(2017) 47, 271–288

The Review of Regional Studies

The Official Journal of the Southern Regional Science Association

Air Quality and the Development of Los Angeles [*]

Miles M. Finney

Department of Economics, California State University - Los Angeles, USA

Abstract: This paper estimates the effect variation in air quality had on neighborhood population growth in Los Angeles during the 1950s and 1960s, a period the area experienced severe ozone problems. Regression results indicate that environmental effects substantially redistributed population spatially. Little evidence is found, however, that the demographic effects persist.
Keywords: air quality, urban, location
JEL Codes: A53, R14, R20

1. INTRODUCTION

For decades, air quality in Southern California has been among the poorest in the U.S., the most prominent problem being ground-level ozone (Dewey, 2000; Kahn, 2000; Hagevik, 1970). Southern California's history of registering some of the highest ozone levels recorded in the country gives the region its singular status.[1] The Los Angeles area began witnessing episodes of extremely poor air quality in the mid-20th century, a period in which the region was rapidly developing. This study examines how the extremes in air quality the city of Los Angeles experienced during this period helped shape its urban form.

This paper estimates the effect of variation in ground-level ozone on neighborhood population growth in Los Angeles. Historical ozone data is used to estimate air quality effects in the 1950's and 1960's, a period with peak recorded ozone levels that have not been approached since. Although at the time the long-term effects of exposure to the pollutant were unknown, its short-term effects, primarily respiratory, could have deterred population growth. This study finds consistent evidence of this effect in both decades.

This paper focuses on the magnitude of the air quality effects. How much did the diminution in air quality in the mid-20th century alter the distribution of population in Los Angeles? The study compares simulated population distributions under various scenarios regarding the spatial variation in ground-level ozone. The redistribution in population induced by the pollutant is estimated to be substantial. A separate question is the impact of Los Angeles's environmental

---

[*] I acknowledge assistance by Sasha Perez, and helpful comments made by participants in the 2015 meetings of the North American Regional Science Conference.

Miles M. Finney is a Professor of Economics at California State University, Los Angeles, CA 90032. Email: mfinney5@calstatela.edu

[1] The most severe air quality episode in the region since 1970 occurred in late June 1974 with ground-level ozone in the Upland area in San Bernardino County peaking at 0.71 ppm (Burke, 1974). This peak, almost ten times the EPA's current eight-hour standard, has not, to the author's knowledge, been reached since in the U.S.

ISSN 1553-0892, 0048-749X (online)
www.srsa.org/rrs

history on its current form. If severe ozone levels during the mid-century redistributed population within the city, do those effects persist today? The tentative answer this study finds is "no." This paper contributes to our understanding of how environmental quality may affect the historical development of an urban area.

2. LOS ANGELES DEVELOPMENT AND AIR QUALITY

The Los Angeles area's topography, an inland valley bordered on the west by the Pacific Ocean and on the east by the San Gabriel Mountains, has contributed to its environmental problems over the course of its settled history. Pollutants that would otherwise dissipate either into the upper atmosphere or be blown eastward would frequently get trapped by temperature inversions or the bordering mountains. The first government ordinance implemented in the region's modern history to address air quality was a 1905 smoke control measure by the city of Los Angeles. The city implemented a series of measures over the following twenty-five years targeting stationary sources of ambient smoke. The composition of the pollutant is unknown today but may not have been related to ozone, given the lack of contemporaneous evidence of the short-term health effects related to the pollutant (Brienes, 1975). During this period, the area's air quality problems were treated largely as an occasional nuisance.

Evidence of health symptoms typically associated with ozone exposure — stinging eyes, irritated throat, and respiratory system restrictions — were not recorded locally until the middle of the century. In 1940, downtown Los Angeles began experiencing episodes of extremely heavy smog (Brienes, 1975; Dewey, 2000). By that time, the city had added approximately one million residents to its 1905 population of 500,000; Los Angeles County as a whole held almost 2.8 million residents. Although unknown at the time, the area was likely experiencing accumulations of ground-level ozone that represented a continuing problem in larger urban areas such as London (Wise, 1968). The primary components of Los Angeles's smog and its association with automobile exhaust were not discovered until the end of the 1940s.[2] By then, Los Angeles was more dependent on the automobile than many urban areas in the U.S. (Bottles, 1987).

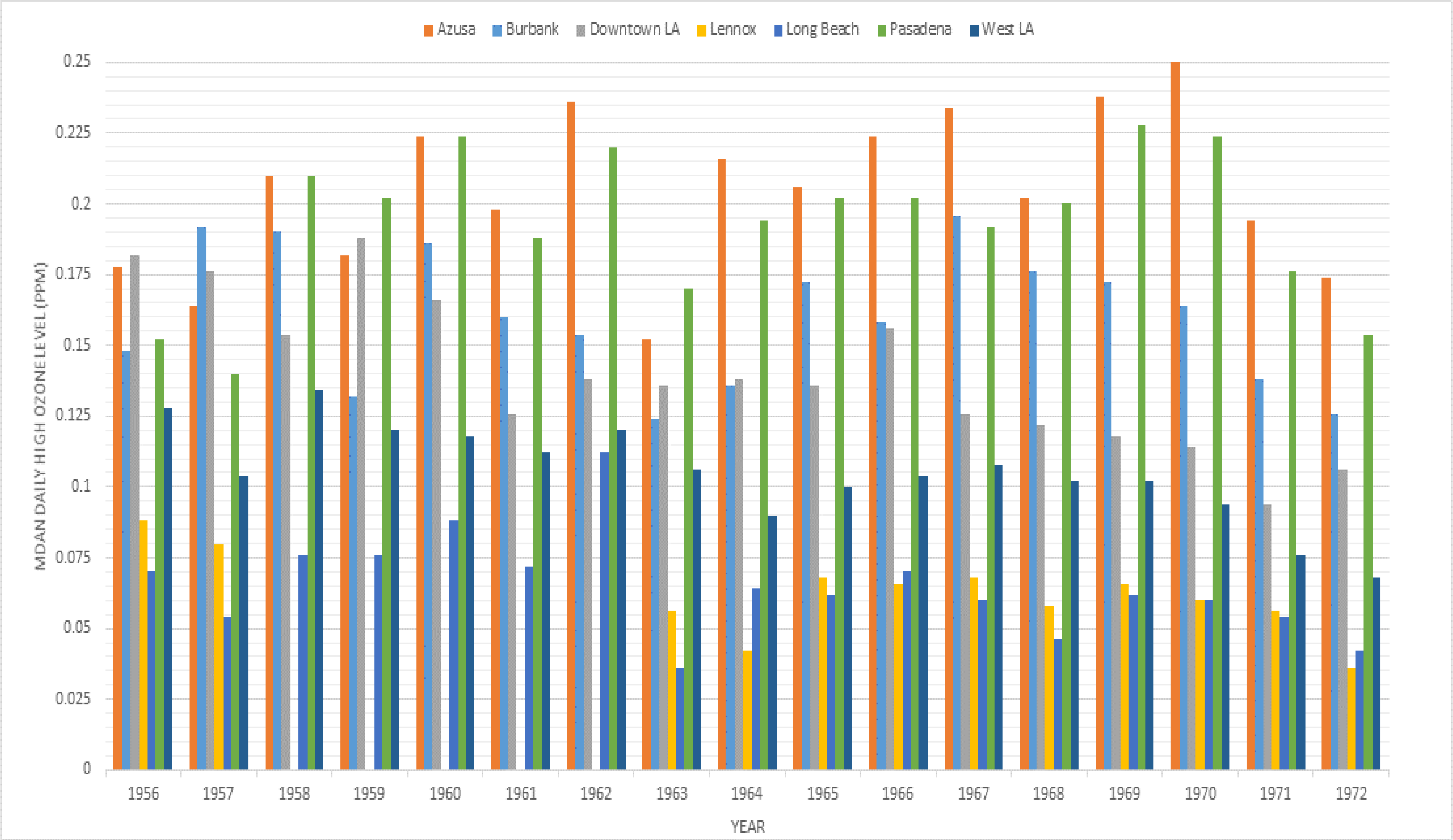
The City of Los Angeles created its first permanent department to fight ambient pollution in 1944; the County followed with its own in 1945. Through a number of reorganizations, the City and County fought the smog problem initially by targeting stationary sources such as oil refining facilities, only to witness the episodes of extremely poor air quality grow more severe. Acceptance in the 1950s of science suggesting that car exhaust was an important contributor to the problem compelled local agencies (and later the state and federal government) to redirect their attention toward automobiles. This eventually led to car companies installing emissions control devices in automobiles in 1963, although the area continued to suffer severe peaks of ground-level ozone for years thereafter.

3. HISTORICAL OZONE LEVELS

Los Angeles County began local air monitoring when it initiated its air quality alert system in 1955. The monitored pollutants included ozone, particulate matter, and sulphur dioxide. This study uses ground-level ozone data compiled in a technical report created for the Los Angeles Air Pollution Control District over the period 1955 to 1972 (Tiao et al., 1973). Figure I illustrates

[2] In the late 1940s, Cal Tech biochemist Arie Haagen-Smit identified ozone as one of the primary pollutants making up the smog that occasionally surrounded the Los Angeles area.

Figure 1: Mean Daily High Ozone Level in Parts Per Million over Smog Season by Monitoring Station



statistics by monitoring station on the mean of the daily high ozone for the five months of smog season (May through September). The monitoring stations are identified by the suburban municipality or area within the city of Los Angeles in which they were placed. The map in Figure 2 illustrates the spatial distribution of air quality for the city of Los Angeles.

The magnitudes of the recorded means in Figure 1 are striking. The statistics imply that in most years, the *typical* day in Pasadena and Azusa during smog season would have triggered an air quality alert by contemporary standards.[3] Long Beach and Lennox are the only stations to record average peak ozone levels that were not substantially above the contemporary EPA standard of 0.07 parts per million (ppm) over an eight-hour period. The EPA standard reflects current scientific knowledge on the level in which ozone begins to adversely affect health. The statistics suggest that in many areas in the county, the average day during smog season diminished health.

The statistics indicate that poor air quality persisted over the seventeen years of the data. Air quality in Pasadena and Azusa actually deteriorated over the period, as measured by a linear trend. The trend in the remaining areas indicate only moderate improvement. Downtown Los Angeles, whose ozone fell on average 0.005 ppm per year, experienced the most improvement; West Los Angeles's yearly peak levels fell by approximately half downtown's rate. Burbank averaged a 0.00095 ppm decline per year, which left its air quality at the end of the period essentially as it was in 1956.

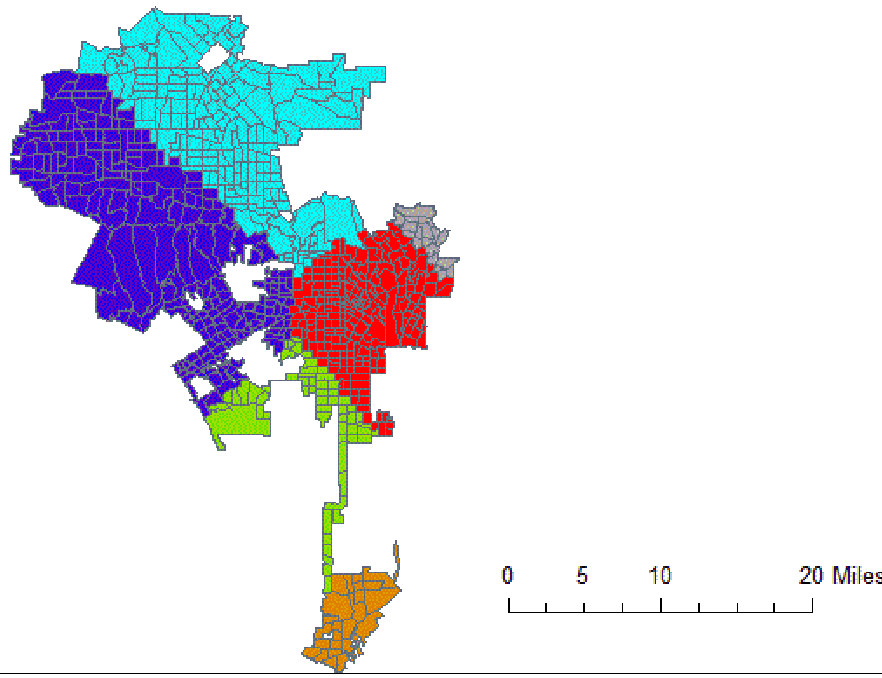
4. ENVIRONMENTAL EFFECTS AND PERSISTENCE

This study hypothesizes that efforts to avoid pollution redistributed population in Los Angeles during a period of severe ground-level ozone. A large literature has examined the long-term mortality risk of ozone exposure (see, for example, Jerrett et al., 2009). These health effects were largely unknown during the 1950s and 1960s; households could not have been making location decisions on the basis of anticipated long term ozone effects. The short-term acute effects of the pollutant, however, would likely have deterred households. Exposure to ground level ozone at lower levels than experienced in Los Angeles during the 1950s and 1960s has been found to induce short-term symptoms such as coughing, throat irritation, chest discomfort, and shortness of breath (Devlin, Raub, and Folinsbee, 1997, Aris et al., 1993). Studies such as Neidell (2009) and Medina-Ramon, Zanobetti, and Schwartz (2005) have documented the relationship between ozone exposure at contemporary levels and hospitalizations especially among those with chronic lung diseases. Exposure to severe ozone levels could have produced demographic shifts in a population that sought to avoid the acute short-term symptoms of the pollutant.

The environmental history of Los Angeles suggests the extreme ozone levels during the 1950's was a *new* phenomenon in the area. Households would have faced a geographic distribution of environmental disamenities that had not previously existed. Knowledge of the spatial variation in environmental quality could have come through personal experience or information passed along in social networks. Ozone could have redistributed population by influencing the location decisions of existing and in-migrating households. Finney (2014) suggests that the demographic

[3] The standard triggering a first stage alert, in which people were encouraged to avoid rigorous outdoor activity, was initially set at an ozone level of 0.50 ppm in 1955. A statewide system was implemented in 1976 lowering the standard for a first stage alert to 0.20 ppm; a 2nd stage alert is triggered at 0.35 ppm.

Figure 2: Los Angeles City



	Monitoring Station Areas and Weighted Mean Ozone Levels (ppm)	
(gray)	Pasadena Station	0.161
(orange)	Long Beach Station	0.076
(green)	Lennox Station	0.105
(cyan)	Burbank Station	0.153
(blue)	West Los Angeles Station	0.130
(red)	Downtown Los Angeles Station	0.161

The ozone statistics are the distance weighted means of the daily high ozone level over the time span of the data.

effects of air quality arise largely from households making intra-urban location decisions. Corresponding changes in the housing market may be consistent with population shifts, even with market capitalization.[4]

Much of the research examining the demographic effects of variation in environmental quality extract marginal willingness to pay estimates from hedonic models of the housing market (e.g. Chay and Greenstone, 2005; Harrison and Rubenfeld, 1978; Graves et al., 1988). This study follows the research that examines the migratory response to variation in environmental goods. This literature generally finds that variation in environmental quality is a determinant of the distribution of population. In the Superfund site literature, Cameron and McConnaha (2006) find that the sites deter residential location for certain demographic groups. Greenstone and Gallagher's (2008) larger study estimates weaker superfund effects. Banzhaf and Walsh (2008) and Kahn (2000) find, in different contexts, that environmental quality partially determines demographic characteristics over space. Banzhaf and Walsh (2008), using data from the Toxic Release Inventory

[4] The simple analysis of the housing market would imply that house prices would be lower in more polluted areas. House price differences would, however, be consistent with less housing (and population) occupying polluted areas. If demand decreases in a market with an upward sloping long run supply, price and quantity of housing in the area would decrease.

program, finds population and income effects at the sub-county level, while Khan (2000) estimates large air quality effects on population movements across counties in Southern California.

This study finds, as in Banzhaf and Walsh (2008), evidence of local demographic effects but looks beyond the estimates to inquire about how the historical pattern of poor air quality in Los Angeles has played a role in shaping the area. The period of severe ground-level ozone in the region can be considered a social disruption which, once lifted, may have residual effects. The existence of network externalities and the durability of housing and infrastructure are two possible reasons demographic effects may persist (Glaeser and Gyourko, 2005; Redding, Sturm, and Wolf, 2007).

The evidence on the existence of social and economic persistence is mixed. Bleakley and Lin (2012) study U.S. cities that developed as transshipment points before transportation technology such as trains made their role obsolete. The study's finding that many of the cities remain today as population centers serves as an example of the long-term persistence of economic effects. Brooks and Lutz (2014) find evidence of economic persistence *within* a particular urban area. The study finds a relationship between the contemporary population distribution in Los Angeles and the spatial pattern of its dismantled streetcars. Evidence that disruptions are not persistent comes largely from the literature on the effect of wars. Davis and Weinstein (2002) find that massive bombing of Japanese cities in World War II had no long-term effect on the country's spatial distribution of population and economic activity. Similar evidence has been found for wartime damage in Germany and Vietnam (Brakman, Garretsen, and Schramm, 2004; Miguel and Roland, 2011).

5. EMPIRICAL SPECIFICATION AND VARIABLES

This study examines the contemporaneous and longer-term effects of environmental quality on the distribution of population in the city of Los Angeles.[5] Equation 1 estimates neighborhood population growth for Los Angeles over the periods 1950-1960 and 1960-1970.

$$\Delta \boldsymbol{y} = \boldsymbol{\gamma}\theta + \boldsymbol{\gamma}^2\Omega + \Delta\boldsymbol{\gamma}\boldsymbol{\varphi} + \boldsymbol{x}\psi + \boldsymbol{\eta}\delta + \boldsymbol{\varepsilon} \tag{1}$$

The dependent variable is the change in population by census tract over the ten-year intervals. The covariates in Equation 1 include air quality, $\boldsymbol{\gamma}$, demographic and economic characteristics, $\boldsymbol{x}$, and geographic characteristics, $\boldsymbol{\eta}$. The geographic variables include census tract land area, distance from the nearest highway, and proximity to the Pacific coast. The demographic covariates are census tract population, percent nonwhite, percent of the population with at least a bachelor's, proportion of those with less than a high school degree, tract median rent, and the number of employed adults.

The demographic covariates capture social characteristics hypothesized to determine population growth. Disproportionately non-white neighborhoods are expected to grow more slowly. Los Angeles was predominantly white and racially segregated during the period. Education level has been found to be positively correlated with urban growth (Glaeser and Saiz, 2004). Neighborhood growth is expected to be positively related to the proportion of college-educated residents and inversely related to the proportion with less than a high school degree. Growth is expected to be inversely related to initial neighborhood population. This follows the empirical

[5] The study focuses on the city of Los Angeles because the air quality monitors in the county were placed primarily near the more densely populated center of the urban area. The coverage of the city's air quality was more precise than it was for the county as a whole.

observation that cities have decentralized over time (Mieszkowski and Mill, 1993). The control for land area changes the interpretation of the dependent variable to population change per unit of land, or population density.

Distance to the nearest highway was constructed using the different road configurations that existed in 1950 and 1960 in Los Angeles.[6] Proximity to transportation is hypothesized to induce population growth. Amenities associated with the coast (such as beaches) suggests that growth would be associated with proximity to the Pacific Ocean. Housing costs, measured by census tract median rent, is expected to deter growth. The number of employed adults by tract is included to account for the effect local economic activity has on population change.[7]

Environmental quality in Los Angeles is measured by the mean of the daily high ozone over the months of May through September (smog season). Air quality is assigned to each neighborhood by calculating the distance-weighted ozone readings from the two monitoring stations nearest each census tract.[8] This produces variation in measured air quality over space as each census tract is assigned a unique ozone value. The ozone covariate is entered linearly and quadratically in separate models. The summary statistics for the covariate are shown in Figure 1 and were discussed in Section 3. Data for the variable were taken from the technical report cited in Section 3 (Tiao et al., 1973).

To address endogeneity, covariates in the models are measured at the beginning of each decade. Location specific characteristics in 1950 are used to determine growth from 1950 to 1960; characteristics in 1960 are used for the subsequent decade. The ozone data series began, however, in the mid 1950's, which means the 1950's growth models use ozone data as of 1956. Local air quality is partially a function of local economic activity giving rise to potential endogeneity. The endogeneity of the air quality variable for both decades may be mitigated, however, by the fact that ground level ozone is more of a regional pollutant than local. Ground level ozone, formed from a chemical reaction in the lower atmosphere, is not directly emitted from sources on the ground. Spatial variation in the pollutant within a region may reflect local topography (for instance, distance to mountains) and winds as much as proximity to sources of the gases that form the pollutant (Lin, Young, and Wang, 2001; Lu and Turco, 1996). A growing area within Los Angeles could contribute to ozone within the region without necessarily disparately impacting its own pollution level.

Following the premise of the exogeneity of ground-level ozone, specifications are reported that also control for the effect of the intertemporal change in environmental quality on growth (Banzhaf and Walsh, 2008). The covariate $\Delta\boldsymbol{\gamma}$ in Equation 1 is the average yearly change in mean ozone over each decade. Population growth is expected to be inversely related to the covariate. Table 1 records summary statistics by period for all the independent variables and the population growth measure.

[6] The modern highway was being built largely during the period studied. I used GIS maps of the current highway grid as a template and used information from the website *California Highways* (http://www.cahighways.org/) to determine whether concurrent major roads or freeways existed in 1950 and 1960.

[7] Household income is not included because the Census did not publish income data by census tract until the 1970 census.

[8] This study has ozone data from seven stations, including the Azusa station in northeast Los Angeles County. The Azusa station was not among the two nearest to any of the census tracts in the city of Los Angeles. The air quality covariate is constructed using data from the remaining six stations. The distance weighted assignments produced a unique air quality value for each census tract.

Table 1: Summary Statistics for the Dependent Variable and Covariates

	1950		1960	
Urban Area	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Population Change	702.585	1586.458	463.024	1245.828
Land Area	1.741	2.332	1.741	2.332
Distance to Pacific Ocean	16.90	7.431	16.90	7.431
Population	2781.015	1998.139	3483.601	1511.597
Percent Non-white	0.119	0.220	0.243	0.301
Median Rent	48.855	17.657	68.363	39.072
Percent with bachelors	5.965	4.088	6.804	5.110
Percent less than HS	19.320	4.637	17.420	4.727
Number of Employed Adults	860.497	666.345	1122.695	521.068
Distance to nearest highway	3926.329	4612.642	1629.76	2079.301
Mean of daily high ozone (ppm)	0.142	0.023	0.143	0.032
Change in Ozone Level	0.021	0.006	-0.003	0.001

The land area and distance to highway and Pacific Ocean covariates are in units generated by the ArcMap software. The proportion with Bachelors (or above) and less than high school are with respect to the total population (not the adult population).

This study uses data from the 1950, 1960, and 1970 Census. Intertemporal analysis involving census tract data is complicated by the fact that the U.S. Census changes tract definitions over time. Measuring population change and accounting for demographic characteristics by census tract requires geographic consistency across census years. This study uses the Los Angeles County Union Census Tract Data Series which reconstructs the data maintaining consistent tract definitions over 1940-1990.[9]

6. SPATIAL INTERACTION

The unit of observation for the dependent variable in Equation 1 is the census tract. The assumption that the error term in the equation is *iid* implies the model is spaceless: deviations from predictions are randomly distributed over space. Violation of the assumption of cross-sectional independence may produce biased parameter estimates (Case, 1992). This study evaluates spatial correlation in specifications of Equation 1 using Moran's *I* statistic and by performing statistical tests for spatial lag or error dependence (Anselin and Bera, 1998).

Testing for residual dependence requires modelling the relationship the spatial units have with one another. This study calculates Moran's $I = \frac{\varepsilon' W \varepsilon}{\varepsilon' \varepsilon}$ using a weight matrix, *W*, that relates census tracts by the (inverse) distances between their geographic centers. The row-standardized

The Moran statistics in Table 2 are generated from residuals taken from regression specifications corresponding to Equation 1. The positive Moran estimates suggest deviations from predicted growth were spatially clustered, in both decades. The spatial correlations, however, are much larger for the 1950s, and are estimated with greater statistical significance.

[9] The data series was created by researchers at the Population Dynamics Lab at the University of Southern California (Ethington, Kooistra, and DeYoung, 2000).

Table 2: Moran's Statistic and Tests for Spatial Dependence

	Model Covering Period:	
	1950-1960	**1960-1970**
Moran's *I*	0.073 [<0.001]	0.010 [0.062]
Robust LM Test Statistic for:		
Error Dependence	18.780 [<0.001]	0.302 [0.583]
Lag Dependence	0.8523 [0.356]	0.009 [0.924]

The air quality covariate is the monthly mean of the daily high ozone. The statistics are generated from regression models using the variables in Appendix A. *p*-values are in brackets

Table 2 also illustrates results from Lagrange multiplier tests distinguishing between the possible sources of spatial dependence. The LM test for spatial error dependence specifies Equation 1's residual term as $\boldsymbol{\varepsilon = \lambda W\varepsilon + \nu}$. Rejection of the null hypothesis, $\boldsymbol{\lambda=0}$, implies spatial error dependence. Alternatively, the spatial lag test specifies the dependent variable as endogenously determined by its own spatially weighted values, $\boldsymbol{\Delta y = \rho\cdot W\cdot\Delta y + \ldots}$ Rejection of the hypothesis, $\boldsymbol{\rho=0}$, leads to the inference of spatial lag dependence. The results in Table 2 indicate statistically significant evidence of error dependence in the 1950s specification. None of the other specifications generate evidence of spatial interaction.

The LM tests suggest using the spatial error model to estimate neighborhood population change in the 1950's. The models presented in this study include the spatial error specification and linear regression models following variations of Equation 1. The standard errors in the regression models are clustered to the geographic area made up of the census tracts assigned to the pairs of air monitoring stations. Fifteen clusters were generated.[10] The adjusted standard errors are estimated assuming residual correlation within the clusters but not across. Moulton (1986) has shown that failure to account for differences in level of aggregation between model covariates and the dependent variable may bias standard error estimates.[11]

7. MARGINAL AIR QUALITY EFFECTS

Table 3 reports marginal air quality effects from regression models with the controls specified in Equation 1. Table 4 reports effects for 1950's growth produced from the spatial error specification described above. Models I and II in the two tables illustrate the linear specification of the ozone covariate; the variable is entered quadratically in Models III and IV. Appendix A illustrates the full regression results from the quadratic specification for each decade.

The air quality effects estimated in the linear and quadratic specifications in Tables 3 and 4 suggest that ground-level ozone deterred neighborhood growth in both decades. All of the models imply areas with higher initial ozone levels grew more slowly. Ozone is a statistically significant determinant of growth in the 1950s specifications; it is significant in the 1960's models that do not

[10] For the six monitoring stations, there are 30 possible permutations of two, given order (closest or second closest) matters. In the data, only 15 permutations, corresponding to geographic areas, occurred. Stations that were distant from one another shared no census tracts.

[11] Tests for multicollinearity were also performed on the regression models. Test results lead to the elimination of the covariate measuring the number of housing units by census tract. The variable scored very high inflation variance factors across the regression specifications.

Table 3: Marginal Effects of the Mean of Daily High Ozone on Population Change

	1950-1960			
	Model I	**Model II**	**Model III**	**Model IV**
Mean of Daily High – 1956	-20320.5**	-20794.4**	42121.9**[a]	49265.9**[a]
	(10069.92)	(10069.92)	(21252.01)	(26752.24)
Mean of Daily High^2 – 1956			-216767.9*[a]	-238849.7*[a]
			(55208.08)	(68129.1)
Change 1956-1960		-9332.6		15423.9
		(17334.19)		(21201.16)
	1960-1970			
	Model I	**Model II**	**Model III**	**Model IV**
Mean of Daily High – 1960	-9927.9*	-1543.0	-9361.6[a]	13342.8
	(3420.911)	(4533.848)	(9693.189)	(12388.03)
Mean of Daily High^2 – 1960			-2115.4[a]	-52430.1
			(31046.72)	(34539.6)
Change 1960-1970		292027.0*		321585.0*
		(88270.48)		(91878.98)

The marginal effects are taken from regression models corresponding to Equation 1. * Significant at 5 percent level; ** 10 percent level. [a] Significant in a joint test of parameters at the 5 percent level. The sample size is 709 observations for the 1950s model; 710 for the 1960s model. Standard errors, in parentheses, are heteroscedasticity adjusted and clustered to fifteen areas created by intersections of monitoring station areas. The air quality covariate is the mean daily high ozone readings during smog season (May through September).

control for the change in air quality over the decade.[12] The results are insensitive to how the error structure over space is modelled. The empirical results, however, generally do not support the hypothesis that the change in air quality within the decade negatively affected growth. The effects for the 1960's models are, counterintuitively, positive and significant.

The quadratic specifications suggest that ozone's deterrent effect becomes more severe as the level of the pollutant increases.[13] The coefficient for the squared term is always negative. Five of the six quadratic specifications estimate an inverted U-shaped function: growth is initially positively related to ozone but the relationship turns inverse at higher pollution levels.[14] The estimated tipping point in which the relationship between ozone and growth turns negative varies from 0.095 ppm to 0.106 ppm for the 1950s specifications (Tables 3 and 4), and 0.127 ppm in the one estimate from the 1960s model. These thresholds are only moderately above the current EPA ambient standard of 0.070 ppm; they are well below the ozone levels prevailing at the time in the more polluted areas such as Pasadena and Burbank. The nonlinear demographic effects are consistent with the evidence of ozone's acute health effects becoming more severe with elevated exposure (Devlin, Raub, and Folinsbee, 1997; Aris et al., 1993).

[12] F-tests for the joint significance of the two air quality parameters were run for the quadratic models. The results indicate for the 1960s Model III that the individual parameter estimates are insignificant but jointly the effect is statistically significant.

[13] Appendix A, showing results for the quadratic models, indicates a relatively high overall goodness of fit. Over half the variation in census tract growth in the 1950s is explained by the model. The 1960s specification explains a third of the variation.

[14] The only exception is Model III for the 1960s growth model, which estimates an air quality effect that is continuously inverse.

Table 4: Marginal Ozone Effects on Population Change from the Spatial Error Specification

	1950-1960			
	Model I	**Model II**	**Model III**	**Model IV**
Mean of Daily High – 1956	-20980.1*	-21880.9*	42892.4	52101.9*
	(7001.06)	(7103.61)	(34742)	(21734.9)
Mean of Daily High^2 – 1956			-226525**	-246863*
			(120405)	(71909.1)
Change 1956-1960		-25639.4		11464.7
		(29876)		(19305.6)

* Significant at 5 percent level; **10 percent level. The sample size for the specifications is 711 observations. The marginal effects are from the spatial error model that includes the covariates in Equation 1. Spatial weights are constructed from linear distances between census tracts. The air quality covariate is the mean daily high ozone readings during smog season (May through September).

8. MAGNITUDE OF AIR QUALITY EFFECTS

This study examines how the extreme ozone levels Los Angeles experienced during a period of rapid development affected the spatial distribution of population in the area. The analysis below estimates aggregate air quality effects by incorporating the actual spatial distribution in recorded ozone. The effects are examined by simulating the spatial distribution of population under various counterfactuals with respect to the pollutant. What would Los Angeles have looked like in the 1950's and 1960's had it not experienced high pollution levels? Comparing the simulated distributions with the actual contemporary distribution of population in Los Angeles informs us on the persistence of air quality effects.

The point estimates in the linear specifications in Table 3 suggest a 0.01 ppm increase in the ozone covariate decreased neighborhood growth by slightly over 200 people in the 1950s; the effects for the 1960s vary from 15 to 99 people, depending on the specification. The equivalent experiment performed using the quadratic specifications produces similar predicted effects when the ozone deviation is evaluated around the mean (approximately 0.14 ppm for both decades). The effects grow substantially however at higher ozone levels. A 0.01 ppm deviation evaluated at a level one standard deviation above the variable's mean causes predicted neighborhood growth to fall by approximately 320 people in the 1950s models. In the 1960s models, the experiment produces a growth decline between 55 and 101 people. These marginal effects are substantial.[15] A 0.01 ppm deviation is within one standard deviation of the air quality covariate, and the census tract neighborhoods averaged slightly over three thousand residents (Table 1).

The map in Figure 2 illustrates the census tract neighborhoods in Los Angeles designated by the monitoring station to which they are closest.[16] The analysis below simulates the effect various spatial distributions of ozone have on the population distribution of Los Angeles. In Table 5, population growth is simulated by assigning each neighborhood, by monitoring station, the mean ozone recorded in downtown Los Angeles (holding constant the ozone levels in the other stations). The simulations are made from Model III in Table 3 for both decades. Downtown Los

[15] Results from Ramsey specification tests were consistent with the hypothesis of some misspecification in the primary models. It is possible that the estimated ozone effects are biased away from zero.

[16] These six areas are not equivalent to the fifteen clusters of tracts used to create the adjusted standard errors in the regression models.

Table 5: Simulated Population Change if Neighborhood Assigned Ozone of Downtown Los Angeles

Monitoring Station Area	Los Angeles Census Tracts	Mean Ozone Level 1956	Predicted Difference in Growth 1950-60	Mean Ozone Level 1960	Predicted Difference in Growth 1960-70
Downtown	227	0.164	-	0.157	-
Burbank	172	0.143	-503	0.162	57
Lennox	57	0.116	-817	0.093	-634
Long beach	24	0.078	-881	0.074	-820
Pasadena	18	0.165	45	0.198	417
West LA	212	0.130	-701	0.129	-278

Notes: There is no data for the Lennox station in 1960. The mean ozone level as of 1963 is used for 1960 for the station.

Angeles and Pasadena had the highest ozone levels in the 1950s. Table 5 records the difference in predicted census tract growth by area under the actual and assigned mean ozone.

Under the simulation, neighborhood growth in each of the areas, except Pasadena, would have substantially slowed or turned negative in the 1950s. Growth in neighborhoods near the Long Beach and Lennox stations would have receded by over 800 people and caused both areas to decline. The simulation suggests Lennox neighborhoods would have lost on average 174 people over the decade; census tracts near the Long Beach station would have declined on average by 490 residents. Growth in the Burbank and West LA areas would have diminished by remained positive. Ozone levels in downtown Los Angeles changed substantially over time, falling in 1960 below the recorded mean for Burbank and Pasadena. The ozone effects under the simulation, however, remain substantial. The Lennox and Long Beach neighborhoods would have again suffered negative growth.[17] Neighborhoods near the Burbank and Pasadena stations would have experienced an increase in growth if given downtown LA's ozone level. The substantial increase of 417 residents for the Pasadena area attests to the area having the poorest air quality in the data by 1960. The simulation suggests spatial variation in pollution during a period the city experienced severe ozone levels substantially redistributed the city's population.

The counterfactual that Los Angeles experienced no variation in air quality is employed to further examine the aggregate contemporaneous effects of ozone and the possible persistence of those effects over time. Tables 6 and 7 record for each decade the city population distribution predicted with and without the counterfactual. The distributions are calculated by adding the neighborhood growth predicted by the regression models to the neighborhood's actual population at the beginning of the respective decade. The statistics are calculated from the Model III specifications in Table 3 using the values of all covariates and, alternatively under the counterfactual, setting variation in ozone across stations to zero.[18]

The two tables illustrate relationships that are consistent with the inferences drawn from the regression model. Areas with relatively poor air quality are predicted to gain population under the counterfactual of no variation in pollution; areas with better air quality would decline.

[17] Lennox's monitoring stations are missing data for 1960, so I use the 1963 mean ozone level in the analysis.

[18] The ozone covariate is set at its mean (found in Table 1) for each census tract under the counterfactual. The squared term is the mean squared.

Table 6: Actual and Projected 1960 Population by Monitoring Station Area

		Predicted Population 1960		
Monitoring Station	Actual Population	Full Model	No Ozone Variation Specified	Percent Difference
Downtown	863,392	850,669	980,075	15.21
Burbank	540,950	551,164	556,447	0.96
Lennox	244,784	239,413	223,268	-6.74
Long Beach	94,986	90,029	81,690	-9.26
Pasadena	63,296	64,301	74,720	16.20
West LA	669,432	676,877	641,373	-5.25

Population would have shifted from West LA, Lennox, and Long Beach toward Downtown LA, Burbank, and Pasadena in both decades under the counterfactual. The simulation suggests that if air quality differences were eliminated, the Lennox and Long Beach areas would have had populations that were more than 6% below what was predicted by the full model in each of the decades. West LA's population declines would have been larger in absolute terms but not as a percentage. The Pasadena area's status as generally having the poorest air quality during the period is reflected in its simulated population change. In both decades it would have been the biggest beneficiary of the elimination of air quality differences. The 16.20% shift in the area's population under the counterfactual in 1960 is the largest predicted increase in the data for either decade.

Inferences drawn from comparing simulated population distributions are sensitive to the full model's precision in estimating actual population. The regression model does not fully account for the initial population shift toward downtown and subsequent move away from the area over the two decades. The full model underpredicts Downtown LA's total population by 12,723 in 1960, and overpredicts the area by 23,193 in 1970. Both prediction errors are the largest in the respective decades. The regression results otherwise imply that air quality differences shifted population toward neighborhoods closer to the coast where the air was cleaner.

The persistence of air quality effects over time can be examined by comparing the contemporary population distribution in Los Angeles to prior distributions. Table 8 compares the city's population distribution in 2010 to predicted distributions for 1970 generated under the counterfactual and from the full model. The empirical evidence suggests that the high ozone levels

Table 7: Actual and Projected 1970 Population by Monitoring Station Area

		Predicted Population 1970		
Monitoring Station	Actual Population	Full Model	No Ozone Variation Specified	Percent Difference
Downtown	873,947	897,140	929,059	3.56
Burbank	662,509	666,265	699,909	5.05
Lennox	263,775	260,819	232,610	-10.82
Long Beach	103,687	101,910	85,550	-16.05
Pasadena	74,020	71,732	81,745	13.96
West LA	823,190	809,709	780,271	-3.64

Table 8: Actual 2010 Population and Predicted 1970 Distribution

		Predicted Population Distribution 1970	
Monitoring Station	2010 Population	Full Model	No Ozone Variation Specified
Downtown	32.61%	31.95%	33.07%
Burbank	26.99%	23.73%	24.92%
Lennox	7.9%	9.29%	8.28%
Long Beach	3.41%	3.63%	3.05%
Pasadena	2.32%	2.55%	2.91%
West LA	26.77%	28.84%	27.78%

in the 1950s and 1960s altered development patterns in the city. The question is whether the altered growth patterns remained over time even after the ozone problem abated.[19] If the ozone effects on the spatial configuration of the city did not persist, the contemporary population distribution may more closely resemble the 1970 distribution under the counterfactual of no contemporaneous variation in ozone. The elimination of the air quality extremes would have allowed pre-existing growth patterns in the city to reassert themselves.

Table 8 presents little evidence of persistence. Among the least polluted areas, Lennox and West LA have contemporary population shares that are closer to the 1970 predictions under the counterfactual of no ozone variation. The contemporary populations in the two areas are smaller than the shares predicted by the full model in 1970; they are smaller than their predicted shares under the counterfactual. The demographic effect of the advantage conferred by the areas' history of relatively clean air apparently did not continue once the advantage subsided. The area around the Long Beach station also enjoyed relatively clean air and would be expected to suffer proportional population losses if history was not persistent. The relative loss in population of the area bears this out although the share remains closer to prediction of the full model than the simulated one. The Burbank neighborhoods' robust population growth since 1970 indicated in Table 8 is further evidence of the lack of persistent effects of Los Angeles ozone history. The contemporary population share of downtown Los Angeles, an area with a history of higher ozone levels, is also closer to the 1970 prediction under the counterfactual – suggesting that the area is closer now to where it would have been if its experience with severe ozone had never occurred.

The simulated relationships provide evidence that underlying growth patterns reasserted themselves over the 40-year period (1970 – 2010) in which air quality differences diminished substantially. This tentative evidence is in line with the literature that does not find economic disruptions are persistent (Brakman, Garretsen, and Schramm, 2004; Miguel and Roland, 2011; Davis and Weinstein, 2002). The neighborhoods near the Pasadena station represent the only substantial evidence of persistence in environmental effects. The contemporary population share of 2.32% is smaller than the predicted proportion in 1970 from the model accounting for air quality differences. The area, which experienced the most severe ozone levels during the period, did not rebound once air quality should have become less of a sorting mechanism.

[19] Although air quality in contemporary Los Angeles does not fully reflect the assumption of the counterfactual, statistics on ground-level ozone suggest that the air is substantially cleaner today. For example, in 1976 the Los Angeles area experienced first stage smog alerts on 102 days. The alerts are now largely in the past; the local air quality district has called only one alert since 1999.

9. CONCLUSION

This study examines the effect variation in ground-level ozone had on neighborhood population growth in Los Angeles during a period when the city experienced its most severe air quality problems. The evidence suggests that poor air quality deterred population growth within the city. Exercises simulating the magnitude of the effect imply that air quality differences substantially redistributed Los Angeles's population in the 1950s and 1960s. This paper looks for evidence that the estimated historical effects persist: Can we detect evidence that contemporary spatial patterns in Los Angeles reflect the past effects of poor air quality? The evidence suggests we cannot.

REFERENCES

Anselin, Luc and Anil K. Bera. (1998) "Spatial Dependence in Linear Regression Models with an Introduction to Spatial Econometrics," in Aman Ullah and David E. A. Giles (eds.) *Handbook of Applied Economic Statistics*. Marcel Dekker: New York.

Aris, Robert M., Dorothy Christian, Patrick Q. Hearne, Kim Kerr, Walter E. Finkbeiner, and John R. Balmes. (1993) "Ozone-induced Airway Inflammation in Human Subjects as Determined by Airway Lavage and Biopsy," *American Review of Respiratory Disease*, 148, 1363–1372.

Banzhaf, Spencer H. and Randall Walsh. (2008) "Do People Vote With Their Feet? An Empirical Test of Tiebout's Mechanism," *American Economic Review*, 98, 843–863.

Bleakley, Hoyt and Jeffrey Lin. (2012) "Portage and Path Dependence," *Quarterly Journal of Economics*, 127, 587–644.

Bottles, Scott L. (1987) *Los Angeles and the Automobile: The Making of the Modern City*, 1st ed. University of California Press: Berkeley CA.

Brakman, Steven, Harry Garretsen, and Marc Schramm. (2004) "The Strategic Bombing of German Cities during World War II and its Impact on City Growth," *Journal of Economic Geography*, 4, 201–218.

Brienes, Marvin. (1975) *The Fight Against Smog in Los Angeles, 1943-1957*. Ph.D. Dissertation. University of California – Davis.

Brooks, Leah and Byron Lutz. (2014) "Vestiges of Transit: Urban Persistence at a Micro Scale," *SSRN Working Paper* 2752034.

Burke, Kathy. (1974) "High Ozone Counts Trigger 2 Alerts in Parts of Southland," *Los Angeles Times* (Los Angeles, CA), June 28, 1974.

Cameron, Trudy A. and Ian T. McConnaha. (2006) "Evidence of Environmental Migration," *Land Economics*, 82, 273–290.

Case, Ann. (1992) "Neighborhood Influence and Technological Change," *Regional Science and Urban Economics*, 22, 491–508.

Chay, Kenneth Y. and Michael Greenstone. (2005) "Does Air Quality Matter? Evidence from the Housing Market," *Journal of Political Economy*, 113, 376–424.

Davis, Donald R. and David E. Weinstein. (2002) "Bones, Bombs and Break Points: The Geography of Economic Activity," *American Economic Review*, 92, 1269–1289.

Devlin, Robert B., James A. Raub and Lawrence J. Folinsbee. (1997) "Health Effects of Ozone," *Science and Medicine*, 4, 8–17.

Dewey, Scott H. (2000) *Don't Breathe the Air: Air Pollution and U.S. Environmental Politics*, 1st ed. Texas A&M University Press: College Station, TX.

Ethington, Philip J., Anne Marie Kooistra, and Edward DeYoung. (2000) Los Angeles County Union Census Tract Data Series, 1940-1990, Version 1.0. University of Southern California: Los Angeles, CA.

Finney, Miles M. (2014) "Information and the Demand for Clean Air," *Contemporary Economic Policy*, 32, 719–28.

Glaeser, Edward L. and Joseph Gyourko. (2005) "Urban Decline and Durable Housing," *Journal of Political Economy*, 113, 345–75.

Glaeser, Edward L. and Albert Saiz. (2004) "The Rise of the Skilled City." Brookings-Wharton Papers on Urban Affairs. The Brookings Institution Press: Washington D.C.

Graves, Phil, James C. Murdoch, Mark A. Thayer, and Don Waldman. (1988) "The Robustness of Hedonic Price Estimation: Urban Air Quality," *Land Economics*, 64, 220–233.

Greenstone, Michael and Justin Gallagher. (2008) "Does Hazardous Waste Matter? Evidence from the Housing Market and Superfund Program," *Quarterly Journal of Economics*, 123, 951–1003.

Hagevik, George H. (1970) *Decision-Making in Air Pollution Control*, 1st ed. Praeger Publishers: New York.

Harrison, David Jr. and Daniel L. Rubinfeld. (1978) "Hedonic Housing Prices and the Demand for Clean Air," *Journal of Environmental Economics and Management*, 5, 81–102.

Jerrett, Michael, Richard T. Burnett, C. Arden Pope III, Kazuhiko Ito, George Thurston, Daniel Krewski, Yuanli Shi, Eugenia Calle, and Michael Thun. (2009) "Long-term Ozone Exposure and Mortality," *New England Journal of Medicine*, 360, 1085–1095.

Kahn, Matthew E. (2000) "Smog Reduction's Impact on California County Growth," *Journal of Regional Science*, 40, 565–582.

Lin, Tsai-Yin, Li-Hao Young, and Chiu-Sen Wang. (2001) "Spatial Variations of Ground Level Ozone Concentrations in Areas of Different Scales," *Atmospheric Environment*, 35, 5799–5807.

Lu, Rong and Richard P. Turco. (1996) "Ozone Distributions over the Los Angeles Basin: Three-dimensional Simulations with the Smog Model," *Atmospheric Environment*, 30, 4155–4176.

Medina-Ramon, Mercedes, Antonella Zanobetti, and Joel Schwartz. (2005) "The Effect of Ozone and PM10 on Hospital Admissions for Pneumonia and Chronic Obstructive Pulmonary Disease: A National Multicity Study," *American Journal of Epidemiology*, 163, 579–588.

Mieszkowski, Peter and Edwin S. Mills. (1993) "The Causes of Metropolitan Suburbanization," *Journal of Economic Perspectives*, 7, 135–147.

Miguel, Edward and Gerard Roland. (2011) "The Long Run Impact of Bombing Vietnam," *Journal of Development Economics*, 96, 1–15.

Moulton, Brent R. (1986) “Random Group Effects and the Precision of Regression Estimates,” *Journal of Econometrics*, 32, 385–397.

Neidell, Matthew J. (2009) “Information, Avoidance Behavior and Health: The Effect of Ozone on Asthma Hospitalizations,” *Journal of Human Resources*, 44, 450–478.

Redding, Stephen J., Daniel M. Sturm, and Nikolaus Wolf. (2007) “History and Industry Location: Evidence from German Airports,” *Review of Economics and Statistics*, 93, 814–831.

Tiao, George C., George. E. P. Box, M. Grupe, S. T. Liu, Steve Hillmer, William S. Wei, and W. J. Humming. (1973). Los Angeles Aerometric Ozone Data 1955-1972 (Report #346). Department of Statistics: University of Wisconsin, Madison.

Wise, William. (1968) *Killer Smog; The World’s Worst Air Pollution Disaster*, 1st ed. Rand McNally: Chicago, IL.

Appendix A: Determinants of Census Tract Growth by Period

Variable	**Δ pop1950-1960**	**Δ pop1960-1970**
time invariant characteristics		
Land Area	45.41	-39.69
	(50.55)	(39.10)
Distance to Pacific Ocean	22.40	43.44*
	(17.04)	(13.13)
characteristics as of beginning of respective decade		
Population	-0.384*	-0.375*
	(0.18)	(0.09)
Percent Non-white	-282.01	-713.70*
	(242.56)	(204.06)
Median Rent	6.72	-0.82
	(5.20)	(1.81)
Percent with bachelors	-22.93**	22.51*
	(12.22)	(11.18)
Percent less than HS	18.92	-17.36
	(13.31)	(15.06)
Number of Employed Adults	-0.134	-0.098
	(0.53)	(0.255)
Distance to nearest highway	-0.009	0.003
	(0.03)	(0.023)
Mean of daily high ozone	42,121.85 **[a]	-9,361.55[a]
	(21252.01)	(9693.19)
Mean of daily high ozone^2	-216,767.90*[a]	-2,115.38[a]
	(55208.08)	(31046.72)
Constant	-561.64	2,978.54*
	(1823.49)	(459.62)
Observations	710	709
R^2	0.51	0.33

The ozone covariate is as of 1956 for the 1950-60 model. Standard errors, in parentheses, are heteroscedasticity adjusted and clustered to fifteen areas created by intersections of monitoring station areas. *significant at the 5 percent level; **10 percent level. [a] Significant in a joint test of parameters at the 5 percent level.