydrocarbon sensitivity in urban locations. J. Geophys. Res., 100, 14,175-14,188.

Sillman, S. (1999). The relation between ozone, NO_x and hydrocarbons in urban and polluted rural environments. Atmos. Environ., 33, 1821-1845.

Sistla, G., Zhou, N., Hao, W., Ku, J., Rao, S., Bornstein, R., Freedman, F., & Thunis, P. (1996). Effects of uncertainties in meteorological inputs on urban airshed model predictions and ozone control strategies. Atmospheric Environment, 30, 2011-2025.

Winner, D., Cass, G., & Harley, R. (1995). Effect of alternative boundary-conditions on predicted ozone control strategy performance: A case-study in the Los Angeles area. Atmospheric Environment, 29, 3451-3464.

TABLE 1. Summary Statistics

Variable	# obs	mean	s.d.	min	max	trend	
Annual O3 data set (1990, 1996, 1997, 1998, 1999, 2001)							
O3 (ppb)							
mean	6310	53.90	8.42	16.80	93.30	0.25	***
						(0.03)	
10^{th} percentile	6310	33.20	7.21	3.00	67.00	0.37	***
						(0.03)	
90^{th} percentile	6310	77.33	13.49	27.00	190.0	-0.03	
						(0.05)	
county-level variables							
NO_x emissions (tons)	6310	56.33	133.49	0.015	2657.4	-1.96	***
						(0.52)	
VOC emissions (tons)	6310	52.14	136.99	0.010	3287.9	-3.16	***
						(0.54)	
population per sq mi	6310	994.79	3565.4	0.006	67348	-4.37	
						(13.98)	
per capita real income	6310	15.02	4.72	0.015	52.504	0.14	***
						(0.02)	
Annual NO_x data set (1990, 1996, 1997, 1998, 1999, 2001)							
NO_x (ppb)							
mean	2437	15.88	8.93	0.0	55.5	0.30	***
						(0.05)	
10^{th} percentile	2437	5.90	4.34	0.0	30.0	-0.15	***
						(0.03)	
90^{th} percentile	2437	29.32	14.34	0.0	90.0	-0.47	***
						(0.09)	
county-level variables							
NO_x emissions (tons)	2437	68.97	194.8	0.008	2657.4	-10.79	***
						(1.18)	
population per sq mi	2437	1919.17	5697.78	0.063	67348	12.11	
						(34.98)	
per capita real income	2437	16.12	4.55	0.061	52.504	0.16	***
						(0.03)	
Daily O3 data set (1980, 1990, 1998)							
O3 (ppb)							
daily maximum 8-hr average	420983	54.51	22.77	0.0	280.0	-0.26	***
						(0.01)	
grid square-level variable							
daily maximum temperature (K)	420983	304.06	4.93	284.67	322.44	-0.027	***
						(0.001)	

Notes: The trend is the coefficient on year when the variable is regressed on a year and a constant (standard errors in parentheses).
Significance codes: 0 `***' 0.001% `**' 0.01% `*' 0.05% `.' 0.1% level.

FIGURE 1a. Spatial means for annual O3

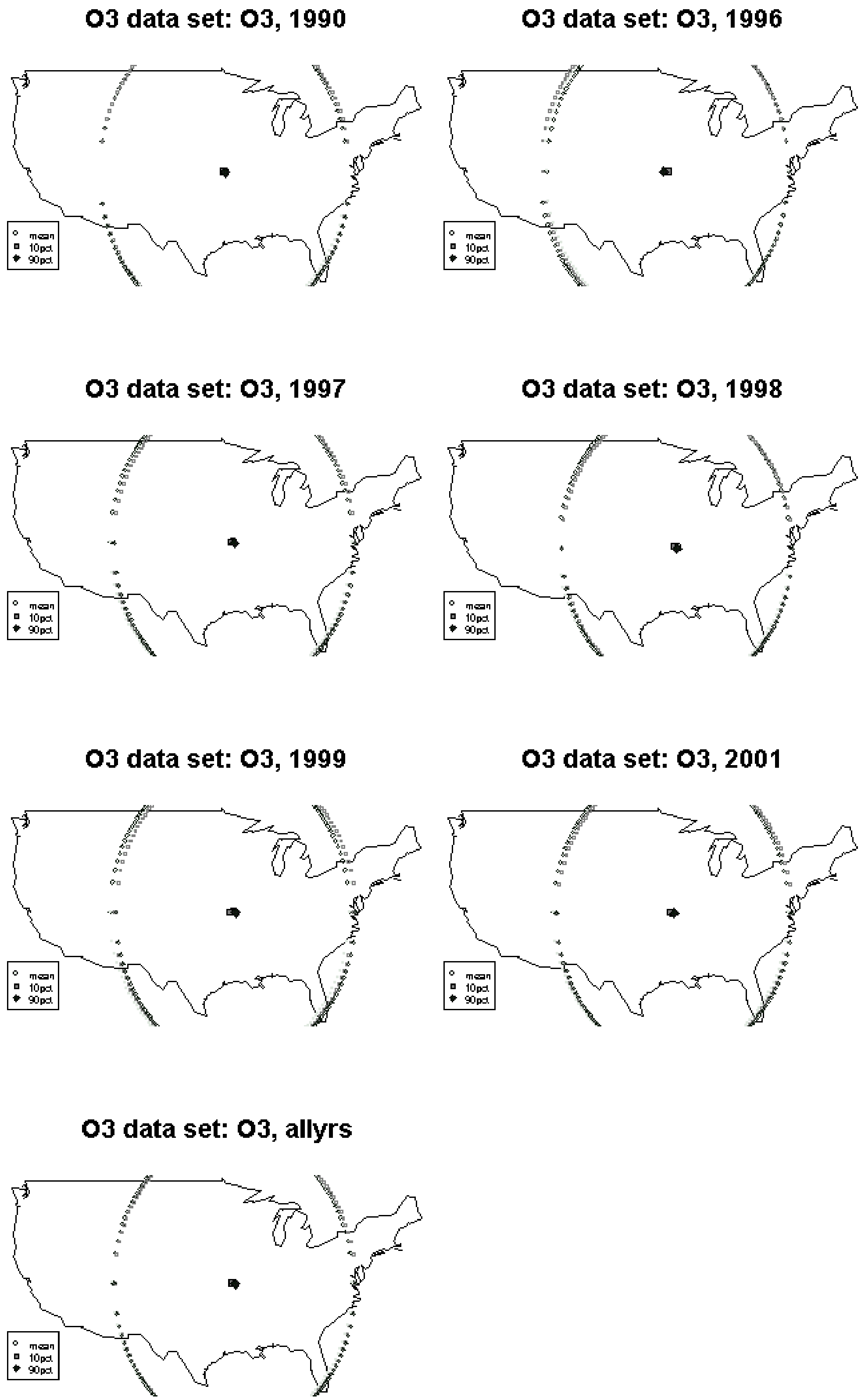

FIGURE 1b. Spatial means for annual controls

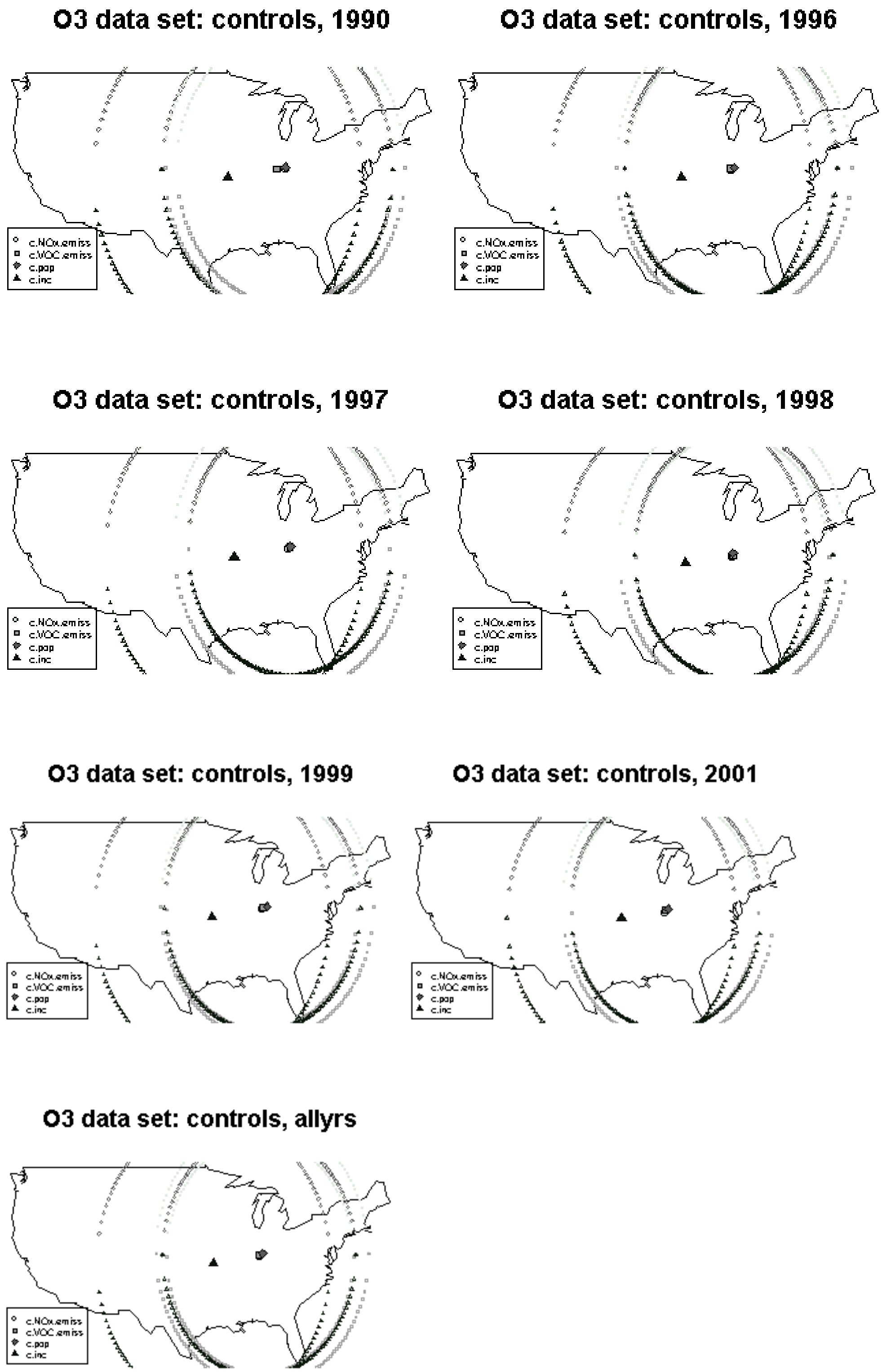

FIGURE 1c. Spatial means for NO_x data set

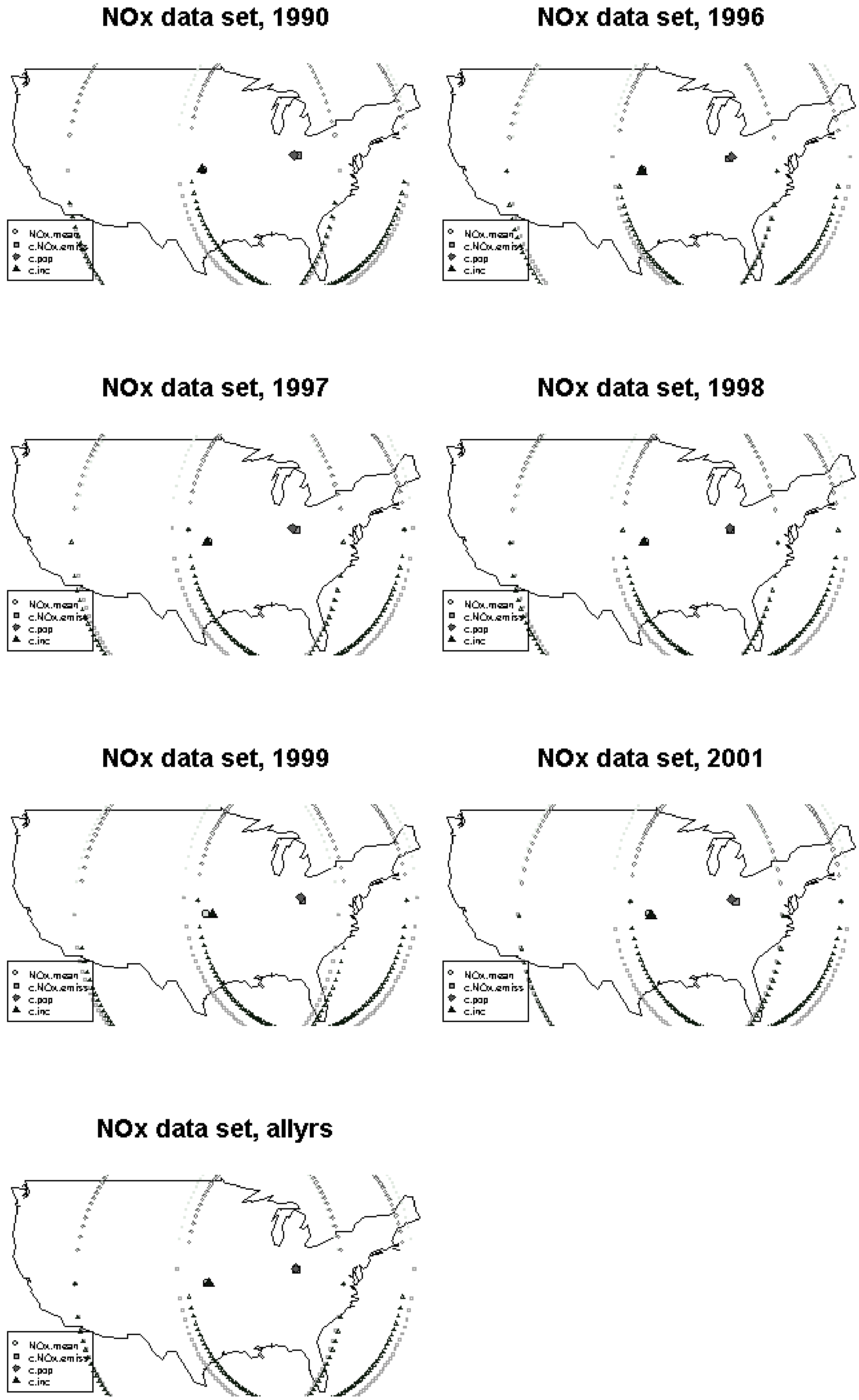

FIGURE 2a. Quartile maps for annual data, 1990

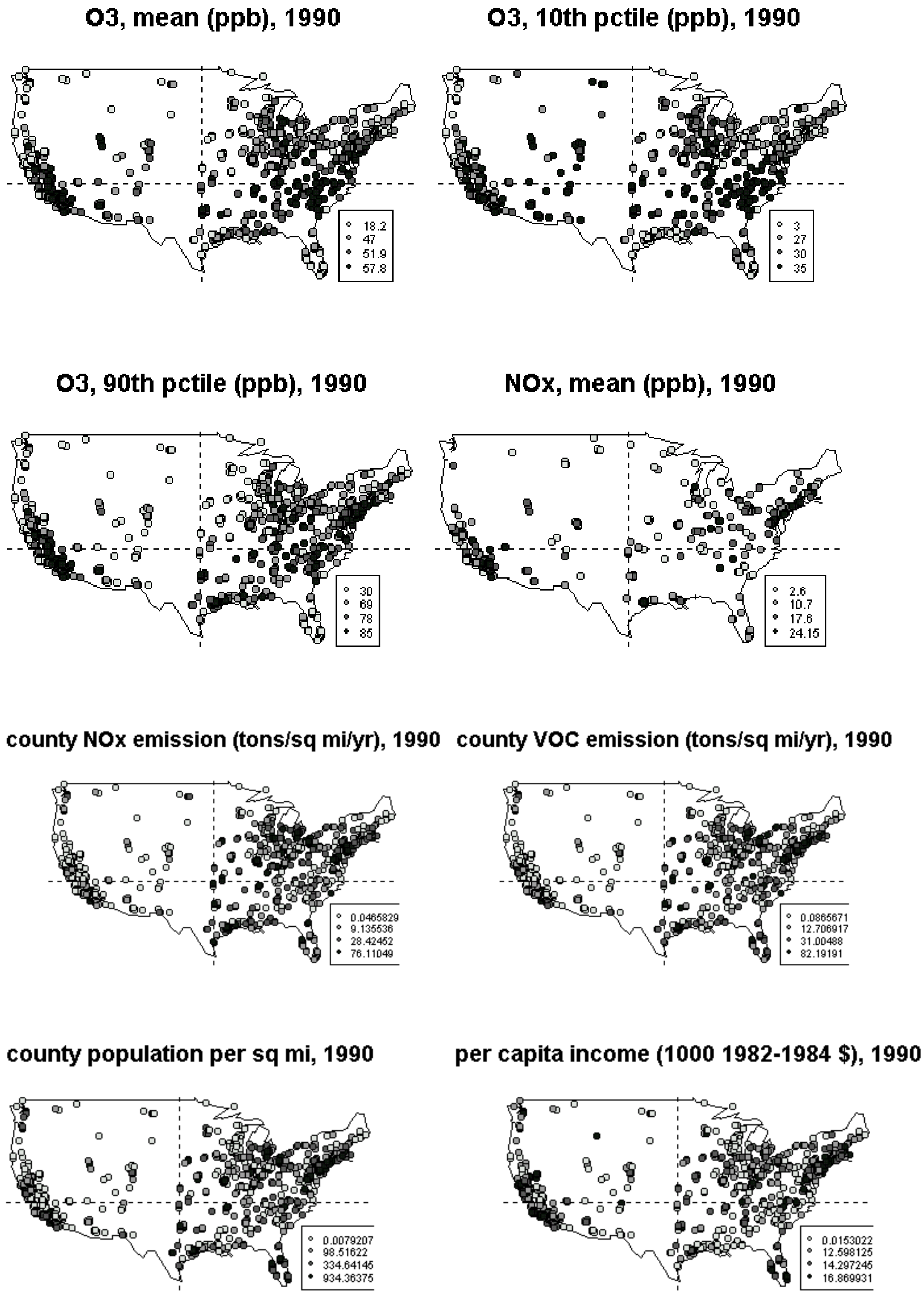

FIGURE 2b. Quartile maps for annual data, 1996

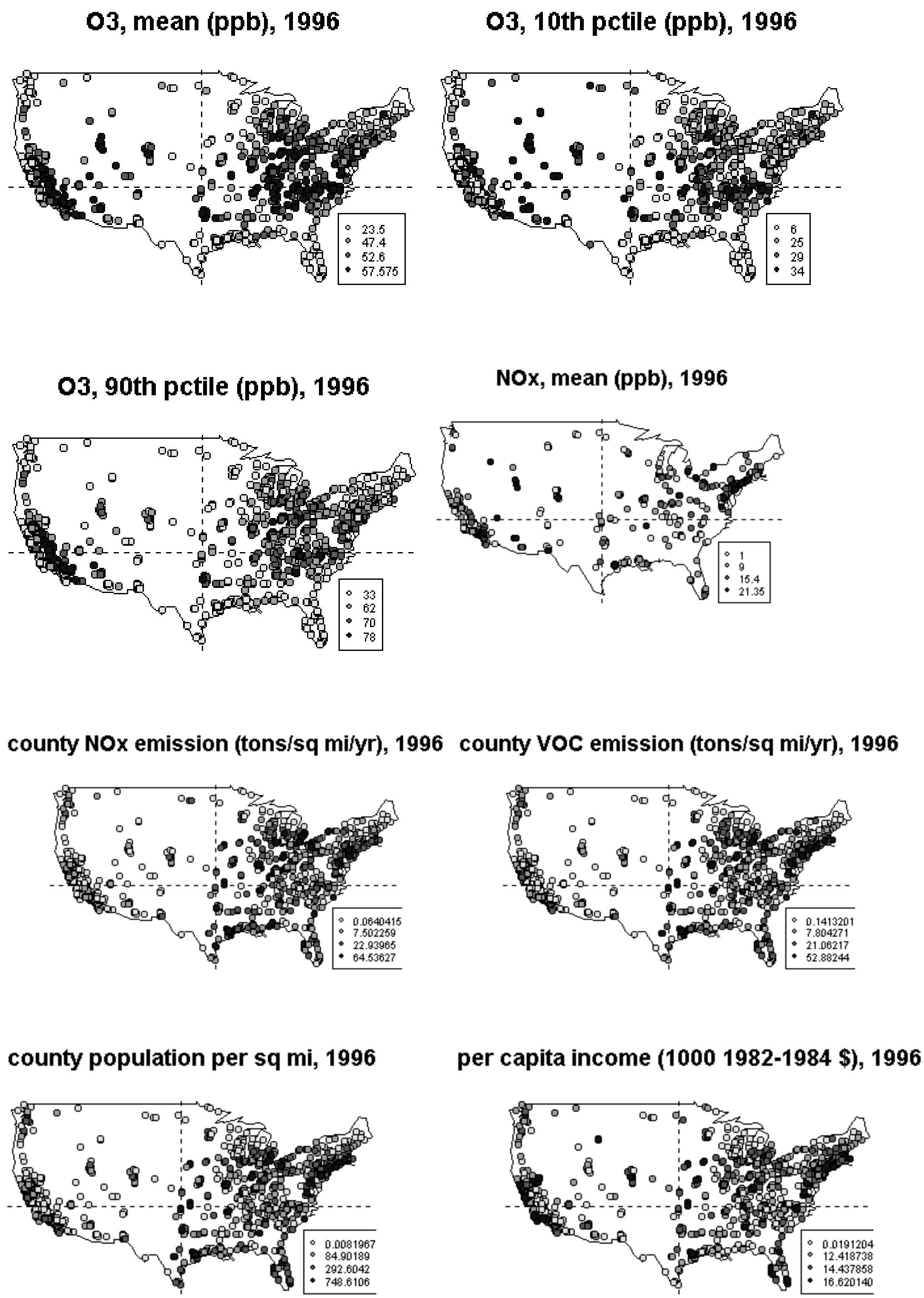

FIGURE 2c. Quartile maps for annual data, 2001

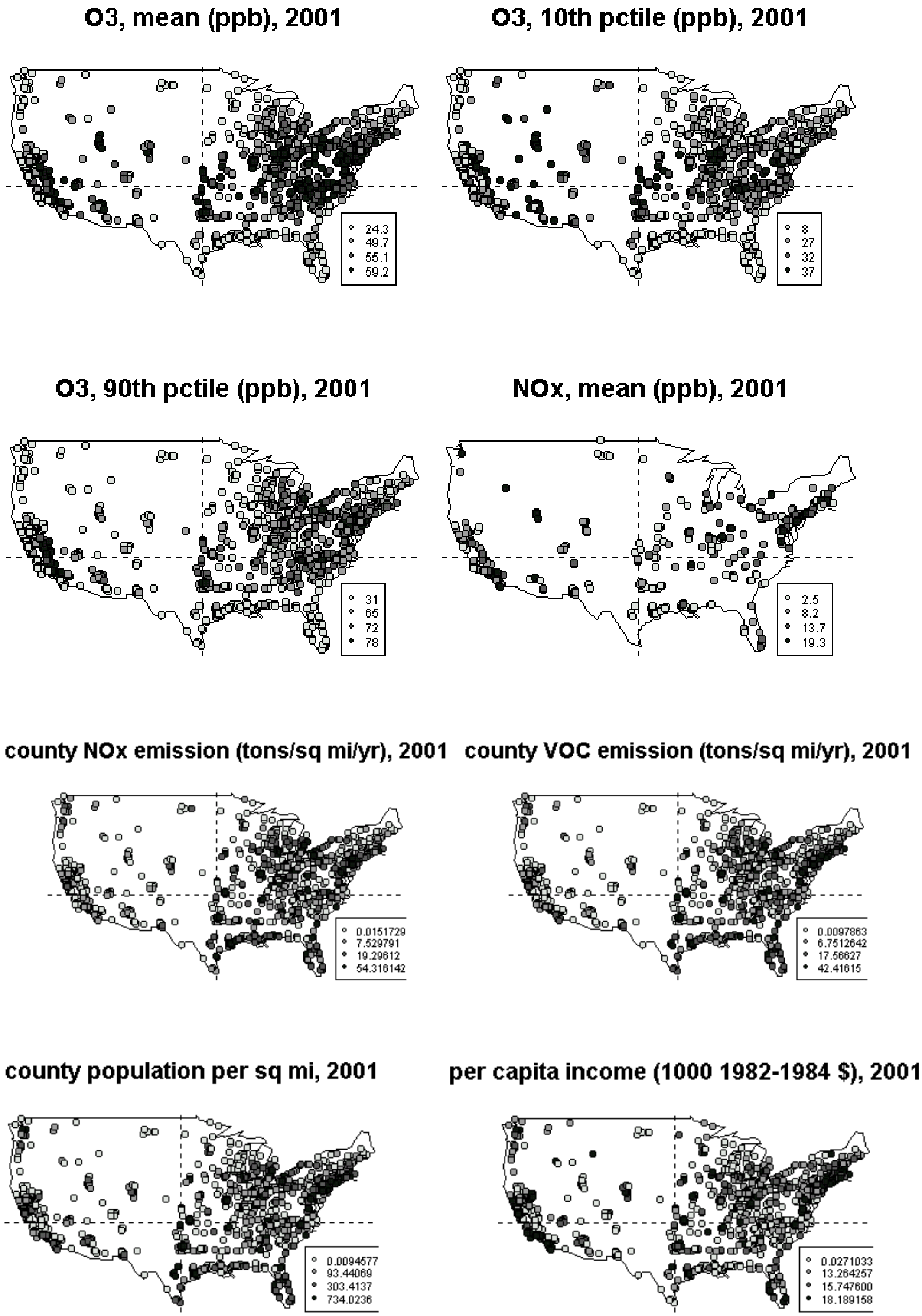

FIGURE 3. Quartile maps for daily data

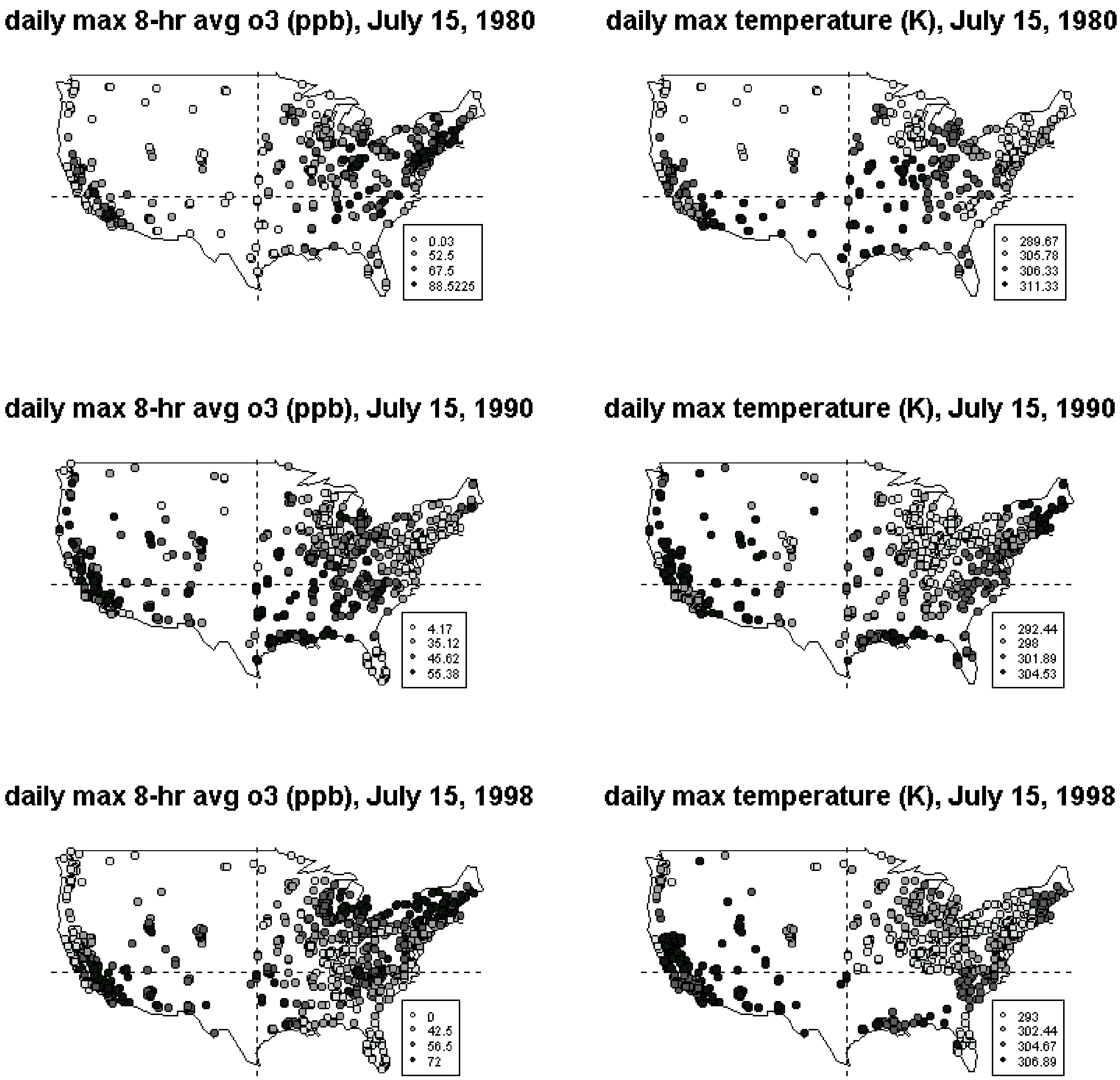

TABLE 2.1: spurious vs. true, 03, 1-500km

95% CI for rho

	1990		1996		1997		1998		1999		2001		all years	
annual mean														
NE	[1.33, 1.70]	S	[1.35, 1.65]	T	[1.39, 1.64]	T	[1.32, 1.55]	S	[1.36, 1.61]	S	[1.33, 1.56]	T	[1.22, 1.42]	T
NW	[0.34, 0.88]	S	[0.57, 0.95]	S	[0.65, 0.95]	T	[0.69, 0.96]	S	[0.65, 0.94]	T	SPURIOUS	S	TRUE	T
SE	[0.89, 1.13]	T	[1.04, 1.85]	T	TRUE	T	[1.04, 1.80]	T	TRUE	T	TRUE*	T	TRUE	T
SW	[0.57, 0.91]	S	TRUE	T	TRUE	T	[0.54, 0.96]	T	TRUE	T	TRUE	T	[0.73, 0.90]	T
US	[1.34, 1.57]	S	TRUE	T	[1.20, 1.42]	T	TRUE	T	[1.18, 1.32]	T	[1.16, 1.36]	T		
annual 90th percentile														
NE	[1.14, 1.46]	T	[1.28, 1.64]	T	[1.28, 1.63]	T	TRUE	T	[1.30, 1.60]	S	[1.17, 1.48]	T	[1.21, 1.42]	T
NW	[0.39, 0.88]	S	TRUE	T	[0.50, 0.90]	S	[0.49, 0.89]	T	[0.60, 0.95]	T	SPURIOUS	S	TRUE	T
SE	[0.78, 1.11]	S	[0.93, 1.20]	T	[0.92, 1.25]	T	[0.94, 1.82]	T	[0.84, 1.20]	S	[1.92, 1.23]	T	[1.00, 1.24]	T
SW	[0.57, 0.92]	S	[0.72, 1.01]	T	[0.48, 0.97]	T	[0.43, 0.94]	T	[0.69, 1.12]	T	TRUE	T	[0.74, 0.90]	T
US	SPURIOUS	S	SPURIOUS	S	SPURIOUS	S	[1.07, 1.30]	T	SPURIOUS	S	TRUE	T		
annual 10th percentile														
NE	TRUE	T	TRUE	T	[1.21, 1.62]	S	TRUE	T	SPURIOUS	S	TRUE	T	[1.13, 1.33]	T
NW	[0.44, 0.94]	S	[0.74, 1.00]	S	[0.76, 1.15]	S	[0.75, 1.00]	T	SPURIOUS	S	[0.69, 1.14]	T	TRUE	T
SE	[0.93, 1.80]	T	TRUE	T	[1.08, 1.87]	T	[1.04, 1.84]	T	[1.04, 1.87]	S	TRUE*	T	TRUE	T
SW	SPURIOUS	S	[0.34, 1.69]	S	TRUE*	T	SPURIOUS	S	[0.57, 1.13]	T	[0.82, 1.48]	T	[0.64, 0.85]	T
US	[0.80, 1.01]	S	[0.86, 1.06]	S	[0.87, 1.03]	S	[1.05, 1.25]	S	[0.86, 1.06]	S	TRUE	T		
daily maximum 8-hour average														
NE	[1.02, 1.26]	T												
NW	[0.72, 0.92]	T												
SE	[0.84, 0.99]	T												
SW	[0.48, 0.74]	S												

* Here, rho.opt is the largest value of rho on rho.grid.fine (i.e., log likelihood is still increasing along this interval)

S = spurious state dependence (spatial autocorrelation in the error term)
T = true state dependence (i.e., reject = TRUE; dependence on distanced X's)

NOTE: need to redo all but O3 mean, NE, to get CI's
For daily data, data from July 5,10,15,20,25,30 used.
Not enough memory to do US, allyrs. Not enough memory to do US for daily data.
Dependent variables are county NOx emissions, county VOC emissions, county population per square mile, county per capita income.
For daily data, dependent variables also include daily maximum temperature and time lagged daily maximum 8-hour average ozone.

TABLE 2.2: spurious vs. true, NOx mean, annual, 1-500km

95% CI for rho

	1990		1996		1997		1998		1999		2001		all years	
NOx mean														
NE	[0.52, 0.97]	S	[0.09, 0.88]	S	[0.09, 0.89]	S	[0.17, 0.92]	S	[0.31, 1.44]	S	[0.33, 0.96]	S	[0.59, 0.86]	T
NW	[0.69, 1.38]	T	[0.58, 0.93]	S	[0.66, 0.96]	S	[0.64, 0.94]	S	[0.62, 0.95]	S	[0.46, 0.89]	T	[0.71, 0.87]	T
SE	[-1.38, 0.25]	T	[0.07, 0.90]	T	TRUE***	T	[-0.14, 0.82]	T	TRUE***	T	TRUE**	T	[0.26, 0.64]	T
SW	TRUE**	T	[0.17, 0.90]	T	[1.06, 1.47]	T	[0.82, 1.41]	T	TRUE***	T	[0.29, 1.79]	T	[0.73, 1.39]	T
US	[0.62, 0.93]	S	[0.60, 0.90]	T	[0.64, 1.38]	S	[0.65, 0.90]	S	[0.81, 1.49]	S	[0.67, 0.93]	S	[0.72, 0.89]	T

* Here, rho.opt is the largest value of rho on rho.grid.fine (i.e., log likelihood is still increasing along this interval)
** CI is NA and rho.opt is neg
*** For some reason, only the upper bound of the interval is given

S = spurious state dependence (spatial autocorrelation in the error term)
T = true state dependence (i.e., reject = TRUE; dependence on distanced X's)

Dependent variables are county NOx emissions, county population per square mile, county per capita income.

TABLE 3.1a: O3 mean, annual, 1990

	Dependent variable is O3 mean				
	Fixed Effects				RE
# distances in best-fit FE model			3		
p-value for test if FE needed given best-fit FE model			[0.00] ***		
# distances in best-fit RE model					3
RE in intercept					Y
RE in emissions coefficients					N/A
p-value for test if RE in intercept needed over a pooled model given best-fit # distances					[0.00] ***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances					N/A
within-group spatial correlation model					exponential
	NE	NW	SE	SW	
county NOx emissions					
own county	0.10	2.82	-1.19	-3.25	-0.05
	(0.55)	(6.10)	(2.56)	(10.69)	(5.34)
1st distance	1.84	11.13	-6.94	10.92	-0.44
	(2.14)	(18.18)	(4.49)	(16.47)	(2.28)
2nd distance	18.10	-108.5 **	-4.13	-63.36 **	12.24
	(13.91)	(33.91)	(9.47)	(22.89)	(11.32)
3rd distance	-9.22	69.05	36.74 *	-63.44 .	27.66 *
	(13.50)	(54.80)	(17.39)	(32.67)	(13.69)
county VOC emissions					
own county	0.50	-2.99	2.92	-4.78	0.00
	(086)	(5.08)	(2.50)	(6.67)	(0.72)
1st distance	-0.55	-11.82	7.89 .	15.43	0.96
	(1.98)	(13.07)	(4.62)	(11.11)	(2.13)
2nd distance	-14.46	80.07 **	1.09	61.42	-13.88
	(12.69)	(25.23)	(11.57)	(19.17)	(10.46)
3rd distance	8.31	-70.95 *	-16.31	73.08 **	-24.71 .
	(12.42)	(35.66)	(16.49)	(27.33)	(12.74)
p-value (Pr > F)	0.00 ***				
adj. R^2	0.98				
# obs	805				805

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.1b: O3 mean, annual, 1996

Dependent variable is O3 mean	Fixed Effects								RE	
# distances in best-fit FE model	3									
p-value for test if FE needed given best-fit FE model	[0.00]	***								
# distances in best-fit RE model									3	
RE in intercept									Y	
RE in emissions coefficients									N/A	
p-value for test if RE in intercept needed over a pooled model given best-fit # distances									[0.009]	***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances									N/A	
within-group spatial correlation model									none	
	NE		NW		SE		SW			
county NOx emissions										
own county	0.28		0.27		-1.80		-15.47		-0.14	
	(0.62)		(8.97)		(2.18)		(12.45)		(0.67)	
1^{st} distance	6.91	***	-29.25	.	-11.65	**	47.58	*	-1.41	
	(2.02)		(15.02)		(3.91)		(18.81)		(1.74)	
2^{nd} distance	45.12	***	393.0	***	11.65		-23.71		1.79	
	(12.82)		(70.41)		(8.35)		(27.59)		(4.48)	
3^{rd} distance	-15.99		352.0	***	34.54	*	102.6	.	-28.28	***
	(14.19)		(92.57)		(13.86)		(59.48)		(7.36)	
county VOC emissions										
own county	-0.56		-2.27		3.31		-2.39		-0.28	
	(0.85)		(9.35)		(2.57)		(10.82)		(0.92)	
1^{st} distance	-6.37	***	20.49		17.68	***	-27.08		2.18	
	(1.87)		(14.93)		(4.65)		(18.67)		(1.69)	
2^{nd} distance	-40.83	***	-403.4	***	-15.30		-17.48		-2.29	
	(11.31)		(71.52)		(12.21)		(42.40)		(4.45)	
3^{rd} distance	16.07		-367.1	***	-5.47		-134.2	.	34.27	***
	(12.96)		(95.07)		(13.82)		(74.48)		(7.62)	
p-value (Pr > F)	0.00	***								
adj. R^2	0.98									
# obs	960								960	

Notes:
1^{st} distance = 1 to 100 km; 2^{nd} distance = 100 to 500 km; 3^{rd} distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.1c: O3 mean, annual, 2001

Dependent variable is O3 mean										
	Fixed Effects								RE	
# distances in best-fit FE model					3					
p-value for test if FE needed given best-fit FE model					[0.00]	***				
# distances in best-fit RE model									3	
RE in intercept									Y	
RE in emissions coefficients									N/A	
p-value for test if RE in intercept needed over a pooled model given best-fit # distances									[0.00]	***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances									N/A	
within-group spatial correlation model									rational quadratic	
	NE		NW		SE		SW			
county NOx emissions										
own county	1.05	.	-12.21		-3.81	.	14.60		-0.14	
	(0.57)		(7.63)		(2.07)		(1.29)		(0.43)	
1st distance	7.48	***	-1.57		-6.74	.	46.31	*	-1.06	
	(1.77)		(14.86)		(3.47)		(19.30)		(1.91)	
2nd distance	22.25	.	-92.45	***	5.95		-31.97	*	-5.22	
	(11.64)		(19.43)		(5.98)		(13.22)		(7.62)	
3rd distance	-37.54	**	592.6	***	50.20	***	40.89		6.58	
	(13.27)		(65.36)		(14.37)		(38.34)		(14.34)	
county VOC emissions										
own county	-9.91		12.71		4.67	.	-5.55		0.86	
	(0.89)		(8.86)		(2.57)		(11.83)		(0.70)	
1st distance	-6.94	***	-21.79		13.27	**	-20.56		1.73	
	(1.82)		(15.95)		(4.76)		(18.40)		(2.13)	
2nd distance	-21.65	.	91.80	***	-14.73		6.67		4.87	
	(22.47)		(18.50)		(13.35)		(23.40)		(8.40)	
3rd distance	35.87	**	-626.0	***	-24.15	.	-31.50		-8.50	
	(13.20)		(66.33)		(13.59)		(60.85)		(14.87)	
p-value (Pr > F)	0.00	***								
adj. R^2	0.99									
# obs	1074								1074	

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.2a: O3 90th percentile, annual, 1990

	Dependent variable is 90th percentile 03								
	Fixed Effects								RE
# distances in best-fit FE model					3				
p-value for test if FE needed given best-fit FE model					[0.00]	***			
# distances in best-fit RE model									3
RE in intercept									Y
RE in emissions coefficients									N/A
p-value for test if RE in intercept needed over a pooled model given best-fit # distances									[0.00] ***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances									N/A
within-group spatial correlation model									rational quadratic
	NE		NW		SE		SW		
county NOx emissions									
own county	0.01		0.02		0.02		0.16		0.01
	(0.01)		(0.11)		(0.04)		(0.19)		(0.01)
1st distance	0.07	.	0.21		-0.01		0.12		-0.01
	(0.04)		(0.32)		(0.08)		(0.29)		(0.04)
2nd distance	0.50	*	-2.07	***	0.25		-1.12	**	0.07
	(0.24)		(0.60)		(0.17)		(0.40)		(0.16)
3rd distance	-0.04		0.09		1.06	***	-1.60	**	0.23
	(0.24)		(0.96)		(0.31)		(0.57)		(0.19)
county VOC emissions									
own county	0.01		-0.01		0.07		-0.22	.	-0.00
	(0.02)		(0.09)		(0.04)		(0.12)		(0.01)
1st distance	-0.03		-0.21		0.09		0.53	**	0.04
	(0.03)		(0.23)		(0.08)		(0.19)		(0.04)
2nd distance	-0.39	.	1.57	***	-0.29		1.08	**	-0.07
	(0.22)		(0.44)		(0.20)		(0.34)		(0.15)
3rd distance	0.07		-0.41		-0.78	**	1.79	***	-0.18
	(0.22)		(0.63)		(0.29)		(0.48)		(0.18)
p-value (Pr > F)	[0.00]	***							
adj. R^2	0.97								
# obs	805								805

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.2b: O3 90th percentile, annual, 1996

Dependent variable is 90th percentile O3									
	Fixed Effects								RE
# distances in best-fit FE model			3						
p-value for test if FE needed given best-fit FE model			[0.00]	***					
# distances in best-fit RE model									3
RE in intercept									Y
RE in emissions coefficients									N/A
p-value for test if RE in intercept needed over a pooled model given best-fit # distances									[0.00] ***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances									N/A
within-group spatial correlation model									exponential
	NE		NW		SE		SW		
county NOx emissions									
own county	0.01		-0.06		-0.01		-0.04		0.00
	(0.01)		(0.14)		(0.03)		(0.20)		(0.01)
1^{st} distance	0.12	***	-0.43	.	-0.09		1.12	***	0.01
	(0.03)		(0.24)		(0.06)		(0.30)		(0.04)
2^{nd} distance	0.73	***	4.43	***	0.22		-0.23		0.02
	(0.20)		(1.11)		(0.13)		(0.44)		(0.16)
3^{rd} distance	-0.35		0.89		0.54	*	3.04	**	-0.02
	(0.22)		(1.46)		(0.22)		(0.94)		(0.23)
county VOC emissions									
own county	-0.00		0.04		0.08	.	-0.24		-0.00
	(0.01)		(0.15)		(0.04)		(0.17)		(0.01)
1^{st} distance	-0.08	**	0.27		0.20	**	-0.54	.	0.00
	(0.03)		(0.24)		(0.07)		(0.30)		(0.04)
2^{nd} distance	-0.63	***	-4.75	***	-0.23		-0.96		-0.03
	(0.18)		(1.13)		(0.19)		(0.67)		(0.17)
3^{rd} distance	0.38	.	-1.22		-0.18		-4.12	***	0.01
	(0.20)		(1.50)		(0.22)		(1.18)		(0.23)
p-value (Pr > F)	[0.00]	***							
adj. R^2	0.98								
# obs	960								960

Notes:
1^{st} distance = 1 to 100 km; 2^{nd} distance = 100 to 500 km; 3^{rd} distance = 500 to 1000 km
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.2c: O3 90th percentile, annual, 2001

	Dependent variable is 90th percentile O3								
	Fixed Effects								RE
# distances in best-fit FE model					3				
p-value for test if FE needed given best-fit FE model					[0.00]	***			
# distances in best-fit RE model									3
RE in intercept									Y
RE in emissions coefficients									N/A
p-value for test if RE in intercept needed over a pooled model given best-fit # distances									[0.00] ***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances									N/A
within-group spatial correlation model									spherical
	NE		NW		SE		SW		
county NOx emissions									
own county	0.02	.	-0.19	.	-0.03		0.19		0.00
	(0.01)		(0.11)		(0.03)		(0.19)		(0.01)
1st distance	0.10	***	-0.21		0.02		0.65	*	0.02
	(0.03)		(0.23)		(0.05)		(0.28)		(0.03)
2nd distance	0.27		-1.54	***	0.10		-0.76	***	-0.08
	(0.17)		(0.29)		(0.09)		(0.19)		(0.11)
3rd distance	-0.63	**	7.90	***	0.65	**	0.76		0.24
	(0.19)		(0.96)		(0.21)		(0.56)		(0.20)
county VOC emissions									
own county	-0.00		0.23	.	0.08	*	-0.42	*	0.00
	(0.01)		(0.13)		(0.04)		(0.17)		(0.01)
1st distance	-0.06	*	-0.06		0.14	*	0.00		0.00
	(0.03)		(0.23)		(0.07)		(0.27)		(0.03)
2nd distance	-0.19		1.66	***	-0.21		0.54		-0.08
	(0.17)		(0.27)		(0.20)		(0.34)		(0.11)
3rd distance	0.67	***	-8.17	***	-0.34	.	-0.82		-0.17
	(0.19)		(0.97)		(0.20)		(0.89)		(0.21)
p-value (Pr > F)	[0.00]	***							
adj. R^2	0.99								
# obs	1074								1074

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.3a: NOx mean, annual, 1990

Dependent variable is mean NOx	Fixed Effects								RE	
# distances in best-fit FE model			3							
p-value for test if FE needed given best-fit FE model			[0.00]	***						
# distances in best-fit RE model									2	
RE in intercept									Y	
RE in emissions coefficients									Y	
p-value for test if RE in intercept needed given best-fit # distances									[0.00]	***
p-value for test if RE in emissions coefficients needed given best-fit # distances									[0.00]	***
within-group spatial correlation model									exponential	
	NE		NW		SE		SW			
county NOx emissions										
own county	0.36		-0.48		4.05		6.75	*	0.49	
	(0.42)		(1.39)		(2.91)		(2.73)		(0.34)	
1st distance	1.23	***	-0.27		4.71		2.49		0.76	
	(0.36)		(3.59)		(4.01)		(4.70)		(0.49)	
2nd distance	0.92		23.76	**	0.81		-32.70	***	0.86	
	(0.61)		(7.29)		(4.81)		(7.22)		(0.73)	
3rd distance	0.80		30.70	***	0.97		15.07	*		
	(1.13)		(8.58)		(3.28)		(7.10)			
p-value (Pr > F)	0.00	***								
adj. R^2	0.89									
# obs	323								323	

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.3b: NOx mean, annual, 1996

	Dependent variable is NOx mean								
	Fixed Effects							RE	
# distances in best-fit FE model				3					
p-value for test if FE needed given best-fit FE model				[0.00]	***				
# distances in best-fit RE model								2	
RE in intercept								Y	
RE in emissions coefficients								Y	
p-value for test if RE in intercept needed over a pooled model given best-fit # distances								[0.00]	***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances								[0.00]	***
within-group spatial correlation model								exponential	
	NE		NW		SE		SW		
county NOx emissions									
own county	0.92	*	2.15	*	5.13	*	11.28 ***	2.79	*
	(0.37)		(0.88)		(2.10)		(3.05)	(1.23)	
1^{st} distance	0.59		0.23		0.27		10.61 *	1.70	.
	(0.37)		(2.53)		(3.29)		(5.14)	(0.90)	
2^{nd} distance	0.24		-5.04		-0.80		-32.35 ***	-3.64	
	(0.69)		(4.71)		(4.50)		(7.84)	(5.81)	
3^{rd} distance	-0.46		-21.44	***	0.76		5.74		
	(1.21)		(6.41)		(2.97)		(7.38)		
p-value (Pr > F)	0.00	***							
adj. R^2	0.88								
# obs	378							378	

Notes:
1^{st} distance = 1 to 100 km; 2^{nd} distance = 100 to 500 km; 3^{rd} distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 3.3c: NOx mean, annual, 2001

	Dependent variable is NOx mean									
	Fixed Effects								RE	
# distances in best-fit FE model					3					
p-value for test if FE needed given best-fit FE model					[0.00]	***				
# distances in best-fit RE model									3	
RE in intercept									Y	
RE in emissions coefficients									Y	
p-value for test if RE in intercept needed over a pooled model given best-fit # distances									[0.00]	***
p-value for test if additional RE in emissions coefficients needed given best-fit # distances									[0.00]	***
within-group spatial correlation model									rational quadratic	
	NE		NW		SE		SW			
county NOx emissions										
own county	-4.84		17.99		19.23		-225.1	.	-0.46	
	(5.97)		(22.04)		(34.95)		(129.8)		(5.00)	
1st distance	-2.76		54.46		17.51		-350.4		2.47	
	(8.91)		(55.15)		(47.04)		(299.9)		(10.94)	
2nd distance	17.41		86.66		20.39		-696.6	**	-13.83	
	(17.20)		(112.5)		(12.14)		(219.3)		(109.4)	
3rd distance	-20.82		-257.2	*	-74.61		91.16	***	40.10	
	(28.02)		(121.3)		(56.53)		(22.11)		(113.6)	
p-value (Pr > F)	0.00	***								
adj. R^2	0.86									
# obs	380								380	

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 4.1a: 03 mean, annual, 1990

	Dependent variable is mean O3											
	Fixed Effects								**RE**		**RE, rational quadratic**	
	NE		NW		SE		SW					
county NOx emissions												
own county	-0.00		-0.01		0.07		0.00		-0.00		0.00	
	(0.01)		(0.10)		(0.07)		(0.15)		(0.01)		(0.00)	
1st distance	0.10		-0.20		0.69		-0.51		-0.00		-0.01	
	(0.07)		(1.176)		(0.44)		(1.49)		(0.02)		(0.02)	
2nd distance	-0.11		-25.32	**	0.33		-10.12		-0.13	**	-0.06	
	(0.30)		(9.16)		(1.58)		(9.62)		(0.04)		(0.05)	
3rd distance	-0.65		-23.82		-2.26		8.50		0.08		0.03	
	(0.46)		(16.81)		(4.22)		(14.13)		(0.05)		(0.06)	
county NOx emissions from the N												
1st distance	-0.09		-3.38	**	-0.46		2.97	*	0.01		0.02	
	(0.06)		(1.09)		(0.44)		(1.23)		(0.02)		(0.02)	
2nd distance	0.47	.	1.92		-1.37		-63.31	***	0.10	*	0.06	
	(0.24)		(4.69)		(1.84)		(16.85)		(0.04)		(0.05)	
3rd distance	0.23		9.09		2.35		5.34		-0.05	.	-0.04	
	(0.17)		(8.08)		(4.84)		(15.77)		(0.04)		(0.05)	
county NOx emissions from the W												
1st distance	0.06	.	-1.08	.	0.30		-3.19	***	0.01		0.01	
	(0.03)		(0.63)		(0.42)		(0.69)		(0.01)		(0.01)	
2nd distance	0.21		-3.76	.	0.21		-5.01		0.11	***	0.06	
	(0.14)		(2.16)		(1.18)		(4.20)		(0.03)		(0.04)	
3rd distance	0.33		3.85	.	0.66		289.4	.	0.14	***	0.07	
	(0.27)		(1.99)		(2.69)		(174.8)		(0.04)		(0.05)	
county NOx emissions from the S												
1st distance	-0.05	.	0.15		-0.18		1.44	***	-0.03		-0.01	
	(0.03)		(0.47)		(0.24)		(0.36)		(0.01)		(0.01)	
2nd distance	-0.04		17.68	**	-0.41		1.29		-0.03		-0.03	
	(0.12)		(6.17)		(0.65)		(2.01)		(0.03)		(0.04)	
3rd distance	0.36		14.77		0.64		2.44		-0.21	***	-0.09	.
	(0.32)		(10.63)		(0.59)		(2.23)		(0.04)		(0.05)	
county NOx emissions from the NW												
1st distance	-0.03		2.83	***	0.04		3.65	**	-0.01		-0.01	
	(0.04)		(0.66)		(0.44)		(1.16)		(0.01)		(0.01)	
2nd distance	-0.06		5.18		0.45		56.96	***	-0.04		-0.03	
	(0.14)		(4.07)		(1.42)		(13.93)		(0.03)		(0.04)	
3rd distance	-0.15		-21.89	**	-1.91		274.5		0.05		0.04	
	(0.15)		(80.53)		(2.72)		(177.4)		(0.03)		(0.05)	
county VOC emissions												
own county	0.00		0.03		-0.04		0.02					
	(0.00)		(0.08)		(0.08)		(0.09)					
1st distance	-0.10		-0.12		-0.87	.	0.19					
	(0.06)		(0.92)		(0.51)		(1.04)					
2nd distance	0.07		19.44	**	0.90		6.62					
	(0.26)		(7.01)		(1.47)		(6.41)					
3rd distance	0.55		19.66		2.84		-3.72					

	(0.38)		(14.29)		(3.29)		(10.66)				
county VOC emissions from the N											
1st distance	0.10	.	2.69	**	0.67		2.56	**			
	(0.05)		(0.93)		(0.48)		(0.86)				
2nd distance	-0.38	.	0.07		0.83		46.01	***			
	(0.21)		(3.44)		(1.39)		(11.85)				
3rd distance	-0.23		-8.52		-3.16		-7.13				
	(0.14)		(6.18)		(4.02)		(11.72)				
county VOC emissions from the W											
1st distance	-0.03		0.89		0.03		2.26	***			
	(0.03)		(0.54)		(0.33)		(0.46)				
2nd distance	-0.14		2.55	.	-0.69		3.48				
	(0.13)		(1.47)		(1.26)		(3.42)				
3rd distance	-0.23		-14.28	*	0.53		275.2				
	(0.23)		(6.97)		(2.97)		(168.4)				
county VOC emissions from the S											
1st distance	0.03		-0.04		0.22		-0.91	***			
	(0.02)		(0.35)		(0.25)		(0.23)				
2nd distance	0.00		-12.32	**	0.12		-0.86				
	(0.12)		(4.30)		(0.70)		(1.26)				
3rd distance	-0.35		-11.85		-1.41		-3.16				
	(0.29)		(9.18)		(1.20)		(2.20)				
county VOC emissions from the NW											
1st distance	0.02		-2.32	***	-0.42		-2.93	***			
	(0.03)		(0.56)		(0.52)		(0.82)				
2nd distance	0.04		-4.47		-0.11		-41.41	***			
	(0.12)		(3.00)		(1.00)		(9.31)				
3rd distance	0.13		27.98	**	1.26		-263.8				
	(0.13)		(10.00)		(2.61)		(169.9)				
p-value (Pr > F)					0.00	***					
adj. R^2					0.99						
# obs					503				503		503
p-value from test that FE not needed					[0.00]	***					
p-value of joint test of NOx emissions from the:											
N					[0.00]	***			[0.03]	*	
W					[0.00]	***			[0.00]	***	
S					[0.00]	***			[0.00]	***	
NW					[0.00]	***			[0.20]		
SW					[0.00]	***			NA		
p-value of joint test of VOC emissions from the:											
N					[0.00]	***					
W					[0.00]	***					
S					[0.00]	***					
NW					[0.00]	***					
SW					[0.00]	***					

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 4.2a: 03 90th percentile, annual, 1990

	Dependent variable is 90th percentile 03											
	Fixed Effects								**RE**		**RE, rational quadratic**	
	NE		**NW**		**SE**		**SW**					
county NOx emissions												
own county	0.00		0.07		0.06		0.43	.	0.00		0.00	
	(0.01)		(0.16)		(0.11)		(0.24)		(0.01)		(0.01)	
1st distance	0.14		-0.88		0.73		-0.98		-0.00		-0.01	
	(0.11)		(1.84)		(0.69)		(2.35)		(0.05)		(0.04)	
2nd distance	-0.17		51.11	***	1.10		-20.50		-0.29	***	-0.14	
	(0.48)		(14.47)		(2.50)		(15.20)		(0.08)		(0.10)	
3rd distance	-1.30	.	-38.36		-4.48		4.42		0.04		-0.05	
	(0.73)		(26.57)		(6.66)		(22.33)		(0.10)		(0.11)	
county NOx emissions from the N												
1st distance	-0.11		-5.48	**	-0.18		-5.80	**	0.03		0.04	
	(0.09)		(1.73)		(0.70)		(1.94)		(0.03)		(0.03)	
2nd distance	0.64	.	0.17		-1.87		-174.8	***	0.25	**	0.14	
	(0.38)		(7.41)		(2.91)		(28.20)		(0.08)		(0.09)	
3rd distance	0.22		20.64		4.20		7.40		-0.02		-0.06	
	(0.26)		(12.76)		(7.65)		(24.92)		(0.07)		(0.09)	
county NOx emissions from the W												
1st distance	0.07		-0.72		0.56		-6.99	***	-0.00		0.00	
	(0.05)		(1.00)		(0.67)		(1.10)		(0.02)		(0.02)	
2nd distance	0.14		-5.62	.	0.07		-14.36	*	0.18	**	0.08	
	(0.22)		(3.41)		(1.87)		(6.64)		(0.06)		(0.08)	
3rd distance	0.60		3.38		-0.96		-528.4	.	0.35	***	0.13	
	(0.43)		(3.14)		(4.26)		(276.2)		(0.08)		(0.10)	
county NOx emissions from the S												
1st distance	-0.06		-0.19		-0.17		3.62	***	0.02		0.00	
	(0.04)		(0.74)		(0.38)		(0.57)		(0.02)		(0.02)	
2nd distance	0.13		33.65	***	-0.58		4.21		0.02		-0.00	
	(0.19)		(9.76)		(1.02)		(3.18)		(0.05)		(0.07)	
3rd distance	0.76		20.29		0.93		5.71		-0.24	**	-0.08	
	(0.51)		(16.79)		(0.93)		(3.53)		(0.08)		(0.09)	
county NOx emissions from the NW												
1st distance	-0.06		4.27	***	-0.12		8.34	***	0.00		-0.02	
	(0.06)		(1.04)		(0.69)		(1.83)		(0.02)		(0.02)	
2nd distance	-0.17		12.16	.	0.17		159.3	***	-0.12	.	-0.07	
	(0.22)		(6.42)		(2.24)		(22.01)		(0.06)		(0.08)	
3rd distance	-0.17		-36.91	**	-1.81		506.3	.	0.08		0.07	
	(0.24)		(12.72)		(4.30)		(280.3)		(0.07)		(0.09)	
county VOC emissions												
own county	0.01		-0.01		0.04		-0.20					
	(0.01)		(0.13)		(0.12)		(0.14)					
1st distance	-0.14		0.40		-1.00		0.38					
	(0.10)		(0.15)		(0.81)		(1.64)					
2nd distance	0.14		37.72	***	0.09		13.64					
	(0.41)		(11.08)		(2.32)		(10.12)					
3rd distance	1.12	.	30.17		4.33		3.99					
	(0.60)		(22.58)		(5.20)		(16.84)					

county VOC emissions from the N											
1st distance	0.14	.	4.23	**	0.43		5.38	***			
	(0.08)		(1.47)		(0.75)		(1.36)				
2nd distance	-0.46		2.45		1.39		125.6	***			
	(0.34)		(5.44)		(2.20)		(18.73)				
3rd distance	-0.23		-17.16	.	-4.40		-12.43				
	(0.23)		(9.76)		(6.35)		(18.53)				
county VOC emissions from the W											
1st distance	-0.03		0.55		-0.15		5.06	***			
	(0.05)		(0.85)		(0.52)		(0.73)				
2nd distance	-0.02		4.14	.	-0.72		9.26	.			
	(0.20)		(2.33)		(1.98)		(5.41)				
3rd distance	-0.39		-16.43		1.33		49.13	.			
	(0.37)		(11.01)		(4.70)		(26.61)				
county VOC emissions from the S											
1st distance	0.05		0.21		0.27		-2.26	***			
	(0.04)		(0.56)		(0.40)		(0.36)				
2nd distance	-0.18		-24.06	***	0.24		-2.59				
	(0.19)		(6.79)		(1.10)		(2.00)				
3rd distance	-0.71		-16.56		-2.04		-6.16	.			
	(0.45)		(14.51)		(1.89)		(3.48)				
county VOC emissions from the NW											
1st distance	0.03		-3.34	***	-0.29		-6.76	***			
	(0.05)		(0.88)		(0.82)		(1.30)				
2nd distance	0.12		-10.35	*	0.19		-113.3	***			
	(0.18)		(4.74)		(1.58)		(14.70)				
3rd distance	0.18		41.55	**	1.75		-475.1	.			
	(0.21)		(15.80)		(4.13)		(268.5)				
p-value (Pr > F)					[0.00]	***					
adj. R^2					0.99						
# obs					503				503		503
p-value from test that FE not needed					[0.00]	***					
p-value of joint test of NOx emissions from the:											
N					[0.00]	***			[0.01]	*	
W					[0.00]	***			[0.00]	***	
S					[0.00]	***			[0.02]	*	
NW					[0.00]	***			[0.17]		
SW					[0.00]	***			NA		
p-value of joint test of VOC emissions from the:											
N					[0.00]	***					
W					[0.00]	***					
S					[0.00]	***					
NW					[0.00]	***					
SW					[0.00]	***					

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 4.3: NOx mean, annual, fixed effects

	Dependent variable is mean NOx											
	1990				**1996**				**2001**			
	NE	NW	SE	SW	NE	NW	SE	SW	NE	NW	SE	SW
county NOx emissions												
own	0.89	-2.79	9.20	5.14 .	1.23 *	-2.20	21.02	7.82 *	5.30	-28.97	150.0	-121.5
county	(0.58)	(8.06)	(9.90)	(3.01)	(0.52)	(1.96)	(14.00)	(3.50)	(7.25)	(36.52)	(819.0)	(296.0)
1st	-0.00	17.48	-2.76	-42.18 **	0.41	-45.33 .	211.4 .	-59.86 ***	36.91	-306.3	19.19	48.48
distance	(2.39)	(60.65)	(21.98)	(15.84)	(2.17)	(24.17)	(107.7)	(20.34)	(49.90)	(487.6)	(34.35)	(48.59)
2nd	4.74	229.0	13.13	-226.0 ***	5.52	-118.7	763.3 *	139.3	294.0 **	187.7	-17.74	83.53
distance	(5.37)	(322.6)	(17.76)	(61.64)	(5.17)	(75.32)	(336.0)	(100.3)	(91.37)	(22.0)	(13.98)	(68.95)
3rd	-172.8	NA	-101.6	-101.6	-0.75	-753.2	-809.7	70.02	-789.7 *	572.6	-32.64	-32.59 *
distance	(718.8)		(94.66)	(94.66)	(10.26)	(470.3)	(544.3)	(18.84)	(373.4)	(52.81)	(14.59)	(13.62)
county NOx emissions from the N												
1st	1.77	18.28	-2.10	-82.39 **	1.30	-0.54	58.75	-23.97	-15.10	34.55	-417.0	-3041
distance	(1.89)	(29.62)	(27.31)	(26.92)	(1.65)	(11.39)	(64.22)	(27.31)	(36.00)	(33.23)	(1695)	(3879)
2nd	-0.65	-3.81	NA	28.96	-2.98	-103.4 *	947.4 *	64.46	-184.6 **	1500	2224	-10860
distance	(3.10)	(72.78)		(92.70)	(3.57)	(44.67)	(450.0)	(161.1)	(59.05)	(1634)	(6824)	(8431)
3rd	3.03	32.39	NA	198.4 .	4.02	300.5	10.80	-15.17	394.6 *	5893	215.8	2567 *
distance	(4.54)	(89.81)		(118.4)	(7.28)	(193.3)	(712.9)	(131.7)	(193.1)	(5668)	4.69	(1029)
county NOx emissions from the W												
1st	-0.21	-6.74	NA	-28.06 *	-2.52	0.87	0.58	-14.43	-52.26	-76.67	-740.0	293.5
distance	(1.84)	(13.15)		(12.94)	(1.56)	(4.64)	(43.44)	(12.27)	(33.03)	(96.02)	(2485)	(849.3)
2nd	-5.06 .	23.55	NA	-39.42	-1.86	4.01	-169.6	13.44	21.52	-43.09	3717	-4838
distance	(2.91)	(38.798)		(35.79)	(3.07)	(30.64)	(110.9)	(74.65)	(54.36)	(515.2)	(16780)	(4220)
3rd	-6.72	NA	NA	77.77 .	-11.90	-45.85 *	22.74 *	4.71	-642.6 **	1241	1728	-681700
distance	(7.92)			(45.94)	(11.03)	(22.59)	(10.28)	(7.17)	(187.6) *	(1645)	(14680)	(445900)
county NOx emissions from the S												
1st	0.56	0.38	NA	4.08	1.59	-0.03	41.54 *	23.55 **	28.81	94.57	274.1	-224.9
distance	(1.26)	(15.49)		(6.15)	(1.31)	(8.12)	(16.93)	(7.93)	(23.24)	(229.5)	(609.5)	(388.4)
2nd	1.80	-154.7	NA	53.93 **	0.27	18.70	-273.9 .	18.78	-53.95	84.09	9008	3250
distance	(2.74)	(213.9)		(19.58)	(3.04)	(109.8)	(142.8)	(17.57)	(33.65)	(1891)	(23860)	(2272)
3rd	3.05	131.4	NA	241.1 **	0.16	586.3 .	-15.95	-83.83	1041 **	2080	2969	-1353
distance	(5.01)	(5.85)		(83.39)	(11.02)	(326.4)	(74.33)	(77.46)	(385.3)	(3579)	(2475)	(3349)
county NOx emissions from the NW												
1st	-20.30	-14.51	NA	74.23 **	0.70	4.40	-47.43	40.01	31.42	-68.25	961.4	23.95
distance	(1.39)	(25.69)		(26.04)	(0.97)	(5.43)	(43.52)	(26.71)	(23.98)	(275.7)	(24.75)	(39.72)
2nd	4.73	-65.19	NA	24.31	3.61	-55.72	-873.4 *	-43.99	115.6	-10.17	-28.44	76.21
distance	(3.57)	(45.34)		(89.66)	(2.99)	(42.11)	(406.8)	(14.18)	(99.46)	(13.44)	(1347)	(84.86)
3rd	-5.71	NA	NA	-78.76 .	-5.80	45.75 *	21.42 *	4.71	44.81	-35.64	-37.71	679800
distance	(4.55)			(45.91)	(7.18)	(22.51)	(10.15)	(7.17)	(179.4)	(25.50)	(1191)	(445900)

p-value (Pr > F)	0.00	***	0.00	***	0.00	***
adj. R^2	0.95		0.93		0.92	
# obs	165		197		179	
p-value from test that FE not needed	[0.0000]	***	[0.0000]	***		
p-value of joint test of emissions from the:						
N	[0.0007]	***	[0.0436]	*	[0.0222]	*
W	[0.0007]	***	[0.0043]	**	[0.0204]	*
S	[0.0027]	**	[0.0002]	***	[0.0082]	**
NW	[0.0015]	**	[0.0039]	**	[0.4739]	
SW	[0.0015]	**	[0.0039]	**	[0.4739]	

Notes:
1st distance = 1 to 100 km; 2nd distance = 100 to 500 km; 3rd distance = 500 to 1000 km
coefficients & std errors are multiplied by 100
controls: county population density, county per capita income, quadrant fixed effect in constant
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

TABLE 5.1: Source-Receptor Coefficients for EPA Regions 1-5, O3 mean, annual

	Dependent variable is mean O3				
	Region 1	Region 2	Region 3	Region 4	Region 5
NOx emissions (tons) from:					
Region 2	2.25	1.77	7.24 ***	11.93 ***	10.30 ***
	(2.16)	(2.45)	(1.72)	(1.15)	(1.12)
Region 3	-1.00	-0.88	-3.90 ***	-6.50 ***	-5.84 ***
	(1.26)	(1.43)	(1.00)	(0.67)	(0.69)
Region 4	0.48 .	0.23	0.98 ***	1.78 ***	1.22 ***
	(0.26)	(0.30)	(0.21)	(0.14)	(0.14)
Region 5	-0.58	-0.37	-1.39 ***	-2.36 ***	-1.79 ***
	(0.37)	(0.42)	(0.29)	(0.20)	(0.20)
year	-0.09	-0.46	-3.24 **	-6.92 ***	-6.26 ***
	(1.55)	(1.76)	(1.24)	(0.82)	(0.85)
county-level variables:					
VOC emission (tons/sq mi)		-9.80			
		(20.27)			
population		-2.32 **			
		(0.76)			
income per capita		14.23 ***			
		(2.16)			
p-value (Pr > F)		0.00 ***			
adj. R^2		0.99			
# obs		3481			
p-value from test that FE not needed over pooled		[0.00] ***			
p-value from test that RE not needed over FE		[0.99]			

Notes:
Region 1 NOx emissions was dropped due to singularity.
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year.
Region fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Pop is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 5.2: Source-Receptor Coefficients for EPA Regions 1-5, O3 10th percentile, annual

	Dependent variable is 10th percentile O3									
	Region 1		Region 2		Region 3		Region 4		Region 5	
NOx emissions (tons) from:										
Region 2	0.92		-4.58	*	0.93		4.73	***	5.25	***
	(1.89)		(2.14)		(1.50)		(1.00)		(1.04)	
Region 3	-0.39		2.57	*	-0.46		-2.64	***	-3.01	***
	(1.10)		(1.25)		(0.88)		(0.58)		(0.60)	
Region 4	0.14		-0.76	**	0.01		0.58	***	0.52	***
	(0.23)		(0.26)		(0.18)		(0.12)		(0.12)	
Region 5	-0.18		0.93	*	-0.13		-0.84	***	-0.84	***
	(0.32)		(0.36)		(0.26)		(0.17)		(0.18)	
year	0.78		3.76	*	0.57		-2.73	***	-2.93	***
	(1.36)		(1.54)		(1.08)		(0.72)		(0.74)	
county-level variables:										
VOC emission (tons/sq mi)			-57.72	**						
			(17.72)							
population			-0.76							
			(0.67)							
income per capita			-0.91							
			(1.89)							
p-value (Pr > F)			0.00	***						
adj. R^2			0.98							
# obs			3481							
p-value from test that FE not needed over pooled			[0.00]	***						
p-value from test that RE not needed over FE			[0.99]							

Notes:
Region 1 NOx emissions was dropped due to singularity.
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year.
Region fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Pop is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 5.3: Source-Receptor Coefficients for EPA Regions 1-5, O3 90th percentile, annual

Dependent variable is 90th percentile O3	Region 1	Region 2		Region 3		Region 4		Region 5	
NOx emissions (tons) from:									
Region 2	0.12	5.59		11.83	***	19.37	***	13.10	***
	(3.13)	(3.54)		(2.49)		(1.66)		(1.71)	
Region 3	0.50	-2.75		-6.18	***	-10.46	***	-7.40	***
	(1.82)	(2.06)		(1.45)		(0.96)		(1.00)	
Region 4	0.53	1.07	*	1.90	***	3.02	***	1.72	***
	(0.38)	(0.43)		(0.30)		(0.20)		(0.21)	
Region 5	-0.56	-1.39	*	-2.49	***	-3.95	***	-2.40	***
	(0.53)	(0.60)		(0.42)		(0.28)		(0.29)	
year	1.41	-2.67		-5.34	**	-11.24	***	-8.53	***
	(2.24)	(2.54)		(1.79)		(1.19)		(1.23)	
county-level variables:									
VOC emission (tons/sq mi)		58.92	*						
		(29.29)							
population		-4.31	***						
		(1.10)							
income per capita		34.01	***						
		(3.13)							
p-value (Pr > F)		0.00	***						
adj. R^2		0.99							
# obs		3481							
p-value from test that FE not needed over pooled		[0.00]	***						
p-value from test that RE not needed over FE		[0.99]							

Notes:
Region 1 NOx emissions was dropped due to singularity.
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year.
Region fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Pop is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: gaus.

TABLE 5.4: Source-Receptor Coefficients for EPA Regions 1-5, NOx mean, annual

Dependent variable is mean NOx	Region 1	Region 2		Region 3	Region 4	Region 5
NOx emissions (tons) from:						
Region 2	-0.00	0.00		0.00	0.00	0.00
	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
Region 3	0.00	-0.00		-0.00	-0.00	-0.00
	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
Region 4	-0.00	-0.00		-0.00	0.00	0.00
	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
Region 5	0.00	0.00		-0.00	-0.00	-0.00
	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
year	0.03	-0.94		-1.35	-0.70	-1.48
	(2.29)	(2.79)		(1.77)	(1.74)	(1.97)
county-level variables:						
population		3.52	***			
		(0.29)				
income per capita		2.41	***			
		(0.42)				
p-value (Pr > F)		0.00	***			
adj. R^2		0.89				
# obs		1044				
p-value from test that FE not needed over pooled		[1.00]				
p-value from test that RE not needed over FE		[0.99]				

Notes:
Region 1 NOx emissions was dropped due to singularity.
Coefficients & std err are multiplied by 1E4 for pop and by 10 for income.
Region fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Pop is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 6.1: State-by-state source receptor coefficients for OTC, O3 mean, annual

	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA		RI	VA	VT
						Dependent variable is mean O3								
NOx emissions (tons) from:														
NJ	1.86	4.19	-1.49	-7.13	-1.14	-0.88	-1.75	-0.43	-1.77	-8.49	***	4.10	1.19	-1.81
	(4.88)	(9.51)	(7.30)	(4.17)	(4.19)	(4.94)	(4.64)	(4.32)	(3.06)	(2.48)		(8.88)	(4.43)	(11.82)
NY	-0.85	-1.82	0.85	0.13	0.98	0.60	0.74	-0.07	0.83	4.67	***	-2.70	-0.35	1.66
	(2.58)	(5.02)	(3.83)	(2.20)	(2.21)	(2.59)	(2.44)	(2.28)	(1.61)	(1.30)		(4.72)	(2.33)	(6.28)
PA	0.98	1.61	0.47	0.54	0.55	0.54	0.007	0.73	-0.52	-1.14	*	2.14	0.98	-0.23
	(0.98)	(1.86)	(1.48)	(0.83	(0.85)	(0.98)	(0.97)	(8.69)	(0.62)	(0.50)		(1.85)	(0.89)	(2.37)
VA	-1.77	-3.48	0.01	-0.46	-1.45	-0.40	0.71	-0.38	0.77	3.77	**	-2.87	-1.66	-0.30
	(2.59)	(4.99)	(3.90)	(2.21)	(2.24)	(2.61)	(2.49)	(2.29)	(1.63)	(1.32)		(4.75)	(2.36)	(6.28)
year	4.71	8.92	1.29	2.46	0.68	1.52	-0.93	1.79	-0.71	-6.49	*	8.65	4.55	-0.90
	(5.22)	(10.04)	(7.90)	(4.45)	(4.52)	(5.26)	(5.06)	(4.64)	(3.29)	2.67		(9.59)	(4.76)	(12.68)

county-level variables:		
VOC emission (tons/sq mi)	42.04	*
	(21.35)	
population	-3.23	***
	(0.76)	
income per capita	16.02	***
	(4.01)	

p-value (Pr > F)	0.00	***
adj. R^2	0.992	
# obs	1108	
p-value from test that FE not needed over pooled	[0.60]	
p-value from test that all OTC coefficients are equal	[0.40]	
p-value from test that RE not needed over FE	[0.99]	

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported.
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all OTC coeff equal, compared FE with all states' VOC & NOx emissions with total OTC VOC & NOx
Signif. codes: 0 \`***' 0.001 \`**' 0.01 \`*' 0.05 \`.' 0.1 \` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 6.2: State-by-state source receptor coefficients for OTC, O3 10th percentile, annual

	Dependent variable is 10th percentile O3												
	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT
NOx emissions (tons) from:													
NJ	-0.28	-2.75	-1.59	-1.49	-4.81	1.33	-0.74	3.20	1.22	-1.66	1.55	1.51	-0.86
	(4.35)	(8.46)	(6.50)	(3.71)	(3.73)	(4.39)	(4.13)	(3.84)	(2.72)	(2.20)	(7.90)	(3.94)	(10.05)
NY	0.34	0.34	0.28	1.11	2.41	-0.57	0.45	-2.64	0.90	0.86	-1.41	-1.61	1.63
	(2.30)	(4.46)	(3.40)	(1.95)	(1.97)	(2.31)	(2.18)	(2.03)	(1.43)	(1.16)	(4.20)	(2.07)	(5.54)
PA	-0.03	1.15	0.41	-0.26	-0.86	0.76	-0.16	1.24	0.30	-0.10	1.25	1.65 *	-0.80
	(0.87)	(1.66)	(1.31)	(0.74)	(0.75)	(0.87)	(0.86)	(0.77)	(0.55)	(0.45)	(1.64)	(0.79)	(2.11)
VA	0.26	1.09	0.96	0.72	2.91	-1.24	0.52	-1.03	-0.19	0.77	-0.72	-1.18	-0.26
	(2.30)	(4.44)	(3.47)	(1.96)	(1.99)	(2.32)	(2.22)	(2.04)	(1.45)	(1.18)	(4.23)	(2.10)	(5.59)
year	1.14	2.14	0.63	-0.01	-4.31	3.52	-0.22	5.01	1.88	-0.22	5.03	5.41	-1.05
	(4.65)	(8.93)	(7.03)	(3.96)	(4.02)	(4.68)	(4.50)	(4.12)	(2.93)	(2.38)	(8.53)	(4.24)	(11.28)
county-level variables:													
VOC emission (tons/sq mi)					48.78	**							
					(19.00)								
population					-3.79	***							
					(6.76)								
income per capita					-0.15								
					(3.57)								
p-value (Pr > F)					0.00	***							
adj. R^2					0.98								
# obs					1108								
p-value from test that FE not needed over pooled					[0.02]	*							
p-value from test that all OTC coefficients are equal					[0.002]	**							
p-value from test that RE not needed over FE					[0.99]								

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported.
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all OTC coeff equal, compared FE with all states' VOC & NOx emissions with total OTC VOC & NOx
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 6.3: State-by-state source receptor coefficients for OTC, O3 90th percentile, annual

	Dependent variable is 90th percentile O3												
	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT
NOx emissions (tons) from:													
NJ	12.50 .	18.61	3.35	4.59	5.13	0.86	-1.10	-0.61	-0.41	-11.95 **	-22.13	3.66	-1.38
	(7.51)	(14.62)	(11.22)	(6.40)	(6.45)	(7.59)	(7.13)	(6.64)	(4.70)	(3.81)	(13.66)	(6.80)	(18.17)
NY	-6.18	-7.94	-0.88	-3.17	-1.49	-0.92	-0.11	0.25	0.19	6.63 ***	-12.49 .	-0.59	1.15
	(3.97)	(7.71)	(5.88)	(3.38)	(3.40)	(3.99)	(3.76)	(3.50)	(2.48)	(2.01)	(6.26)	(3.58)	(9.57)
PA	3.12 *	4.15	1.39	2.57 *	1.32	1.57	0.86	1.25	0.65	-1.40 .	6.59 *	1.20	0.24
	(1.51)	(2.87)	(2.27)	(1.28)	(1.30)	(1.50)	(1.49)	(1.34)	(0.95)	(0.77)	(2.84)	(1.37)	(3.65)
VA	-8.20 *	-12.80 .	-3.55	-3.49	4.52	-1.70	-0.46	-1.54	-0.77	5.04 *	-13.73 .	-4.05	-0.93
	(3.98)	(7.68)	(6.00)	(3.39)	(3.44)	(4.01)	(3.83)	(3.53)	(2.50)	(2.03)	(7.31)	(3.62)	(9.66)
year	16.07 *	25.73 .	7.38	9.30	8.37	4.18	0.42	2.75	1.71	-8.93 *	30.23 *	7.73	0.14
	(8.03)	(15.43)	(12.15)	(6.85)	(6.95)	(8.09)	(7.78)	(7.13)	(5.06)	(4.11)	(14.74)	(7.32)	(19.50)

county-level variables:		
VOC emission (tons/sq mi)	28.74	
	(33.83)	
population	-2.18	.
	(1.17)	
income per capita	4.06	***
	(0.62)	
p-value (Pr > F)	0.00	***
adj. R^2	0.99	
# obs	1108	
p-value from test that FE not needed over pooled	[0.02]	*
p-value from test that all OTC coefficients are equal	[0.01]	**
p-value from test that RE not needed over FE	[0.99]	

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported.
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all OTC coeff equal, compared FE with all states' VOC & NOx emissions with total OTC VOC & NOx
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 6.4: State-by-state source receptor coefficients for OTC, NOx mean, annual

	Dependent variable is mean NOx														
	Fixed Effects													Parallel	
	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT		
NOx emissions (tons) from:															
NJ	-0.63	-3.99	-2.76	-0.66	2.09	1.97	4.67	-2.53	-1.00	-3.17	1.13	-1.58	-1.60	0.16	
	(9.50)	(11.70)	(15.39)	(5.73)	(9.33)	(14.54)	(13.85)	(6.61)	(7.02)	(3.99)	(11.87)	(8.23)	(14.58)	(0.46)	
NY	-0.01	1.47	0.46	0.08	-1.16	-2.59	-3.26	1.26	0.01	1.72	-0.65	0.70	1.12	-0.27	
	(5.03)	(6.17)	(8.17)	(3.02)	(4.92)	(7.66)	(7.20)	(3.51)	(3.68)	(2.10)	(6.27)	(4.32)	(7.75)	(0.26)	
PA	0.57	-0.12	0.05	0.05	0.76	1.96	1.21	-0.38	0.24	-0.88	1.06	0.10	-0.38	0.38	
	(1.89)	(2.29)	(3.47)	(1.16)	(1.94)	(2.92)	(2.80)	(1.34)	(1.40)	(0.81)	(2.44)	(1.67)	(3.01)	(0.24)	
VA	-0.01	2.05	2.12	0.37	-1.57	-1.00	-1.93	1.23	0.25	1.99	-1.67	0.45	0.61	-0.30	
	(5.02)	(6.14)	(8.52)	(3.06)	(5.02)	(7.73)	(7.43)	(3.50)	(3.74)	(2.13)	(6.32)	(4.39)	(7.74)	(0.31)	
CT														-1.11	
														(0.15)	
year	0.38	-3.71	-4.00	-1.20	2.27	4.73	3.71	-2.75	-0.87	-4.49	2.41	-0.99	-1.73	0.01	
	(10.07)	(12.35)	(17.53)	(6.18)	(10.17)	(15.61)	(15.11)	(7.07)	(7.56)	(4.31)	(12.76)	(8.90)	(15.74)	(0.01)	
county-level variables:															
NOx emission (tons/sq mi)					37.21	**								23.80	*
					(13.57)									(11.36)	
pop					3.73	***								4.10	***
					(0.51)									(0.46)	
income per capita					-7.74									-7.90	
					(6.23)									(5.97)	
p-value (Pr > F)					0.00	***								0.00	***
adj. R^2					0.92									0.92	
# obs					517									517	
p-value from test that FE not needed over pooled					1										
p-value from test that all OTC coefficients are equal					1									[0.49]	
p-value from test that RE not needed over FE					[0.99]										

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported.
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all OTC coeff equal, compared FE with all states' NOx emissions with total OTC NOx
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: ratio.

TABLE 7.1: Section 126 O3 mean, annual

	Dependent variable is mean O3																	
	CT		DC		DE	MA		MD		ME		NH	NJ	NY	PA		RI	VT
NOx emissions (tons) from:																		
NC	-1.12		-1.64		-1.75	-1.21		-1.52		-1.73		-0.59	-0.89	-0.55	-2.67	***	-0.59	-1.95
	(1.11)		(2.15)		(1.58)	(9.35)		(0.94)		(1.09)		(1.02)	(0.97)	(0.68)	(0.55)		(2.08)	(2.65)
OH	0.59		0.85		1.11	0.73		1.06		1.09		0.32	0.44	0.38	2.05	***	-0.05	1.44
	(0.88)		(1.72)		(1.26)	(0.74)		(0.74)		(0.87)		(0.81)	(0.77)	(0.54)	(0.44)		(1.64)	(2.10)
VA	-0.31		-0.52		-0.47	-0.20		-0.55		-0.54		-0.14	-0.19	-0.13	-1.07	***	0.36	-1.36
	(0.52)		(1.01)		(0.74)	(0.44)		(0.43)		(0.51)		(0.48)	(0.46)	(0.32)	(0.26)		(0.97)	(1.24)
WV	0.58		1.11		0.23	0.31		0.26		0.32		-0.15	0.13	-0.14	-0.60	*	-0.73	0.30
	(0.58)		(1.12)		(0.90)	(0.50)		(0.51)		(0.59)		(0.57)	(0.52)	(0.37)	(0.30)		(1.07)	(1.43)
year	2.13	*	3.86	.	2.37	2.11	*	2.27	*	2.03	*	0.47	1.05	0.87	3.11	***	1.79	2.15
	(1.05)		(1.99)		(1.47)	(8.78)		(0.87)		(1.01)		(9.77)	(0.91)	(0.65)	(0.52)		(2.03)	(2.49)
county-level variables:																		
VOC emission (tons/sq mi)								43.46	*									
								(22.12)										
population								-3.34	***									
								(0.78)										
income per capita								20.14	***									
								(2.34)										
p-value (Pr > F)								0.00	***									
adj. R^2								0.99										
# obs								1019										
p-value from test that FE not needed over pooled								[0.61]										
p-value from test that RE not needed over FE								[0.99]										

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 7.2: Section 126 O3, 10th percentile, annual

	Dependent variable is 10th percentile O3											
	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VT
NOx emissions (tons) from:												
NC	-0.51	-1.04	-0.35	-0.97	-0.58	-0.99	-0.20	1.50 .	0.69	-0.63	-0.15	-1.56
	(0.97)	(1.87)	(1.37)	(0.81)	(0.81)	(0.95)	(0.89)	(0.84)	(0.59)	(0.48)	(1.81)	(2.30)
OH	0.38	0.39	0.11	0.74	0.55	0.55	0.17	-1.33 *	-0.54	0.47	-0.18	1.32
	(0.77)	(1.49)	(0.19)	(0.65)	(0.64)	(0.76)	(0.70)	(0.67)	(0.47)	(0.38)	(1.43)	(1.83)
VA	0.10	0.39	0.41	-0.15	0.06	-0.17	0.07	1.24 **	0.59 *	-0.11	0.76	-1.14
	(0.45)	(0.88)	(0.64)	(0.38)	(0.38)	(0.44)	(0.42)	(0.40)	(0.27)	(0.22)	(0.85)	(1.08)
WV	0.11	-0.25	-0.20	0.06	-0.59	0.47	0.04	0.02	-0.01	0.09	0.22	0.39
	(0.51)	(0.94)	(0.78)	(0.43)	(0.44)	(0.51)	(0.50)	(0.45)	(0.32)	(0.26)	(0.93)	(1.24)
year	1.68 .	2.01	0.95	2.13 **	0.96	1.66 .	0.72	-0.71	-0.01	1.45 **	1.41	2.25
	(0.92)	(1.73)	(1.28)	(0.73)	(0.77)	(0.88)	(0.85)	(0.79)	(0.56)	(0.46)	(1.77)	(2.17)
county-level variables:												
VOC emission (tons/sq mi)					53.01 **							
					(19.23)							
population					-4.00 ***							
					(0.68)							
income per capita					6.47 .							
					(3.77)							
p-value (Pr > F)					0.00 ***							
adj. R^2					0.98							
# obs					1019							
p-value from test that FE not needed over pooled					[0.09] .							
p-value from test that RE not needed over FE					[0.99]							

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 7.3: Section 126, O3 90th percentile, annual

	Dependent variable is 90th percentile 03											
	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VT
NOx emissions (tons) from:												
NC	-0.19	-2.21	-2.79	-0.70	-2.47 .	-1.39	-0.66	-2.43	-1.31	-4.29 ***	-1.11	-2.78
	(1.71)	(3.31)	(2.43)	(1.44)	(1.44)	(1.68)	(1.58)	(1.49)	(1.05)	(0.85)	(3.21)	(4.08)
OH	-0.42	0.88	1.71	-7.44	1.54	0.61	0.22	1.41	0.77	3.21 ***	-2.07	1.40
	(1.36)	(2.64)	(1.93)	(1.15)	(1.14)	(1.34)	(1.25)	(1.89)	(0.83)	(0.67)	(2.53)	(3.24)
VA	-0.30	-1.33	-1.15	0.22	-1.28 .	-0.40	-0.49	-1.16	-0.62	-1.67 ***	0.89	-1.49
	(0.80)	(1.56)	(1.14)	(0.68)	(0.67)	(0.79)	(0.74)	(0.71)	(0.49)	(0.39)	(1.50)	(1.92)
WV	2.01 *	3.61 *	1.32	0.82	1.54 *	0.44	-0.06	0.53	0.28	-0.70	3.04 .	0.37
	(0.90)	(1.73)	(1.38)	(0.77)	(0.78)	(0.91)	(0.88)	(0.80)	(0.57)	(0.46)	(1.65)	(2.20)
year	1.55	6.44 *	4.10 .	1.25	3.93 **	1.12	-0.40	2.00	1.42	4.47 ***	1.22	1.84
	(1.62)	(3.07)	(2.27)	(1.35)	(1.37)	(1.56)	(1.51)	(1.41)	(0.10)	(0.81)	(3.14)	(3.84)

county-level variables:		
VOC emission (tons/sq mi)	27.25	
	(34.08)	
population	-2.18	.
	(1.21)	
income per capita	42.45	
	(6.68)	
p-value (Pr > F)	0.000	***
adj. R^2	0.99	
# obs	1019	
p-value from test that FE not needed over pooled	[0.07]	.
p-value from test that RE not needed over FE	[0.99]	

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 7.4: Section 126, NOx mean, annual

	Dependent variable is mean NOx													
	Fixed Effects												Parallel	
	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VT		
NOx emissions (tons) from:														
NC	-0.58	-0.45	0.64	0.13	-0.23	0.85	1.92	-0.47	0.17	-0.13	-1.26	-0.78	-0.81	**
	(2.17)	(2.60)	(3.34)	(1.26)	(2.04)	(3.20)	(2.81)	(1.49)	(1.48)	(0.87)	(2.62)	(3.26)	(0.25)	
OH	0.25	0.27	-0.54	-0.13	0.00	-1.10	-1.61	0.38	-0.21	0.26	0.65	0.63	0.25	
	(1.72)	(2.07)	(2.62)	(0.99)	(1.61)	(2.54)	(2.23)	(1.19)	(1.18)	(0.69)	(2.08)	(2.62)	(0.27)	
VA	0.02	0.01	0.79	0.08	-0.12	1.12	1.06	-0.22	-0.05	-0.07	-0.54	-0.43	-0.33	.
	(0.99)	(1.23)	(1.61)	(0.58)	(0.95)	(1.50)	(1.27)	(0.72)	(0.68)	(0.41)	(1.23)	(1.61)	(0.19)	
WV	0.05	-0.57	-0.70	-0.17	0.38	-0.07	0.14	-0.29	-0.22	-0.46	0.49	-0.03	-0.08	
	(1.10)	(1.36)	(1.97)	(0.69)	(1.13)	(1.73)	(1.70)	(0.78)	(0.84)	(0.48)	(1.41)	(1.73)	(0.29)	
AL													0.89	
													(0.65)	
year	-0.08	-0.62	-2.80	-0.96	-0.51	-1.37	-3.10	0.00	-0.86	-0.46	0.25	0.66	0.01	
	(2.08)	(2.41)	(3.35)	(1.19)	(1.96)	(3.02)	(2.59)	(1.42)	(1.37)	(0.83)	(2.49)	(3.07)	(0.01)	
county-level variables:														
NOx emission (tons/sq mi)					31.95 *								19.93	.
					(14.07)								(11.71)	
population					4.01 ***								4.34	***
					(0.53)								(0.47)	
income per capita					-15.40 *								-16.51	**
					(6.63)								(6.36)	
p-value (Pr > F)					0.00 ***								0.00	***
adj. R^2					0.92								0.92	
# obs					479								479	
p-value from test that FE not needed over pooled					[1.00]									
p-value from test that RE not needed over FE					[0.99]									

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: ratio.

TABLE 8.1: State-by-state source-receptor coefficients for states under NOx SIP call, O3 mean, annual

					Dependent variable is mean O3						
	AL	CT	DC	DE	GA	IL	IN	KY	MA	MD	MI
NOx emissions (tons) from:											
NC	-3.15 ***	-1.15	-1.73	1.75	-5.10 ***	-1.92 ***	-3.73 ***	-4.62 ***	-1.27	-1.58 .	-3.66 ***
	(0.89)	(1.03)	(1.99)	(1.46)	(0.85)	(0.53)	(0.61)	(0.60)	(0.87)	(0.87)	(0.69)
OH	2.52 ***	0.60	0.95	1.10	3.93 ***	1.43 ***	3.10 **	3.65 ***	0.77	1.08	2.91 ***
	(0.71)	(0.82)	(1.59)	(1.16)	(0.67)	(0.42)	(0.48)	(0.47)	(0.69)	(0.69)	(0.55)
VA	-1.73 ***	-0.32	-0.55	0.47	-2.71 ***	-1.01 ***	-1.74 ***	-2.77 ***	-0.24	-0.57	-1.63 ***
	(0.42)	(0.48)	(0.94)	(0.69)	(0.39)	(0.25)	(0.28)	(0.28)	(0.41)	(0.40)	(0.32)
WV	-0.52	0.60	1.11	0.23	-0.39	-0.22	-0.87 *	-0.65 *	0.32	0.26	-1.21 **
	(0.47)	(0.54)	(1.04)	(0.83)	(0.48)	(0.29)	(0.34)	(0.32)	(0.46)	(0.47)	(0.37)
year	2.82 ***	2.18 *	3.94 *	2.35 ..	4.93 ***	1.90 ***	3.85 ***	4.34 ***	2.18 **	2.29 **	3.21 ***
	(0.83)	(0.98)	(1.84)	(1.36)	(0.82)	(0.50)	(5.77)	(0.56)	(0.81)	(0.82)	(0.65)
	MO	NC	NJ	NY	OH	PA	RI	SC	TN	VA	WV
NOx emissions (tons) from:											
NC	-1.14	-2.10 ***	-0.86	-0.66	-2.59 ***	-2.70 ***	-0.65	-3.85 ***	-3.09 ***	-1.83 *	-3.28 *
	(0.75)	(0.54)	(0.90)	(0.63)	(0.49)	(0.51)	(1.93)	(0.76)	(0.68)	(0.90)	(1.41)
OH	1.03 .	1.56 ***	0.41	0.42	2.18 ***	2.06 ***	-0.02	2.75 ***	2.53 ***	1.08	2.44 *
	(0.60)	(0.43)	(0.71)	(0.50)	(0.39)	(0.40)	(1.52)	(0.60)	(0.54)	(0.72)	(1.12)
VA	-0.73 *	-0.75 **	-0.14	-0.12	-1.29 ***	-1.07 ***	0.33	-1.60 ***	-1.84 ***	-0.54	-1.57 *
	(0.36)	(0.25)	(0.43)	(0.29)	(0.23)	(0.24)	(0.90)	(0.35)	(0.32)	(0.42)	(0.65)
WV	-0.60	-0.21	0.14	-0.10	-0.98 ***	-0.60 *	0.75	-0.09	-0.18	0.68	-0.41
	(0.42)	(0.30)	(0.48)	(0.34)	(0.27)	(0.28)	(0.99)	(0.41)	(0.36)	(0.50)	(0.76)
year	1.58 *	2.15 ***	1.00	0.88	2.51 ***	3.11 ***	1.85	3.69 ***	3.23 ***	2.88 ***	3.66 **
	(0.71)	(0.52)	(0.84)	(0.60)	(0.47)	(0.49)	(1.88)	(0.71)	(0.65)	(0.85)	(1.33)
county-level variables:											
VOC emission (tons/sq mi)					-25.27						
					(17.51)						
population					-0.92						
					(0.65)						
income per capita					6.86 *						
					(2.82)						
p-value (Pr > F)					0.000						
adj. R^2					0.99						
# obs					2884						
p-value from test that FE not needed over pooled					[0.00] ***						
p-value from test that all SIP call coefficients are equal					[0.00] ***						
p-value from test that RE not needed over FE					[0.99]						

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all SIP call coeff equal, compared FE with all states' VOC & NOx emissions with total SIP call VOC & NOx.
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 8.2: State-by-state source-receptor coefficients for states under NOx SIP call, O3 10th percentile, annual

Dependent variable is 10th percentile O3

	AL	CT	DC	DE	GA	IL	IN	KY	MA	MD	MI
NOx emissions (tons) from:											
NC	-1.60 .	0.56	-1.17	-0.34	-1.85 *	0.57	-2.28 ***	-2.91 ***	-1.06	-0.66	-3.14 ***
	(0.83)	(0.96)	(1.85)	(1.36)	(0.79)	(0.49)	(0.57)	(0.55)	(0.80)	(0.81)	(0.64)
OH	1.32 *	0.39	0.48	0.10	1.40 *	0.39	1.93 ***	2.35 ***	0.80	0.59	2.57 ***
	(0.66)	(0.76)	(1.48)	(1.08)	(0.62)	(0.39)	(0.45)	(0.44)	(0.64)	(0.64)	(0.51)
VA	-0.85 *	0.08	0.35	0.41	-0.55	-0.41 .	-0.88 ***	-1.54 ***	-0.21	0.04	-1.19 ***
	(0.39)	(0.45)	(0.87)	(0.64)	(0.36)	(0.23)	(0.26)	(0.26)	(0.38)	(0.37)	(0.30)
WV	-0.48	0.13	-0.24	-0.20	-0.30	-0.02	-0.73 *	-0.83 **	0.06	-0.59	-1.47 ***
	(0.44)	(0.50)	(0.96)	(0.77)	(0.45)	(0.27)	(0.32)	(0.30)	(0.43)	(0.44)	(0.34)
year	1.40 .	1.76 .	2.11	0.92	2.00 **	0.53	2.73 ***	2.83 ***	2.23 **	9.86	2.70 ***
	(0.77)	(0.91)	(1.72)	(1.27)	(0.76)	(0.47)	(0.54)	(0.52)	(0.76)	(0.76)	(0.60)
	MO	**NC**	**NJ**	**NY**	**OH**	**PA**	**RI**	**SC**	**TN**	**VA**	**WV**
NOx emissions (tons) from:											
NC	0.58	-0.61	1.55 .	0.54	-0.36	-0.66	-0.23	-2.36 ***	-2.07 **	-0.48	-0.42
	(0.70)	(0.50)	(0.83)	(0.59)	(0.46)	(0.48)	(0.18)	(0.70)	(0.64)	(0.84)	(1.31)
OH	-0.38	0.46	-1.38 *	-0.48	0.34	0.46	-0.14	1.80 **	1.69 ***	-0.06	0.04
	(0.56)	(0.40)	(0.66)	(0.47)	(0.36)	(0.38)	(1.41)	(0.56)	(0.50)	(0.67)	(1.03)
VA	0.16	0.13	1.33 ***	0.60 *	-0.13	-0.11	0.73	-0.75 *	-0.93 **	0.48	-0.19
	(0.33)	(0.23)	(0.40)	(0.27)	(0.21)	(0.22)	(0.84)	(0.33)	(0.29)	(0.39)	(0.61)
WV	-0.46	-0.33	0.04	0.04	-0.22	-0.10	0.24	-0.80 *	-0.27	-0.26	0.38
	(0.39)	(0.28)	(0.45)	(0.32)	(0.25)	(0.26)	(0.92)	(0.38)	(0.34)	(0.46)	(0.71)
year	-0.37	0.45	-0.79	0.01	0.93 *	1.46 **	1.49	1.70 *	2.53 ***	1.17	1.17
	(0.66)	(0.48)	(0.79)	(0.56)	(0.44)	(0.45)	(1.75)	(0.66)	(0.60)	(0.79)	(1.23)
county-level variables:											
VOC emission (tons/sq mi)					-46.10 **						
					(16.28)						
population					-0.50						
					(0.60)						
income per capita					-11.81 ***						
					(2.62)						
p-value (Pr > F)					0.00 ***						
adj. R^2					0.98						
# obs					2884						
p-value from test that FE not needed over pooled					[0.00] ***						
p-value from test that all SIP call coefficients are equal					[0.00] ***						
p-value from test that RE not needed over FE					[0.99]						

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all SIP call coeff equal, compared FE with all states' VOC & NOx emissions with total SIP call VOC & NOx.
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 8.3: State-by-state source-receptor coefficients for states under NOx SIP call, O3 90th percentile, annual

Dependent variable is 90th percentile O3

	AL	CT	DC	DE	GA	IL	IN	KY	MA	MD	MI
NOx emissions (tons) from:											
NC	-4.45 ***	-0.21	-2.27	-2.79	-8.05 ***	-2.31 **	-3.84 ***	-6.10 ***	-7.48	-2.51 .	3.51 ***
	(1.33)	(1.53)	(2.96)	(2.18)	(1.27)	(0.79)	(0.91)	(0.89)	(1.29)	(1.29)	(1.03)
OH	3.33 **	-0.41	0.92	1.71	6.12 ***	1.76 **	3.26 ***	4.72 ***	-0.04	1.56	2.78 ***
	(1.05)	(1.22)	(2.37)	(1.73)	(1.00)	(0.63)	(0.72)	(0.70)	(1.03)	(1.02)	(0.82)
VA	-2.31 ***	-0.31	-1.35	-1.15	-4.60 ***	-1.41 ***	-2.31 ***	-3.60 ***	0.20	-1.29 *	-1.85 ***
	(0.62)	(0.71)	(1.40)	(1.02)	(0.57)	(0.37)	(0.42)	(0.42)	(0.60)	(0.60)	(0.48)
WV	-0.15	2.02 *	3.61 *	1.32	-0.15	-0.32	-0.62	-0.61	0.82	1.54 *	-1.26 *
	(0.71)	(0.81)	(1.54)	(1.24)	(0.72)	(0.43)	(0.51)	(0.48)	(0.69)	(0.70)	(0.55)
year	4.06 **	1.59	6.49 *	4.09 *	7.62 ***	2.12 **	3.65 ***	5.28 ***	1.30	3.95 **	2.71 **
	(1.24)	(1.45)	(2.75)	(2.03)	(1.22)	(0.75)	(0.86)	(0.84)	(1.21)	(1.22)	(0.96)

	MO	NC	NJ	NY	OH	PA	RI	SC	TN	VA	WV
NOx emissions (tons) from:											
NC	-1.78	-4.35 ***	-2.42 ..	-1.38	-3.50 ***	-4.31 ***	1.07	-5.96 ***	-5.46 ***	-3.30 *	-5.51 **
	(1.12)	(0.81)	(1.33)	(0.94)	(0.74)	(0.76)	(2.87)	(1.12)	(1.02)	(1.35)	(2.10)
OH	1.73 .	3.32 ***	1.39	0.80	2.95 ***	3.22 ***	-2.04	4.27 ***	4.30 ***	2.14 *	4.12 *
	(0.89)	(0.64)	(1.06)	(0.75)	(0.58)	(0.60)	(2.26)	(0.89)	(0.81)	(1.07)	(1.66)
VA	-1.36 *	-2.14 ***	-1.13 . .	-0.61	-1.86 ***	-1.67 ***	0.87	-2.77 ***	-3.17 ***	-1.62 **	2.55 **
	(0.53)	(0.37)	(0.63)	(0.44)	(0.34)	(0.35)	(1.34)	(0.53)	(0.47)	(0.63)	(0.97)
WV	-0.92	-0.11	0.54	0.29	-1.31 **	-0.70 .	3.05 *	0.06	-0.05	1.53 *	-0.43
	(0.62)	(0.45)	(0.72)	(0.51)	(0.40)	(0.42)	(1.48)	(0.61)	(0.54)	(0.74)	(1.14)
year	1.84 .	4.62 ***	1.98	1.44	2.78 ***	4.48 ***	1.27	5.90 ***	5.37 ***	5.03 ***	5.68 **
	(1.05)	(0.77)	(1.26)	(0.89)	(0.70)	(0.72)	(2.81)	(1.06)	(0.97)	(1.27)	(1.98)

county-level variables:	
VOC emission (tons/sq mi)	-8.11
	(26.07)
population	-0.87
	(0.97)
income per capita	33.23 ***
	(4.19)
p-value (Pr > F)	0.00 ***
adj. R^2	0.99
# obs	2884
p-value from test that FE not needed over pooled	[0.00] ***
p-value from test that all SIP call coefficients are equal	[0.00] ***
p-value from test that RE not needed over FE	[0.99]

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
For joint test that all SIP call coeff equal, compared FE with all states' VOC & NOx emissions with total SIP call VOC & NOx.
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 8.4: State-by-state source-receptor coefficients for states under NOx SIP call, NOx mean, annual

Dependent variable is mean NOx

	Fixed Effects											Parallel	
	AL	CT	DC	DE	GA	IL	IN	KY	MA	MD	MI		
NOx emissions (tons) from:													
NC	-0.42	-0.67	-0.31	0.79	-1.05	0.17	-1.15	-0.51	0.25	-0.10	-1.38	-0.40	*
	(8.88)	(2.13)	(2.55)	(3.28)	(1.99)	(1.36)	(1.56)	(1.34)	(1.23)	(2.00)	(2.44)	(0.18)	
OH	-0.11	0.33	0.17	-0.63	0.71	-0.01	0.97	0.39	-0.19	-0.07	1.00	0.28	
	(3.87)	(1.69)	(2.04)	(2.58)	(1.58)	(1.09)	(1.25)	(1.06)	(0.98)	(1.58)	(1.95)	(0.19)	
VA	-0.24	-0.05	0.03	0.82	-0.61	-0.12	-0.92	-0.29	0.07	-0.11	-1.01	-0.27	*
	(2.40)	(0.97)	(1.20)	(1.56)	(0.93)	(0.64)	(0.75)	(0.62)	(0.57)	(0.94)	(1.22)	(0.13)	
WV	NA	-0.01	-0.56	-0.67	-0.14	-0.31	-0.17	-0.03	-0.17	0.33	-0.03	-0.13	
		(1.08)	(1.33)	(1.93)	(1.07)	(0.75)	(0.88)	(0.72)	(0.67)	(1.11)	(1.16)	(0.20)	
AL												0.16	
												(0.46)	
year	-1.24	-0.08	-0.81	-2.96	0.02	-0.45	0.85	0.16	-1.07	-0.68	1.74	0.010	*
	(9.74)	(2.04)	(2.37)	(3.29)	(1.89)	(1.28)	(1.43)	(1.26)	(1.17)	(1.93)	(2.28)	(0.005)	

	MO	NC	NJ	NY	OH	PA	RI	SC	TN	VA	WV
NOx emissions (tons) from:											
NC	-0.30	-0.68	-0.36	0.21	-0.82	-0.07	-1.20	-0.16	0.09	-0.56	-6.12
	(1.14)	(3.10)	(1.47)	(1.46)	(1.90)	(0.86)	(2.57)	(1.68)	(1.48)	(1.73)	(15.09)
OH	0.30	0.31	0.31	-0.22	0.78	0.22	0.61	0.03	-0.10	0.35	5.43
	(0.90)	(2.49)	(1.17)	(1.16)	(1.51)	(0.68)	(2.04)	(1.33)	(1.18)	(1.37)	(14.79)
VA	-0.38	-0.50	-0.24	-0.22	-0.51	-0.07	-0.52	-0.00	0.11	-0.24	-4.39
	(0.54)	(1.41)	(0.71)	(0.67)	(0.91)	(0.40)	(1.21)	(0.78)	(0.69)	(0.81)	(12.56)
WV	-0.09	0.83	-0.28	-0.30	-0.49	-0.45	0.48	0.05	0.21	-0.06	NA
	(0.63)	(1.60)	(0.76)	(0.82)	(0.94)	(0.47)	(1.38)	(0.91)	(0.79)	(0.97)	
AL											
year	0.04	1.32	-0.16	-0.99	0.63	-0.57	0.14	-0.02	0.31	0.16	5.70
	(1.06)	(2.85)	(1.39)	(1.35)	(1.84)	(0.82)	(2.45)	(1.58)	(1.39)	(1.62)	(13.34)

	Fixed Effects		Parallel	
NOx emission (tons/sq mi)	49.85	***	41.39	***
	(12.85)		(10.66)	
population	3.17	***	3.42	***
	(0.49)		(0.44)	
income per capita	11.97	*	12.36	*
	(5.35)		(5.16)	
p-value (Pr > F)	0.00	***	0.00	***
adj. R^2	0.90		0.91	
# obs	968		968	
p-value from test that FE not needed over pooled	1			
p-value from test that all SIP call coefficients are equal	1		[0.55]	

Notes:
All coefficients & std err are multiplied by 1E4, except for income per capita, which is multiplied by 100, and year
State fixed effects in constant not reported
County income per capita is in 1000 1982-1984 $
Population is in population per sq mi
Couldn't test if RE needed b/c # obs different due to singularities
For joint test that all SIP call coeff equal, compared FE with all states' NOx emissions with total SIP call NOx.
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
Among the spatial models considered, the most adequate within-group correlation structure in RE (i.e., with lowest AIC & BIC) is: none.

TABLE 9: Daily maximum 8-hour average ozone

Dependent variable is daily maximum 8-hour average ozone	1990		1998	
time lagged daily maximum 8-hour average ozone				
own	0.44	***	0.47	***
	(0.01)		(0.01)	
1st distance	-0.05	***	-0.11	***
	(0.01)		(0.01)	
2nd distance	-0.04	**	-0.02	
	(0.01)		(0.01)	
county NOx emissions				
own	0.00		0.00	
	(0.00)		(0.01)	
1st distance	-0.51	***	0.70	***
	(0.10)		(0.14)	
2nd distance	-0.46	***	1.00	***
	(0.11)		(0.14)	
county VOC emissions				
own	-0.00		-0.01	
	(0.01)		(0.02)	
1st distance	0.36	***	-0.62	***
	(0.09)		(0.14)	
2nd distance	0.29	**	0.89	***
	(0.10)		(0.13)	
county-level controls				
population	-0.00		-0.00	
	(0.00)		(0.00)	
income	0.36	***	0.28	**
	(0.17)		(0.10)	
daily maximum temperature	1.71	***	1.49	***
	(0.03)		(0.03)	
p-value (Pr>F)	0.00	***	0.00	***
adj. R^2	0.56		0.60	
# obs	23421		25904	
p-value from test that distances emissions not needed	[0.00]	***	[0.00]	***
p-value from joint test of all 2nd distances	[0.00]	***	[0.00]	***

Notes:
Distances: 1st distance = 1 to 500 km; 2nd distance = 500 to 1000 km
Controls: region, state, county, day
Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1