The relationships of sprawl and ozone air quality in United States' metropolitan areas

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Abstract This article reports the results of an examination of the relatizonships between degree of sprawl and improvements in ozone air quality for 52 metropolitan areas in the US. It also examines state political alignment and environmental resources with regard to these two primary objects of investigation. Evidence of a relationship between sprawl and air quality improvement was identified, but the evidence is ambiguous. More research appears warranted to explore the sprawl–air quality improvement relationship.

Keywords Environment · Government expenditures · Ozone air quality · Politics · Regional sprawl

Introduction and background

Sprawl is a hearty perennial in the garden of issues that city planners must tend. The emergence of the automobile-dominated transportation system over the past 50+ years brought with it a shift in urban form (Ewing 1997). Dense urban centers gave way to a more dispersed set of land uses at their fringe as metropolitan areas grew. In short, the wealth and increased mobility of post-World War II America brought with them an urban landscape which uses more land for dispersed activities than preceding urban areas did (Blumenfield 1968).

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Scholars and practitioners alike have observed and assessed these changes (Whyte 1957; Ottensman 1977; Downs 1994). Gordon and Richardson (1997) and Ewing (1997), even while disagreeing about fundamental aspects of this change, observed the accelerating diffusion of activities across the urban fringe as growth occurred. In a number of works, this spreading out has been either hailed as bringing people in contact with more preferred settings (Gordon and Richardson 1997) or criticized as harmful to the environment (Burchell et al. 1998) and damaging to the social fabric (Popenoe 1977). This paper examines the question of the degree of impact on ozone air quality that can be associated with sprawl. It does this by examining the relationship between degree of sprawl and degree of improvement in air pollution from ozone. Over the period 1982–1996, in this study's US metropolitan areas, urbanized land increased at an annual average rate of almost 2%. At the same time, due to a concerted national air pollution control program, ozone pollution in these areas improved almost 25%. However, not all areas urbanized at the same rate and not all areas made the same progress in ozone air pollution abatement. An examination of the effect of sprawl on air quality gains can shed light on the relationship between urban development and environmental quality. The core research question upon which this article reports is "What is the relation between sprawl and improvement in ozone air pollution in US metropolitan areas?". Since pollution control is directly influenced by state governments, it is prudent to consider state differences through incorporation of both state policies and state expenditures for environmental protection.

This work sought to examine political and land-use policy differences as a way to gain insight into future policy design that would impact ozone concentrations. An attempt to include precursor emissions rather than ambient ozone concentrations would likely make the study less, rather than more, policy relevant since it would introduce the complexity of relations between precursor emissions and ambient ozone. The photochemistry of ozone formation is exceedingly complicated and any attempt to model it would push this investigation into an ambiguous area. To bring such a topic into a policy model would almost assuredly deflect attention away from the relationships between environmental outcomes and the critical variables the paper seeks to explore and which have been identified frequently as important in ozone management.

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The definition and consequences of sprawl

Sprawl can mean many things to many people. It has been referred to as a particular set of land uses (Whyte 1957), transportation characteristics (Cervero 1989), or economic conditions (Gordon et al. 1989). This research views sprawl as a diminution of development intensity of land uses adjacent to a more urbanized area. The intensity of these land uses is associated with development that is both expanding spatially and, as it expands, diminishing the metropolitan area's population density. Associated with this is increasing vehicle miles traveled per capita (VMTPC) as additional travel is required to conduct the daily activities of the metropolitan area.

The impacts of sprawl have been described by many authors (Real Estate Research Corporation 1974; Ewing 1997; Gordon and Richardson 1997). As growth sprawls at the boundary of metropolitan areas, environmental problems have been associated with sprawl. Air pollution from increased use of cars is an important one (Godish 1997). Both carbon monoxide and ozone problems have been identified as products of increased use of automobiles (US EPA 1996, 1998, 1999). However, water pollution from sprawl has also been identified as of environmental concern in areas with sprawl. Sedimentation, heavy metals, and chemicals have all been associated with runoff that accompanies sprawl growth (Lipton and Wellman 1995). Critics of sprawl growth have also asserted that the isolation associated with large lot development, segregation of land uses, and reliance on cars for transportation have all contributed to a growing alienation in the society that has evolved in this setting (Baumgartner 1988; 1000 Friends of Oregon 1996). Proponents of the new urbanism have asserted that moving away from sprawl development can not only have environmental benefits but also enhance the sense of community and diminish a feeling of alienation that derives from the isolation of sprawl growth (Fodor 1999).

Sprawl and air quality

Human exposure to ozone has been associated with changes in lung function, reduction to immune system effectiveness, and increased hospital admissions (Godish 1997). Additionally, damage to the growth of some species of vegetation has been reported (US EPA 1996). The most current data available indicate that over 25 areas in the US do not meet the national ambient air quality standards for ozone, exposing their residents to unacceptable health effects (US EPA 1999).

Ozone is an indirect air pollutant. It is not emitted from any source, but is formed through the chemical reaction of volatile organic compounds (VOCs) and oxides of nitrogen (NOX) in the presence of sunlight. Automobiles can be important sources of both VOCs and NOX. As a result, much attention to meet ozone standards has focused on auto emissions (Stensvaag 1999). Every revision of the Clean Air Act has sought to reduce emissions from autos; consequently, ozone pollution has been reduced in the US, even though it remains a significant air pollutant.

Since sprawl development has, as a feature, increased use of the automobile, this can pose a barrier to improving ozone air pollution levels. With dispersed land uses, the increased use of cars can lead to increased VOC and NOX emissions above what would otherwise occur, thereby undercutting progress in controlling ozone. Since auto emission standards generally are uniform nationally (the exception is California's more restrictive standards), under this situation we would expect that those areas with especially sprawling development would make less progress in ozone control.

State governments are the source of land-use control authorities and air pollution control programs alike. State land-use policies as well as environmental policies can influence the development of sprawl in metropolitan areas (Brookings Institution 2000). Conservative politics generally advocate less intervention by the government, thereby placing less restrictions on sprawl. State expenditures on environmental control are also important in influencing environmental outcomes such as ozone pollution progress. Moreover, some critics of sprawl have asserted that increased governmental expenditures are associated with sprawl as problems that require government intervention increase (Fodor 1999).

Methods

Research questions

This paper explores the relationships among sprawl, ozone air pollution, state politics, and state environmental expenditures. In particular, this research seeks to examine the following:

1. Can growth in the metropolitan areas with ozone problems be characterized as sprawl?
2. Is sprawl associated with a particular state's political alignment or profile of environmental expenditures?
3. Are ozone air quality gains reduced by sprawl?
4. Are ozone air quality gains associated with a particular state's political alignment or profile of environmental expenditures?

Measurement and data

The period of observation is 1982–1996, and the unit of observation is the metropolitan urban area. The metropolitan areas were those 52 metropolitan areas that exceeded the national ambient air quality standard for ozone in 1982 and for which the Federal Highway Administration had data available on characteristics of sprawl (US Department of Transportation 1998). Data from the Federal Highway Administration contain for each of these metropolitan areas the annual average per cent change for (1) urbanized land, (2) population density,

(3) vehicle miles traveled per capita, and (4) income per capita. This data set on sprawl characteristics also was employed by Noland and Cowart (1999) in their examination of metropolitan highway capacity and growth of vehicle miles traveled.

Ozone data were obtained from the US EPA National Air Quality and Emissions Trends Reports for 1982 (1984) and 1996 (1998). Environmental expenditures for each of the relevant states were obtained from *The Book of the States – 1996* (Council of State Governments 1997). Since the effect of interest, should it exist, involves air quality but the expenditure data available were for total environmental expenditures, some masking of relationship would be expected.

State political characterization employed three measures developed by Erickson et al. (1993). Strength of partisanship index was derived by them from CBS/*New York Times* interviews of citizens across the period 1976–1988. The index is the difference of the percentage of respondents identifying themselves as Democrats and those identifying themselves as Republicans. The ideological index was developed in a similar manner: it is the percentage of the respondents in a state identifying themselves in the CBS/*New York Times* polls as liberal minus the percentage identifying themselves as conservative. The policy liberalism index developed by Erickson et al. is the standardized score of the state's respondents for characterization concerning consumer protection, criminal justice, legalized gambling, the Equal Rights Amendment, and tax progressivity. As a result, the policy liberalism index can be viewed as a general measure of the state's orientation to liberal policies.

Table 1
The 1990 population (in thousands) for metropolitan areas and their states

City	Metropolitan area	Respective state
Albany	861	18,185
Allentown	595	12,056
Atlanta	2,960	7,353
Baltimore	2,382	5,072
Boston	3,228	6,092
Buffalo	1,189	18,185
Charlotte	1,162	7,323
Chicago	7,411	11,847
Cincinnati	1,526	11,173
Cleveland	2,202	11,173
Columbus	1,345	11,173
Dallas	2,676	19,128
Denver	1,623	3,823
Detroit	4,267	9,594
Fort Worth	1,361	19,128
Fort Lauderdale	1,255	14,400
Hartford	1,158	3,274
Houston	3,322	19,128
Indianapolis	1,380	5,841
Jacksonville	907	14,400
Kansas City	1,583	5,359
Los Angeles	8,863	31,878
Louisville	949	3,884
Memphis	1,007	5,320
Miami	1,937	14,400
Milwaukee	1,432	5,160
Minneapolis	2,539	4,658
Nashville	985	5,320
New Orleans	1,285	4,351
New York City	8,547	18,185
Norfolk	1,443	6,675
Oklahoma City	959	3,301
Omaha	640	1,652
Orlando	1,225	14,400
Philadelphia	4,922	12,056
Phoenix	2,238	4,428
Pittsburgh	2,384	12,056
Portland	1,515	3,204
Providence	1,134	990
Rochester	1,062	18,185
Sacramento	1,340	31,878
Salt Lake City	1,072	2,000
San Antonio	1,325	19,128
San Diego	2,498	31,878
San Francisco	1,604	31,878
San Jose	1,498	31,878
Seattle	2,033	5,533
St. Louis	1,836	5,359
Tampa	2,068	14,400
Tucson	667	4,428

Exploratory methodology

The analysis proceeded in three steps. First, descriptive statistics were examined for the relevant variables in order to identify significant trends. Second, correlations were explored for the variables in order to identify associations. Third, ordinary least squares regression analysis was used to examine air quality improvements based on the results of the preceding analyses.

Characteristics of ozone metropolitan areas

As Table 1 shows, the 1990 population for these metropolitan areas ranged from approximately 600,000 to 8.9 million. The mean population was slightly above 2,000,000. Examination of the distribution of populations showed a median population of approximately 1,500,000 and the upper and lower 95% levels of approximately 2,600,000 and 1,600,000 respectively.

Sprawl

Each of the metropolitan areas was examined for degree of sprawl. Two measures of sprawl were employed (Table 2): (1) average annual per cent change of population density for the metropolitan area 1982–1996; and (2) average annual per cent change in urbanized land area for the metropolitan area 1982–1996. While the population density changes range from a positive to a negative value, the predominant change in population density over the period indicates a dispersal of population for most of the metropolitan areas.

Examination of the annual change in urbanized land areas indicates that for most areas the period 1982–1996 saw metropolitan areas add urbanized land. Similar to the situation of population density, the range of values observed was both positive and negative. However, with mean, median, and the upper and lower 95% bounds all positive values, the predominant feature is that almost all areas saw an annual increase in urbanized land. When population density and urbanized land expansion are examined together for the areas, the picture is of

Table 2
Per cent annual average change in sprawl characteristics (US Department of Transportation 1998)

City	Population density	Urbanized land	Income per capita	Vehicle miles traveled per capita
Albany	–0.26	0.2	2.41	4.11
Allentown	–1.8	2.94	2.12	2.14
Atlanta	1.63	1.45	2.73	2.56
Baltimore	–0.11	1.52	1.2	0.86
Boston	–1.3	1.72	2.7	1.57
Buffalo	–2.95	3.04	2.41	2.05
Charlotte	0.12	3.41	2.86	1.66
Chicago	–1.86	2.65	2.09	3.5
Cincinnati	–0.27	1.07	2.01	2.63
Cleveland	–1.09	1.54	2.01	2.76
Columbus	–1.8	3.21	2.01	2.86
Dallas	0.6	1.09	1.2	1.78
Denver	0.95	1.01	1.68	1.06
Detroit	–1.35	1.29	2.36	2.86
Fort Worth	–0.05	1.22	1.2	2.71
Fort Lauderdale	–0.23	2.64	1.97	0.91
Hartford	0.35	0.49	2.7	2.94
Houston	1.06	0.67	1.2	1.37
Indianapolis	–0.03	1.11	2.21	3.72
Jacksonville	0.44	1.61	1.97	1.53
Kansas City	–0.92	–0.55	2.01	2.73
Los Angeles	0.05	1.47	1.2	1.54
Louisville	–0.08	0.66	2.01	4.45
Memphis	–0.2	1.89	2.79	2.93
Miami	–0.76	1.99	1.97	2.23
Milwaukee	0.1	0.13	1.95	2.68
Minneapolis	–0.9	2.73	2.31	2.99
Nashville	–1.46	3.13	2.79	4.13
New Orleans	–0.37	0.61	1.24	2.62
New York City	–0.48	0.69	2.41	2.21
Norfolk	1.59	0.35	2.19	1.89
Oklahoma City	–0.07	3.17	0.43	0.11
Omaha	–0.28	1.03	1.96	3.49
Orlando	1.76	2.2	1.97	0.83
Philadelphia	–1.29	3.19	2.12	0.64
Phoenix	–1.3	4.94	1.74	0.66
Pittsburgh	–1.88	2.38	2.12	2.64
Portland	–0.43	2.13	2.18	3.28
Providence	–0.42	1.04	2.17	3.02
Rochester	–1.25	1.04	2.41	5.08
Sacramento	0.35	2.49	1.2	1.64
Salt Lake City	–0.31	2.3	2.15	4.03
San Antonio	0.59	1.23	1.2	2.27
San Diego	1.14	1.49	1.2	1.75
San Francisco	–0.97	2.19	1.2	1.76
San Jose	0.9	1.15	1.2	1.23
Seattle	0.59	1.58	1.88	1.17
St. Louis	–1.28	1.93	2.01	3.37
Tampa	0.21	2.8	1.97	2.1
Tucson	–1.93	4.56	1.74	4.26

expanding urban areas accompanied with a growing dispersal of the population across the area.

Increased reliance on the automobile is one characteristic of sprawl that can impact ozone air pollution. Table 2 also provides information on the average annual per cent change in vehicle miles traveled per capita (VMTPC) across the metropolitan areas. All of the areas present an increase in VMTPC. The national annual average VMTPC of 2.3% exceeded either the addition of urbanized land (1.8%) or the change in population density (–0.4%), indicating the expected accelerating use of the automobile. Table 2 also presents the average annual per cent change in per capita income across the areas over the period of observation. It is interesting to note that the national average VMTPC of 2.3% also outstrips national average growth in income in the metropolitan areas (1.9%), affirming the growing role of the automobile in these areas.

Ozone air quality

The national ambient air quality standard for ozone is 0.12 parts per million of ozone. The air quality for ozone air pollution is measured by the US EPA as the second highest monitored concentration of ozone in the ambient air for a 1-h period from the monitors that each state is required to operate in the metropolitan areas. The profile distributions of ozone air quality for 1982 and 1996 are provided in Table 3. Two characteristics are apparent.

Table 3
Ozone concentration profiles (in ppm) (US EPA 1984, 1998)

City	1982	1996	Change in ozone 1982–1996
Albany	0.12	0.09	0.03
Allentown	0.15	0.11	0.04
Atlanta	0.14	0.12	0.02
Baltimore	0.14	0.12	0.02
Boston	0.16	0.09	0.07
Buffalo	0.11	0.1	0.01
Charlotte	0.12	0.13	–0.01
Chicago	0.12	0.1	0.02
Cincinnati	0.13	0.11	0.02
Cleveland	0.13	0.11	0.02
Columbus	0.13	0.11	0.02
Dallas	0.17	0.12	0.05
Denver	0.14	0.09	0.05
Detroit	0.16	0.1	0.06
Fort Worth	0.17	0.13	0.04
Fort Lauderdale	0.09	0.09	0
Hartford	0.17	0.1	0.07
Houston	0.21	0.16	0.05
Indianapolis	0.12	0.12	0
Jacksonville	0.12	0.09	0.03
Kansas City	0.1	0.1	0
Los Angeles	0.32	0.14	0.18
Louisville	0.17	0.11	0.06
Memphis	0.13	0.13	0
Miami	0.14	0.09	0.05
Milwaukee	0.13	0.11	0.02
Minneapolis	0.1	0.09	0.01
Nashville	0.11	0.11	0
New Orleans	0.17	0.1	0.07
New York City	0.17	0.12	0.05
Norfolk	0.11	0.1	0.01
Oklahoma City	0.11	0.09	0.02
Omaha	0.09	0.07	0.02
Orlando	0.1	0.1	0
Philadelphia	0.18	0.12	0.06
Phoenix	0.12	0.11	0.01
Pittsburgh	0.14	0.11	0.03
Portland	0.12	0.12	0
Providence	0.15	0.1	0.05
Rochester	0.11	0.08	0.03
Sacramento	0.16	0.12	0.04
Salt Lake City	0.14	0.11	0.03
San Antonio	0.14	0.12	0.02
San Diego	0.21	0.1	0.11
San Francisco	0.14	0.08	0.06
San Jose	0.14	0.11	0.03
Seattle	0.09	0.11	–0.02
St. Louis	0.16	0.11	0.05
Tampa	0.12	0.1	0.02
Tucson	0.12	0.09	0.03

Table 4
Political profiles [scores, developed by Erickson et al. (1993), as discussed in the text]

City	State party identification	State ideology identification	State policy liberalism
Albany	8	–3.1	2.12
Allentown	3.7	–10.6	1.01
Atlanta	27	–17.7	–1.04
Baltimore	22.2	–5.7	0.85
Boston	18.3	–0.8	1.64
Buffalo	8	–3.1	2.12
Charlotte	19	–20.7	–0.96
Chicago	6.1	–10.1	0.41
Cincinnati	4.4	–10.1	0.64
Cleveland	4.4	–10.1	0.64
Columbus	4.4	–1.01	0.64
Dallas	13.4	–23.2	–0.65
Denver	–4	–8.6	0.48
Detroit	2.1	–8.8	1.18
Fort Worth	13.4	–23.2	–0.65
Fort Lauderdale	6.6	–17.1	–0.37
Hartford	7.8	–4.4	1.19
Houston	13.4	–23.2	–0.65
Indianapolis	–1.7	–16.7	–1.2
Jacksonville	6.6	–17.1	–0.37
Kansas City	7.8	–15.8	0.24
Los Angeles	6.2	–6.2	1.49
Louisville	24.3	–13.2	–0.32
Memphis	12.9	–16.6	–0.85
Miami	6.6	–17.1	–0.37
Milwaukee	7.1	–10.5	1.23
Minneapolis	9.5	–12.8	0.79
Nashville	12.9	–16.6	–0.85
New Orleans	35.3	–23	–1.04
New York City	8	–3.1	2.12
Norfolk	3.3	–17.9	–0.84
Oklahoma City	20.9	–27.3	–0.98
Omaha	–9.3	–18.7	0.44
Orlando	6.6	–17.1	–0.37
Philadelphia	3.7	–10.6	1.01
Phoenix	0.6	–18.2	–1.05
Pittsburgh	3.7	–10.6	1.01
Portland	7.4	–7.9	1.39
Providence	12.7	–2.1	0.68
Rochester	8	–3.1	2.12
Sacramento	6.2	–6.2	1.49
Salt Lake City	–17.4	–28	–0.44
San Antonio	13.4	–23.2	–0.65
San Diego	6.2	–6.2	1.49
San Francisco	6.2	–6.2	1.49
San Jose	6.2	–6.2	1.49
Seattle	7.8	–5.9	0.35
St. Louis	7.8	–15.5	–0.55
Tampa	6.6	–17.1	–0.37
Tucson	0.6	–18.2	–1.05

First, with the exception of a handful of outliers, the air quality in most metropolitan areas is quite similar. Second, there has been substantial improvement in air quality from 1982–1996. This marked improvement can be attributed to the vigorous air pollution control program of the Clean Air Act, which required both nationwide auto emission reductions as well as tailored state implementation plans to control unique local sources. The profile of ozone improvement from 1982–1996 is indicated also in Table 3. If sprawl is a major promoter of automobile air pollution, we would expect to see those areas with higher sprawl to be making less progress in ozone reduction.

State political alignment

The political alignment of a state may have a substantial influence on both land use and environmental policies. As discussed above, Erickson et al. (1993) developed indices for characterizing state political alignment. For the areas under investigation, these values are shown in Table 4. These cover state party identification, state political ideology and state policy liberalism. Erickson et al. point out that while the meaning of party identification and ideological identification may vary with the state, degree of policy liberalism is likely to be more resistant to local definition.

Another characteristic of state activity in the environmental area concerns expenditures on state environmental programs. Table 5 presents for 1996 aggregate state environmental expenditures for the states of the metropolitan areas as well as the per capita state environmental expenditures. These data can assist in exploring the question of the degree to which environmental expenditures relate to degree of sprawl and control of ozone air pollution.

Table 5
Environmental expenditures ($100) (Council of State Governments 1997)

City	Total state environmental expenditures	Per capita state environmental expenditures
Albany	294,800	16.21116
Allentown	401,575	33.30914
Atlanta	43,734	5.947776
Baltimore	61,412	12.10804
Boston	66,459	10.90923
Buffalo	294,800	16.21116
Charlotte	66,861	9.130274
Chicago	220,713	18.63029
Cincinnati	37,449	3.351741
Cleveland	37,449	3.351741
Columbus	37,449	3.351741
Dallas	386,523	20.20718
Denver	37,779	9.88203
Detroit	183,999	19.17855
Fort Worth	386,523	20.20718
Fort Lauderdale	499,734	34.70375
Hartford	94,250	28.78742
Houston	386,523	20.20718
Indianapolis	91,648	15.69046
Jacksonville	499,734	34.70375
Kansas City	33,324	12.95645
Los Angeles	653,462	20.49884
Louisville	45,804	11.793
Memphis	224,582	42.21466
Miami	499,734	34.70375
Milwaukee	66,196	12.82868
Minneapolis	99,965	21.46093
Nashville	224,582	42.21466
New Orleans	87,452	20.09929
New York City	294,800	16.21116
Norfolk	120,700	18.0824
Oklahoma City	34,950	10.5877
Omaha	50,004	30.26877
Orlando	499,734	34.70375
Philadelphia	401,575	33.30914
Phoenix	64,449	14.55488
Pittsburgh	401,575	33.30914
Portland	117,137	36.55961
Providence	49,496	49.99596
Rochester	294,800	16.21116
Sacramento	653,462	20.49884
Salt Lake City	68,819	34.4095
San Antonio	386,523	20.20718
San Diego	653,462	20.49884
San Francisco	653,462	20.49884
San Jose	653,462	20.49884
Seattle	116,767	21.10374
St. Louis	33,324	6.218324
Tampa	499,734	34.70375
Tucson	64,449	14.55488

Results

The relationships of principal interest concern sprawl and air quality as they relate to each other and to state political alignment and expenditures.

Sprawl

The first area of interest in sprawl concerns its properties. Is the growth that is occurring in the metropolitan areas occurring as sprawl? As indicated earlier, Table 2 suggests that the answer to this question is in the affirmative: sprawl has been a characteristic of the development that has taken place during the period of examination. Population densities for the metropolitan areas have declined at an annual average rate of –0.36%. Furthermore, while the range of population density change spans positive to negative values, the substantial majority of the areas present declining population densities as a characteristic over the period of investigation. Similarly, the substantial majority of the areas also show a sustained expansion of the urbanized area during the period of observation. One of the characteristics of concern in the relationship between sprawl and air quality is the vehicle miles traveled per capita (VMTPC). Table 2 shows that for all metropolitan areas VMTPC increased; and these increases generally exceeded those of the urbanized land and population density. This suggests an accelerating and more intensive use of automobiles even as the metropolitan areas grow. Table 6 examines the correlations among the characteristics of sprawl. Declines in population density can be associated with expansion of the urban area. To a lesser degree, declines in population density can also be correlated with increases in VMTPC.

When the relationship between sprawl and political alignment of the state is explored (Table 7), we find that a larger population density decline correlates somewhat with a more liberal state. This appears at variance to the expectation that greater sprawl would be associated with more conservative politics. However, examination of the urbanized land expansion provides some weak evidence that the more conservative a state, the more likely is sprawl to occur. Given the moderate correlations involved and the contradictory results, the most sound observation based on the evidence at hand may be that state politics and sprawl are not tightly associated.

One assertion frequently made is that sprawl and public expenditures are associated (Fodor 1999). Either sprawl creates conditions that demand greater expenditures to protect the environment and provide public services, or

Table 6
Correlations of changes in population density (*PopDen*), urban land (*UrbLand*) and vehicle miles traveled per capita (*VMTPC*) for ozone metropolitan areas 1982–1996

Variable	PopDen	UrbLand	VMTPC
PopDen	1.0000	–0.4826	–0.3153
UrbLand	–0.4826	1.0000	–0.1988
VMTPC	–0.3153	–0.1988	1.0000

the absence of public effort to ameliorate impacts of growth, evidenced by low public expenditures, allows unchecked growth to take place. Table 8 examines the correlations among the measures of sprawl and state expenditures to protect the environment. These results show that a larger population density decline correlates weakly with less overall expenditures and negligibly when expenditures are examined on a per capita basis. Increasing VMTPC moderately correlates with less overall state environmental expenditures. These two results provide a hint of support that declining public expenditures are associated with sprawl. However, as was the case with political alignment, the evidence is moderate at best. This may suggest a decoupling of size and intensity of effort to protect the environment or may be due to a masking of effect due to measurement error.

Air quality

The associations among air quality measures in the metropolitan areas and sprawl are presented in Table 9. Change in urbanized land appears moderately correlated with the initial air quality level in 1982 and the improvement in air quality that took place from 1982–1996; the evidence suggests a weak relationship between an increase in urbanized land area and diminished air quality improvements. In other words, as urbanization rises, ozone improvement falls; however, this association is far from strong. It is noteworthy that neither population density changes nor VMTPC changes are associated with air quality changes. These results taken as a package suggest that further exploration of the relationship between air quality and sprawl could be a fruitful area of inquiry. Examination of air quality improvement and state politics (Table 10) suggests that the more liberal a state ideology, the larger the air quality gains. Similarly, the more liberal a state policy approach, the larger the air quality gains. Further, this relationship strengthens as the state political characteristic that is examined is more reflective of operational policy than ideology. These results offer some support to the concept of the association between environmental improvement and liberality of a state politics. When the analysis is extended to state environmental expenditures and air quality improvement (Table 11), we find a moderate association between the overall state expenditures and air quality improvement. However, when state expenditures per capita are examined, there is little evidence that this measure of state effort can be associated with air quality gains. Total environmental expenditures cover far more than air quality, so we would expect attenuation in the relationship between expenditures and air quality improvements. As noted earlier, this likely would diminish the correlations identified and may explain the weak associations. Expenditure data focused on air quality would be preferred, but were not available. It is noteworthy that overall and per capita state environmental expenditures are moderately correlated.

Table 7
Correlation of measures of sprawl and state political alignment for ozone metropolitan areas

Variable	PopDen	UrbLand	VMTPC	StatePartyID	StateIdeologyID	StatePolicyLib
PopDen	1.0000	−0.4596	−0.3410	0.1586	−0.2724	−0.2692
UrbLand	−0.4596	1.0000	−0.1867	−0.1545	−0.1292	−0.2110
VMTPC	−0.3410	−0.1867	1.0000	−0.1326	0.0561	0.0375
StatePartyID	0.1586	−0.1545	−0.1326	1.0000	−0.0704	−0.1883
StateIdeologyID	−0.2724	−0.1292	0.0561	−0.0704	1.0000	0.8534
StatePolicyLib	−0.2692	−0.2110	0.0375	−0.1883	0.853	1.0000

Table 8
Correlation of measures of sprawl (1982–1996) and state environmental expenditures (1996)

Variable	PopDen	UrbLand	VMTPC	State$96	State$PerCap
PopDen	1.0000	−0.4823	−0.3160	0.2071	0.0317
UrbLand	−0.4823	1.0000	−0.1989	0.0299	0.1003
VMTPC	−0.3160	−0.1989	1.0000	−0.3132	0.0378
State$96	0.2071	0.0299	−0.3132	1.0000	0.3812
State$PerCap	0.0317	0.1003	0.0378	0.3812	1.0000

Table 9
Correlation of measures of sprawl and air quality (*AQ*) levels and improvement 1982–1996

Variable	PopDen	UrbLand	VMTPC	AQ82	AQ96	AQDelta
PopDen	1.0000	−0.4826	−0.3153	0.1857	0.2969	0.0589
UrbLand	−0.4826	1.0000	−0.1988	−0.2390	−0.1308	−0.2147
VMTPC	−0.3153	−0.1988	1.0000	−0.1117	−0.1152	−0.0705
AQ82	0.1857	−0.2390	−0.1117	1.0000	0.5631	0.8896
AQ96	0.2969	−0.1308	−0.1152	0.5631	1.0000	0.1235
AQDelta	0.0589	−0.2147	−0.0705	0.8896	0.1235	1.0000

Table 10
Correlation of air quality levels and improvement and state political alignment in ozone metropolitan areas 1982–1996

Variable	AQ82	AQ96	AQDelta	StatePartyID	StateIdeologyID	StatePolicyLib
AQ82	1.0000	0.5205	0.9056	0.1509	0.1345	0.1988
AQ96	0.5205	1.0000	0.1093	0.2242	−0.1734	−0.1964
AQDelta	0.9056	0.1093	1.0000	0.0643	0.2426	0.3290
StatePartyID	0.1509	0.2242	0.0643	1.0000	−0.0704	−0.1883
StateIdeologyID	0.1345	−0.1734	0.2426	−0.0704	1.0000	0.8534
StatePolicyLib	0.1988	−0.1964	0.3290	−0.1883	0.8534	1.0000

As a related matter, when state environmental expenditures and state political alignment are examined (Table 12), there is, at best, only moderate evidence that the degree of state policy liberality translates into increased resources devoted to environmental protection. If we define effort as a per capita expenditure, there appears little evidence that there is a relationship between state political alignment and expenditures for environmental protection.

Predicting air quality gains

We began this analysis with some expectation that degree of sprawl, a state's political alignment, and its resource commitment to environmental protection are important in determining success in reducing ozone air pollution. Table 13 presents the results of OLS regression analyses of these hypotheses. To remove the effect of the influence of the magnitude of the problem, the 1982 ozone levels were included as a predictor in the equations. The top charts in Table 13 show results presented using change in population density as the measure of sprawl and per capita environmental expenditures as the measure of state fiscal commitment. The bottom charts of Table 13 show results using change in urbanized land as the measure of sprawl and aggregate state environmental expenditures as the measure of state fiscal commitment. Results indicate that, first, the baseline conditions of air quality are important in determining the potential for pollution reduction. Second, a state's policy liberalism is significant: as policy liberalizes, more air quality gains can be realized. The model results do not indicate that state expenditures are important in achieving ozone air quality gains. Although lacking statistical significance, the signs on these partial slope coefficients suggest that as sprawl slows, there may be more air quality gains. Similarly, there are suggestions from the results to explore further the effects of expenditures' rise, and their possible impacts to produce more air quality gains. Lacking statistical significance for these two predictors, such results indicate a direction for further inquiry rather than conclusion.

Discussion

Evidence examined in this research indicates that the 52 metropolitan areas with ozone problems have experienced sustained growth that can be characterized by sprawl. Decreasing population density, expanding urbanized area, and increasing vehicle miles traveled per capita characterized the substantial majority of the areas. Further, use of automobiles in the area, as represented by VMTPC, outstripped changes in population density and urbanized land expansion, signaling an accelerating use of automobiles in these metropolitan areas. In general, there was found to be moderate association between declines in population density and urban area expansion; association between declines in population density and VMTPC growth were identified, but were less strong. Contradictory results were found concerning the possible association between sprawl and state political alignment, indicating a need for further inquiry. Sprawl could only weakly be associated with state expenditures, also indicating an area of further exploration.

Evidence was, at best, only moderate concerning the relationship between sprawl and a retarding effect on ozone improvement. Degree of urbanized land expansion was moderately associated with retarding ozone improvements; evidence of association between population density declines and ozone improvements was not found. Similarly, increases in VMTPC could not be substantially associated with diminution of ozone gains. These results raise questions about the relationship between sprawl and air quality and warrant further exploration.

When air quality improvements were examined with regard to state political alignment, evidence suggests a moderate relationship between policy liberalism and ozone improvements. While there was evidence that aggregate state environmental expenditures and ozone improvement were related, there was little evidence of an association between per capita state environmental expenditures and ozone gains. Given the traditional importance of public expenditures in environmental debates, these findings also merit further exploration.

When the results of these analyses are combined into OLS regression models, the original ozone magnitude and the state's policy liberalism were found to be significant. While

Table 11
Correlation of air quality levels and improvement and state environmental expenditures (aggregate and per capita) 1982–1996

Correlations

Variable	AQ82	AQ96	AQDelta	State$96	State$PerCap
AQ82	1.0000	0.5625	0.8895	0.3801	–0.0330
AQ96	0.5625	1.0000	0.1226	0.1512	–0.0197
AQDelta	0.8895	0.1226	1.0000	0.3728	–0.0288
State$96	0.3801	0.1512	0.3728	1.0000	0.3812
State$PerCap	–0.0330	–0.0197	–0.0288	0.3812	1.0000

Table 12
Correlation of state environmental expenditures (aggregate and per capita) and state political alignment in ozone metropolitan areas 1982–1996

Variable	State$96	State$PerCap	StatePartyID	StateIdeologyID	StatePolicyLib
State$96	1.0000	0.3747	–0.0918	0.0950	0.2631
State$PerCap	0.3747	1.0000	–0.1879	–0.1050	–0.0493
StatePartyID	–0.0918	–0.1879	1.0000	–0.0704	–0.1883
StateIdeologyID	0.0950	–0.1050	–0.0704	1.0000	0.8534
StatePolicyLib	0.2631	–0.0493	–0.1883	0.8534	1.0000

Response: AQDelta

Summary of Fit

RSquare	0.845044
RSquare Adj	0.83127
Root Mean Square Error	0.013516
Mean of Response	0.033
Observations (or Sum Wgts)	50

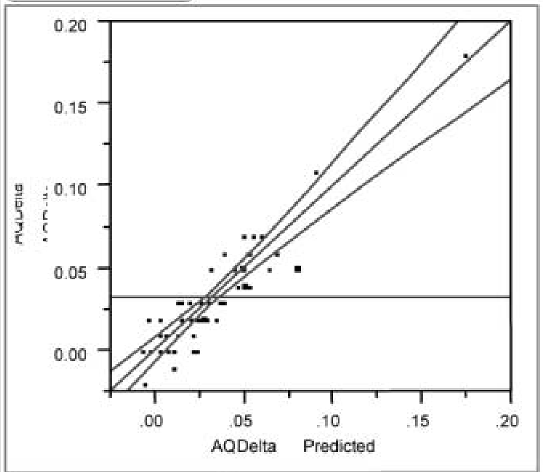
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.076429	0.008632	-8.85	<.0001
AQ82	0.7589751	0.052605	14.43	<.0001
PopDen	-0.001233	0.001995	-0.62	0.5397
StatePolicyLib	0.0045804	0.002	2.29	0.0268
State$PerCap	0.0000669	0.000174	0.39	0.7020

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
AQ82	1	1	0.03802596	208.1609	<.0001
PopDen	1	1	0.00006975	0.3818	0.5397
StatePolicyLib	1	1	0.00095775	5.2429	0.0268
State$PerCap	1	1	0.00002709	0.1483	0.7020

Whole-Model Test



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.04482959	0.011207	61.3513
Error	45	0.00822041	0.000183	Prob>F
C Total	49	0.05305000		<.0001

Response: AQDelta

Summary of Fit

RSquare	0.843548
RSquare Adj	0.829641
Root Mean Square Error	0.013581
Mean of Response	0.033
Observations (or Sum Wgts)	50

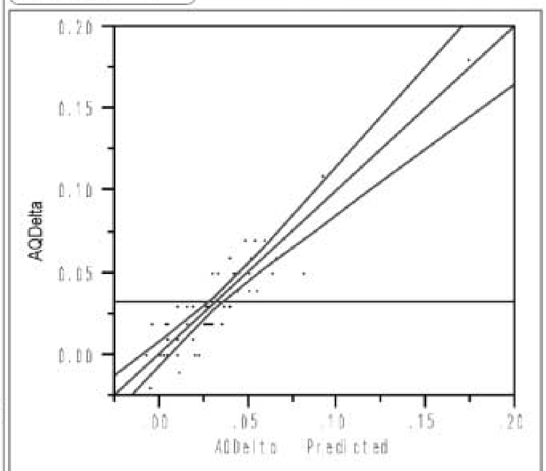
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.07318	0.008725	-8.39	<.0001
AQ82	0.7453112	0.055932	13.33	<.0001
UrbLand	-0.000166	0.001836	-0.09	0.9282
StatePolicyLib	0.0047738	0.002004	2.38	0.0215
State$96	3.0563e-9	1.032e-8	0.30	0.7685

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
AQ82	1	1	0.03274972	177.5632	<.0001
UrbLand	1	1	0.00000151	0.0082	0.9282
StatePolicyLib	1	1	0.00104713	5.6774	0.0215
State$96	1	1	0.00001617	0.0877	0.7685

Whole-Model Test



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.04475021	0.011188	60.6569
Error	45	0.00829979	0.000184	Prob>F
C Total	49	0.05305000		<.0001

Table 13
Regressions to predict changes in ozone levels

the signs on the partial slope coefficients for sprawl and state expenditures point in the expected direction, the lack of statistical significance indicates that further examination may be merited.

In summary, evidence was found that sprawl has characterized the ozone areas examined, but that this sprawl's relationship to ozone gains appears weaker and more ambiguous than expected. Further, relationships between sprawl and state politics and expenditures raise questions concerning conventional wisdom such that additional research into these areas appears warranted. Understanding these relationships would better position planners and decision makers to attack the impacts of sprawl.

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