An Analysis of Improvements in Urban Air Quality: Implications from the South Coast Air Basin

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I. INTRODUCTION

The first recognized episodes of air pollution in Los Angeles occurred in the summer of 1943.[1] Visibility was measured at only three blocks and people suffered from smarting eyes, respiratory discomfort, nausea, and vomiting. The phenomenon was termed a "gas attack" and blamed on a nearby butadiene plant. However, the situation did not improve after the plant was shut down. In response to this event and several others the City of Los Angeles began its air pollution control program in 1945, establishing the Bureau of Smoke Control in its health department. Two years later California Governor Earl Warren signed into law the Air Pollution Control Act, authorizing the creation of an Air Pollution Control District (APCD) in every county of the state. The Los Angeles County APCD was the first of its kind in the nation. Its first major enforcement program was started in late 1947 and required permits for all major industries.

In spite of early control efforts air pollution continued to worsen. In 1955 residents of the Los Angeles region suffered through the highest ozone level ever recorded --- 68 parts per one hundred million (PPHM), approximately 5.7 times the current health based ambient standard of 12 PPHM. In 1970 the South Coast Air Basin's maximum one-hour ozone concentration was recorded at 58 PPHM. By 1975 the basin's maximum one-hour ozone concentration was 39 PPHM but the area registered Stage 1 Smog Alerts (> 20 PPHM ozone) on 118 days during the year.

In 1977 the regional South Coast Air Quality Management District (AQMD) was formed from the merger of four air pollution control districts, representing Orange County and portions of Los Angeles, Riverside, and San Bernardino counties. Again, immediate relief was not forthcoming as the basin's maximum one-hour ozone concentration was 49 PPHM and the area exceeded the Stage 1 Smog Alert level on 102 days in 1980.

Since 1980, air pollution in the South Coast Air Basin has shown steady improvement. As is illustrated in Table 1 the maximum one-hour concentration has declined from 49 PPHM in1980 to 19 in 2001. In addition, Stage 1 Smog Alerts have been completely eliminated, with the last recorded alert registered in 1998. The annual average of the daily maximum readings has also shown steady improvement, falling from 8.47 PPHM in 1980 to 5.49 PPHM in 1999, the last year of our hourly data. A corresponding decline in

[1] Much of this history can be found at www.aqmd.gov/aqmd/intraqmd.html.

the annual standard deviations suggests that residents of the South Coast Air Basin are subjected to many fewer high ozone days at the upper tail of the distribution.

Not surprisingly, the basin has also experienced a reduction in the "spatial inequality" of air pollution. As shown in the next section, the areas that had the worst (best) air quality in 1980 have seen the largest (smallest) improvements in air quality; i.e., there has been a "convergence" of air quality exposure across space in the South Coast Air Basin.

Thus, there are two interesting air quality trends in the South Coast Air Basin: 1) the decreasing level of ozone and 2) the decreasing spatial variation. From a social science perspective it seems appropriate to analyze these trends "quasi-experimentally"; i.e., as a treatments, and investigate the consequences. Specifically, we investigate two questions. First, we consider the pattern of the *distribution* of environmental quality in the region. Harrison and Rubinfeld (1978) found that the air control policy for the Boston metropolitan area was pro-poor, especially with regard to the physical improvements in air quality (the corresponding monetary benefits were decidedly less pro-poor). In a study of the South Coast Air Basin of California (SCAB), Brajer and Hall (1992) found that ethnic minorities and children received the greatest exposure to both ozone and fine particulate air pollution. Sadd, et al (1999) confirmed this result for toxic air pollutants in the same study area. In addition, Pastor, et al (2002), using multivariate analysis that controls for covariates such as population density, income, and other neighborhood measures, find that race plays a persistent explanatory role in predicting the distribution of environmental hazards near schools in the Los Angeles Unified school district.

Thus, the existing literature dealing specifically with the SCAB seems to suggest that ethnic minorities are subjected to higher exposure to both the criteria air pollutants and air toxics, even if one accounts for differences in income, education, land use, and other potential determinants of exposure. Presumably then, the benefits of improvements in air quality would fall disproportionately on such groups. Is this conjecture correct?

The second question that we investigate is if there is still a property value premium associated with ambient air quality in the SCAB. Using the hedonic price method (Rosen, 1974; Freeman, 1979), we examine housing prices over the period 1980 – 2000 and test whether or not the effect of air pollution on house prices disappears as air pollution converges across space.[2] A priori, as the air pollution converges spatially, one would

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[2] The hedonic method has been used extensively to provide estimates of the value of specific housing characteristics. For example, location vis-à-vis high voltage power lines, hazardous and non-hazardous disposal sites, and other NIMBYs and LULUs (see Brookshire, et al, 1985; Murdoch, Singh, and Thayer, 1993; McClelland, et al 1990; Smith and Desvousges, 1986; Kiel, 1995; Kiel and McClain, 1995; Hite, et al, 2001; Kiel and Zabel, 2001), air pollution

expect any property value premiums due to air quality differences to dissipate in much the same way that property values have been shown to "rebound" from smaller scale environmental clean-ups(see Kiel (1995); Kohlhase (1991); Dale, et al, 1999) .

Organization of the Study

In the next section we present a comprehensive analysis of ozone air pollution in the South Coast Air Basin, the objective of which is to determine whether or not air pollution has demonstrated convergence over the study period. In Section III we present evidence on the distributional consequences of the improvement in air pollution. Next we turn to the estimation and analysis of the hedonic prices for air quality, concluding with preliminary insights gained from the analysis.

II. Air Pollution 1980 - 2000

Air pollution in the SCAB has shown dramatic improvement over the period 1980 – 2000. This is true for each of the criteria air pollutants, including our focus ozone, the primary pollutant in the class of photochemical oxidants that are formed by a chemical reaction between volatile organics and nitrogen oxide in the presence of ultra-violet radiation.

The Air Quality Management District has divided the South Coast Air Basin into receptor zones, which are illustrated in Figure 1. The boundaries of the receptor zones are determined through knowledge of both topography and meteorology (wind patterns, etc.) and air quality within a receptor zone is purported to be relatively homogeneous. Unfortunately, all receptor zones are not subject to continuous routine monitoring. We confine our analysis to those receptor zones that are either continuously monitored or are in the interior of the basin to allow interpolation between monitored receptor zones. These latter receptor zones, shown in Figure 2, are identified by name in Table 2.

Our analysis of ozone over time is based on hourly data for each operational monitoring station for the period 1980 – 1999 (or 2000 in some cases). These data, obtained from the AQMD, are summarized in Table 3, in which the annual average of the daily maximum ozone levels is presented by station for both 1980 and 1999 (columns 2 and 3 of Table 3). Note that ozone air pollution, as measured by the annual average, has improved in every receptor zone. In addition to the reduction in mean annual ozone the

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in California (Beron, et al, 1999; Brookshire, et al, 1982; Murdoch and Thayer, 1988; Brucato, et al, 1990; Beron, et al, 2001), water quality (Mooney and Eisgruber, 2001), and open space (Acharya and Bennett, 2001) have all been valued using the hedonic price method.

corresponding standard deviations for the receptor zones (not shown in the table) show significant decreases over the study period, indicating a narrowing of the distribution around a lower mean. More evidence that ozone has improved over time is presented in columns 4 and 5 of Table 3, which illustrate how the number of violations of the health-based federal air quality standard (> 12 PPHM) has changed over time. As is evident, the changes are quite dramatic.

Ozone Convergence

It is important to understand any changes in the spatial distribution of ozone over time. Such changes will have consequences in the housing market as well as in the analysis of the incidence of ozone exposure. First, we consider the relationship between the initial (1980) ozone levels to the percent change in ozone from 1980 to 1999 receptor-by-receptor using the annual average of the daily maximum values for ozone (*OZMAX*) (see Figure 3). The pattern depicted in Figure 3 confirms that air pollution control efforts led to a significant improvement in overall ozone and suggests a significant measure of convergence. In the five receptor zones with the lowest ozone levels in 1980 (receptors 3, 4, 12, 17, 18), ozone improved by 11.4% on average. In contrast, in the five receptor zones with the highest average ozone levels in 1980 (receptors 9, 23, 32, 34, 35), ozone improved by 45.5% on average. Such differential growth rates would necessarily produce convergence in ozone. The convergence is incomplete, however. Figure 4 shows the relationship between 1999 *OZMAX* and 1980 *OZMAX*. The slight upward trend indicates that those areas with the highest measures in 1980 remain the highest in 1999.

More striking are the corresponding pictures of the relationship between number of days violating the national hourly standard (*NV*) in 1980 and 1999 and the number of days violating the state hourly standard (*SV*); i.e., hourly reading > 9 PPHM. Figures 5 and 6 show the relationship for *NV*, while figures 7 and 8 depict the *SV* situation. Looking first at Figure 5, we see that many of the receptor areas show improvements approaching 100 percent. However, the worst areas (the right side) have not kept pace, *relatively*. This leads to the obvious pattern displayed in Figure 6—flat relationship until we get to the receptors that had more than 120 violations in 1980. Unlike *NV,* the *SV* has yet to be constrained by zero so that the patterns displayed in figures 7 and 8 show somewhat smoother relationships. The conclusion is the same however. It appears that in relative terms, the good areas in 1980 are still the good areas, perhaps even a little better, in 1999. As discussed below, this trend has some significance for the hedonic analysis.

III. Distributional Consequences of Ozone Improvement

In order to examine the distributional effects of changes in ozone levels over time, we constructed a data set for the California South Coast Air Basin counties of Los Angeles, Orange, Riverside, and San Bernardino for the period 1980-99. In addition to the air pollution data described above, our data set included several variables that characterize the census tracts in the study region. Measures of the age composition, ethnic composition, income and poverty level, and commuting time for a census tract were constructed using tract-level data from the 1980, 1990, and 2000 *Census of Population and Housing*. (See Table 4.) For the years between any two census endpoints, the weighted average of the beginning and ending values were assigned; e.g., the 1982 value would be the 1980 value + 0.2 times the growth between 1980 and 1990. Incompatibilities in census geography were resolved using the tract relationships published by the US Census and working with tract totals. For example, if 1980 tracts A and B were re-defined in 1990 to be X, Y and Z, then the 1980 value of (say) percentage white in the 1990 geography would be based on the total population data in 1980 in tracts A and B. Variables that depict these neighborhood/community influences were matched to the receptor level air pollution data using common location indicators.

Summary statistics for the years 1980, 1990, and 1999 are provided in Table 5. Several interesting observations can be gleaned from a brief inspection of the summary statistics. First, there was a large shift in the ethnicity of the region over the 1980 – 1999 period. The proportion of whites and African Americans in the sample of census tracts has markedly declined whereas the populations Asians and Hispanics have significantly increased. Second, there has been a significant decrease in the percent of the population greater than 65, implying a much younger population mix. Simultaneously, the percent suffering from poverty has shown a marked increase. Third, the time it takes to commute to work in the basin has increase approximately nine percent in the last decade.

As the ozone air pollution has changed over time so has the residential location of the various population groups. These relative movements are displayed in Figures 5 (African Americans and Asians and 6 (whites and Hispanics) generated using the ARC-GIS software package. In each map there are 25 receptor zones displayed. A uniform distribution for a specific population group across space would suggest that four percent of the population resided in each receptor zone. Therefore, we create three categories for each population group: (1) less than four percent of the population group in the zone; (2)

4 – 6 percent of the group population in the zone; and (3) greater than six percent of the group population in the zone. Consider each group individually.

In 1980 the African American population is heavily concentrated in five receptor zones clustered around central Los Angeles County. Over time the population de-concentrates somewhat as movement is out of the West San Gabriel Valley (receptor zone 8) and into the Central San Bernardino Valley (receptor zone 34). This movement, relative to air pollution is likely detrimental to African Americans since receptor zone 34 has higher overall ozone than central Los Angeles County.

The Asian American population over time moves out of receptor zone 2, into receptor zones 4, 6, 9, and 10. These movements are likely air pollution neutral. The Hispanic population, while increasing in overall magnitude, shows little temporal movement, with the exception of a relative movement into receptor zone 34 and out of receptor zone 11. Finally, the white population has tended to concentrate over time moving out of zones 4, 5, and 9 and into Orange County (receptor zone 19). These movements would seem to be benefit the white population since it seems they are moving into zones with lower overall air pollution.

Air Pollution Exposure Over Time

To assess the distribution of pollution (or "incidence"), we need to capture the three trends that are operating over the period 1980 to 1999. Air pollution is both improving and converging across the entire study region and there are large-scale changes in both the absolute numbers of the various population groups as well as changes in relative location. As a first attempt to capture the impact of these changes by population group we calculate a measure of the total air pollution exposure over time. This measure, labeled total violations per population group, is calculated as

$$TV_j = \sum_{i=1}^{25} V_i \bullet P_{ij}$$

where TV is total violations of the federal health based standard for ozone for each population group (subscript j), V represents the annual number of violations of (> 12 PPHM) in each receptor zone (subscript i), and P is the population of group j in receptor i. The calculated values for each population group in 1980, 1990, and 1999 are displayed in Table 6. As is illustrated each population group has experienced a dramatic decrease in person violations over the study period, ranging from 78.5 percent to 94.2 percent. Whites and African Americans have the largest reductions as a consequence of declining relative populations in the region. Similarly, Hispanics and Asian Americans have smaller reductions.

An alternative measure of exposure over time is presented in Figure 11, in which the average number of violations for each population group in each year is displayed. Average exposure (AV_j) is calculated as

$$AV_j = \sum_{i=1}^{25} V_i \bullet P_{ij} \Big/ \sum_{i=1}^{25} P_{ij}$$

As is illustrated African Americans had the lowest average exposure in 1980, whereas whites suffered the highest exposure levels, with the other population groups between these extremes. This is a surprising result since it suggests a type of reverse environmental racism not often found in the literature. The pattern of average ozone exposure persists throughout the 1980's and early 1990's as overall air pollution improves. However, in the mid to late-1990's the relative exposure relationship is reversed. This finding implies that African Americans in the South Coast Air Basin received a less than proportionate share on the ozone improvement over time. In the next sub-section we empirically test this hypothesis.

Spatial Association: Ozone Air Pollution and Population Over Time at the Receptor Level

Our initial attempt at characterizing the spatial relationship between ozone air pollution, measured by violations of the federal health-based standard (>12 PPHM), and population groups uses correlation coefficients. Since the approach does not explain exposure levels, rather it provides information on the spatial association between pairs of variables; that is, the approach is non-behavioral.

Table 7 shows the Pearson correlation coefficients between receptor zone exposure levels and various socioeconomic variables. It should be noted that the dissimilarity index is calculated at %White - %Minority. As is indicated there is essentially no significant relationship between ozone violations and the various socioeconomic variables at the receptor zone level (number of observations equals 25 in any year), the exception being the correlation between ozone violations and Asian Americans in 1980 and 1999. These results are somewhat surprising but are similar to those reported by Brajer and Hall (1992).

The correlation coefficient analysis was conducted at the receptor zone level. This level of aggregation could cause any possible micro-relationship between ozone pollution and the location of population groups to be masked. In order to test for this possibility we conducted further spatial association analysis at the census tract level. The results of this exercise are provided in the next sub-section.

Spatial Association: Ozone Air Pollution and Population Over Time at the Census Tract Level

The benefit of moving to a more disaggregated level of analysis is not without an associated cost. Specifically, one must assign pollution values, which are collected at the receptor zone level utilizing hourly monitoring, to the set of census tracts that are located within the receptor zone. To complete this task we used an interpolation procedure contained in the ARC GIS compute software package. Essentially, census tract values are determined by distance weighting the surrounding receptor zone information. The result is a estimated number of violations for each census tract in our study area. We completed this task for the three census data years 1980, 1990, and 2000 and did not attempt to interpolate between census years due to inconsistent census tract boundary problems over time. The ozone violation data are then matched with the corresponding census tract socioeconomic indicators to create data sets with 2201, 2259, and 2832 observations, respectively, for the selected years.

The results presented below are based on multivariate analysis rather than simple correlation, as we attempt to control for factors other than race and ethnicity. We use two different estimation methods, ordinary least squares and group-wise logit. It should be noted that in each case the estimated models are non-behavioral in that no direction of causation is to be inferred.

The ordinary least squares results are presented in Table 8. Since the sum of the individual population groups will sum to one we have omitted the white category from the regression. The coefficients on the remaining population groups are interpreted as deviations from the omitted group, as represented by the intercept term.

Consider the pattern over time. As indicated in Table 8 each of the population groups is the beneficiary of a large decrease in the average number of violations between 1980 and 1990 (intercept term). However, the period 1990 –1999 is characterized by only a small improvement. In fact, both Hispanics and those below the poverty level become worse off in the latter period.

Next consider the pattern within a specific time period. In 1980, consistent with Figure 11, African Americans and Asian Americans experience better overall air pollution than do whites and Hispanics. Furthermore, African American and Asian American populations have better air pollution than whites and Hispanics over the entire study period. This is quite surprising given the literature regarding environmental justice. On the contrary, the advantage that African Americans hold in 1980 dissipates over time in that they experience 62% less violations in 1980 but only 42% less violations in 1999.

Asian Americans actually increase their relative advantage over whites over the study period. The Hispanic population is decidedly worse off than whites in 1980 but receive a greater than proportionate decrease in ozone violations over the study period and by 1999 are essentially equivalent to whites, although they continue to trail both African Americans and Asian Americans. Those populations below the poverty line are initially disadvantaged in that they experience overall worse air quality in 1980. In addition, this group is even more disadvantaged in 1999 than in 1980. This temporal analysis indicates that there could be significant error in a single year cross-sectional study that does not account for population movements across time.

In Table 9 we present the group-wise logit results. The logic of this estimation model is that within a census tract there is a probability of being subject to a violation, given the existing air quality and the census tract population. In a strict logit model these probabilities can be converted to a set of zeros and ones that refer to individuals that experience violations and those that do not. In the group-wise logit model the data are expressed as number of violations within the population. These values are then regressed against the set of explanatory variables we used in the OLS estimation.

The odds-ratios are relative to 1.0 and indicate, relative the omitted group (whites), the likelihood that a specific socioeconomic group will experience a violation. For example, a one percent increase in Asian Americans in a census tract in 1980 would be associated with a 0.00023 percent decrease in the likelihood of violation. Specific group values below (above) 1.0 indicate that those groups are likely to experience a smaller (larger) number of violations. Thus, in 1980 African Americans and Asian Americans are likely to experience fewer violations than whites. The situation is reversed for Hispanics and those below poverty. Over time, African Americans lose their initial advantage, relative to whites, whereas the relative situation for the other groups does not change.

Conclusion: Distributional Consequences of Ozone Improvement

There are two patterns that emerge from our analysis. First, African Americans and Asian Americans experience better overall air quality throughout the study period, relative to whites. Hispanics and those below poverty generally experience worse air quality, relative to whites. Second, the initial advantage of African Americans tends to dissipate over time whereas Asian Americans improve upon their initial advantage. Hispanic populations tend to experience larger than proportionate improvements in air quality over time. On the other hand, those populations below poverty receive a smaller than proportionate share of the air quality improvements and are relatively worse off in 1999 than in 1980.

III. Hedonic Analysis

The theoretical framework for our analysis relies on the "first stage" of the hedonic price method developed by Rosen (1974) and Freeman (1979). The first stage of the method facilitates the estimation of the marginal willingness to pay (MWTP) for the attributes that comprise a composite commodity like residential housing.[3] The equilibrium price of housing is described by a hedonic price function. Let

$$P = P(a), \tag{3}$$

denote the hedonic function which relates the price of a home to a vector (*a*) of structural, neighborhood, and environmental variables. The marginal cost or hedonic price of an additional unit of a particular characteristic, a_i, is then calculated as the partial derivative of *P(a)* with respect to that characteristic.

$$P_{a_i} = \frac{\partial P}{\partial a_i} \tag{4}$$

The rational consumer will choose the optimal bundle of attributes by maximizing utility subject to an income constraint, which depends on *P*. Formally, let

$$U = U(X, a) \tag{5}$$

be an individual's utility function, where X is a composite commodity, all other goods, with a price that is assumed to be equal to one. The budget constraint is

$$Y = X + P(a), \tag{6}$$

where *Y* represents income. The first order necessary conditions yield

$$\frac{U_{a_i}}{U_X} = P_{a_i} \tag{7}$$

for each attribute in *a*, where subscripts denote partial differentiation. Equation (7) shows that the individual's housing choice decision ensures that his/her indifference curve is tangent to the price gradient and that individual marginal willingness to pay ($MWTP_i$) for a specific characteristic (a_i) is revealed by the hedonic price, P_{a_i}.

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[3] Our initial analysis does not utilize the "second stage" estimates of the MWTP functions (See Bartik (1987); Epple (1987); Beron, et al, 2001).

Therefore, this overview suggests that we collect data on *P* and *a,* estimate the hedonic price function *P(a),* differentiate it with respect to the characteristic of interest, and analyze the resulting estimate of the MWTP.[4]

Impact of Ozone Convergence

Accurate empirical estimation of the MWTP for a specific housing attribute is contingent on there being variation in that characteristic. For example, if every house has exactly three bedrooms then one could not empirically estimate the hedonic price associated with bedrooms. In effect, the coefficient on bedrooms would be indistinguishable from the constant term in the estimated regression. This further implies that as air pollution completely converges over time (e.g., zero variation in air pollution or differences eliminated in all receptor zones) then the estimated coefficients on air pollution would be zero and that our empirical analysis could not identify the premium for air pollution differences. This result is not spatial in that it does not require spatial relationships.

In reality we are not moving from some air pollution to zero air pollution. Rather, we are moving from one spatial pattern to another over time. In fact, we are moving from a spatial pattern with large pollution differences to a spatial pattern that demonstrates less overall air pollution and less spatial diversity or variability. This implies that, as we move from the initial pattern to the subsequent pattern, the hedonic price of air pollution should become smaller (in the limit it would disappear and we would not be able to estimate the value that home buyers attach to air pollution differences), all else constant. This is the hypothesis we will test below --- that as air pollution differences across receptor zones diminish, then the hedonic price of air pollution will approach zero.

In order to empirically test this hypothesis, we consider yearly estimates of the hedonic price of ozone by relating the price of a house as a function of its structural characteristics, neighborhood characteristics, and air quality, as measured the annual average of the daily maximum ozone readings (OZMAX), the number of days that violate the national (NV) or state (SV) standard. For home i, in receptor zone j, in year t, the regression is

$$\log(P)_{ijt} = \alpha_t + \beta_t S_{ijt} + \lambda_t N_{ijt} + \gamma_t OZONE_{jt} + \varepsilon_{ijt}$$

where $Log(P)_{ijt}$ denotes the logarithm of the sale price of home i, located in receptor zone j, in year t, α is the constant, β, λ, and γ are the parameters to be estimated in each year,

[4] In a similar manner profit-maximizing producers operate so that their marginal willingness to accept for an additional unit of the i^{th} characteristic is equal to the hedonic price. Thus, producer offer curves are tangent to the hedonic price gradient, which can be viewed as double envelope curve.

S_{ijt} is a vector of house specific structural characteristics, N_{ijt} is a vector of neighborhood characteristics, and $OZONE_{jt}$ is ozone measure in receptor zone j in year t, and ε_{ijt} is a random disturbance term. [5]

Our primary objective is to examine γ, the parameter on ozone, over time. Thus, we estimate separate models for each year and then consider time pattern of the estimates.

Data Specifics

In order to examine the relationship between air pollution and housing values, we have constructed a data set that includes approximately 1.3 million observations from the California South Coast Air Basin counties of Los Angeles, Orange, Riverside, and San Bernardino for the period 1980-2000. An observation relates to a specific sale of an owner occupied single family home. The sales transaction data were obtained from First American Real Estate Solutions (FARES). These data include complete descriptive information on every piece of property (residential, commercial, etc.) in California. The data set is continually updated and, for every property, contains the address and other location information (census tract, etc.), a detailed list of structural attributes, and information on the two most recent sales (date, price, and terms). The data is generally available to appraisers and real estate brokers and agents on a fee for use basis.

The dependent variable in the first stage estimation of the hedonic price function is the natural logarithm of home sale price of owner-occupied single-family dwellings sold during 1980-1999. House price was deflated to constant dollars (1982 – 1984 = 100) using the regional all items consumer price index.

The independent variables are organized into three groups---house level, neighborhood level, and air pollution level. Table 11 provides variable names, descriptions, and relevant units of measurement for the data used in the analysis. The structural variables include both quantity and quality measures. House size or quantity is described by square footage of living space, number of bathrooms and lot size measured as land area. House quality is described by house age, the presence of a pool, the number of fireplaces, the house construction style, the roof material, the house condition, and central air conditioning.

We matched each home in our sample with five measures of neighborhood/community quality. Four variables describe the census tract in which each house is located. Measures

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[5] The neighborhood characteristics actually represent an additional level because they are measured at the census tract level.

of the age, ethnic composition, travel time to work, and percent below poverty of a neighborhood were constructed using tract-level data from the 1980, 1990, and 2000 Censuses. Each of the census tract variables is meant to proxy for a specific aspect of the neighborhood rather than being a reflection of the individuals who purchase property in the neighborhood. For the years between any two census endpoints, the weighted average of the beginning and ending values were assigned; e.g., the 1982 value would be the 1980 value + 0.2 times the growth between 1980 and 1990. Incompatibilities in census geography were resolved using GIS—each home is located in its correct tract regardless of year.

In addition to the census tract variables, we utilize three other neighborhood indicators: (1) school quality, measured by a set of dummy variables (approximately 85 dummies) representing the various school districts; (2) neighborhood accessibility to the beach measured either as a zero-one dichotomous classification or by miles from the nearest beach; and (3) TOPO calculated as the maximum elevation minus the minimum elevation in the census tract. Air pollution is measured by calculating the number days that the region violated the federal hourly ozone standard in each year (NV), the state standard (SV) and the average of daily maximums (OZMAX).

Variables that depict neighborhood/community influences are matched to the housing data via location, a standard GIS operation. For our neighborhood/community variables the matching exercise is straightforward since a home is located within a specific census tract, a school district, and a specific receptor zone.

Representative summary statistics for the years 1980, 1990, and 1999 are provided in Table 11. Several interesting observations can be gleaned from a brief inspection of the summary statistics. First, the real average home sale price increased significantly from 1980 to 1990 (approximate 2.6% compounded annual rate of real appreciation), but declined for most of 1990's, with the 1999 value falling just behind the 1980 value.[6, 7] Second, average housing characteristics are quite similar across time although the sample of homes in 1999 seems somewhat older, smaller (e.g., living and land area) and in generally worse condition with fewer amenities (e.g., central air conditioning, baths) than the 1980 or 1990 samples. Third, there was a large shift in the ethnicity of the region over the 1980 – 1999 period. The proportion of whites in the sample of census tracts has markedly declined as other ethnic groups have significantly increased.

[6] The all items consumer price index for Los Angeles, Orange, and Riverside counties was used to deflate the house prices.

[7] In a recent Wall Street Journal Article (August 28, 2002) Jonathan Clements reported that nationally home prices have appreciated at 5.8% per year over the past 27 years, with an annual real appreciation rate of 1.2% per year.

Initial Result

The estimates on the variables of interest are displayed in Table 12. Since the empirical results are based on a semi-log specification, the parameter estimates quite amenable to interpretation; i.e.,

$$\frac{\partial P}{\partial X_i} = \lambda_i P, \qquad (9)$$

where P is the sale price of a home, X_i is the ith characteristic, and λ_i is the parameter estimate for the ith characteristic. Therefore, the estimated parameter times 100 denotes the percentage change in house price for a one more unit of the pollution. The full set of parameter estimates is available upon request. (See Appendix.) Here, we simply note that all variables are generally significant and have the anticipated relationship to sales price. The R-Square values generally exceed 0.75.

The pattern displayed in Table 12 is strikingly counter to our expectations. Not only does the effect of ozone seem to be strongly significant in spite of the convergence in ozone, the magnitude of the effect has actually increased. There are at least four alternative explanations for this. First, it is possible that the hedonic model is missing an important variable that is highly correlated with the location of the receptor zones. This possibility seems minimal, however, given the large number of characteristics that have been controlled for in the model and we are unable to think of additional ways to rule out the possibility. Second, we could be seeing the effects of an "outlier" phenomenon. Because ozone is so much better in most areas, the areas that still experience a modest number of violations for a group that could be given too much weight under the least squares estimator. This is difficult to discern with plots because of the size of the dataset; hence, we take an alternative approach below. Third (although related to the outlier possibility), there may be "stigma" effects in the property value markets. Under this hypothesis, an area could be viewed as one with "bad" air quality despite having experienced dramatic improvements. As noted in the introduction, previous research has considered this possibility with respect to highly localized environmental problems. Fourth, it is possible that the results are correct. This would seem to imply that the preferences for environmental quality in the study area have changed in favor of better air quality during our study period. This could be a result of the availability of information about the consequences of urban air pollution as well as the "advertising" campaigns of various non profit and advocacy organizations. We attempt to rule out as many of these alternative hypotheses as possible.

The central issue is with the house premiums associated with the air pollution receptor zones. Using receptor zone fixed effects in place of the ozone measures, we first estimate the "total" premiums for each receptor for each year. In each year, the premium is relative to receptor zone 37, the left out category; thus, the premium for zone 37 is zero in each year. This gives a dataset with 25 estimates for each of twenty-one years that can be matched up with the ozone data and other receptor level data. The outlier hypothesis can be "tested" by examination of auxiliary regressions on the premiums:

$$prem_{it} = \alpha_t + \zeta_t OZONE_{it} + \eta_{it} . \quad (10)$$

Note that in (10) we specify different parameters for each year. The estimates are presented in Table 13. First, notice that the estimates are generally negative (and significant). This is not unexpected given that we found significance in the hedonic model. Moreover, just as in the hedonic regressions, the estimates increase substantially over the time period. Figures 12a – 13b show representative estimated lines and scatter plots for model (10). Notice that in each case the latter figure illustrates two clumps of data—relatively low pollution and high premiums and relatively high pollution and low premiums. The latter figures show classic "outlier" character.

To further investigate this, we re-estimated the models using just the ranks of the data. Rank regressions will be much less susceptible to departures from normality. (See Table 14—only SV is presented.) The interesting result is that the rank regressions look essentially the same from 1994 on. This is, again, an indication of outlier phenomenon.

Turning next to the issue of stigma, the hypothesis is that an area becomes stigmatized as a bad air quality area so that housing price differentials persist even when air quality improves; i.e., house prices fail to rebound in response to the improvement in the environment. Given the previous finding, we decided to attempt to study this hypothesis using the ranked data. The basic idea is to compare the ranks in one period to the ranks in previous periods. If the ranks of premiums appear to be more closely correlated with the ranks of pollution in previous periods, then we would argue that there is some support for the hypothesis. Thus, we constructed 4 five year periods (1980-1984, 1985-1989, etc.) and calculated the average of the annual ranks for each period. This gives a time series cross-sectional dataset with four periods and twenty five units. Stacking theses data, we can estimate the relationship between average premium rank and average pollution rank in the contemporaneous period and in the lag period. Representative results are presented in Table 15; i.e., just those for the final period. Interestingly, the results seem to indicate rejecting the stigma hypothesis because the contemporaneous measures seem to out-perform the lagged measures. The results for models (3) and (6) also support rejecting the stigma hypothesis. Another interesting result in Table 15 is that it appears as though SV "fits" the model better. This has some intuitive appeal because NV loses so much resolution by 2000.

Concluding Comments

Our conclusions are preliminary at this point. The dramatic decreases in ozone and relative spatial convergence of ozone exposure over the study area, suggest that hedonic price differentials should disappear for at least two reasons. First, the lack of spatial variation implies that "voting with your feet" does not yield lower exposure. Second, with increases in the "good" we would expect marginal willingness to pay to decrease. Surprisingly, our initial hedonic estimations found exactly the opposite of this—the differentials remain strongly significant and actually increase in absolute value. Further analysis of the data, seem to suggest that the while there is general spatial convergence, a couple of areas remain relatively bad. These create a type of outlier phenomenon that actually tilts the hedonic in favor of greater MWTPs. We also investigated the possibility of stigma effects but did not find any evidence to support that hypothesis. Thus, it appears that some of the unexpected finding may be due to a "design" problem that would need to be addressed before concluding that the differentials have in fact disappeared. Unfortunately, there does not appear to be an obvious procedure for dealing with this situation although nonparametric or some other "robust" approach seems the most likely.

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Table 1
Trends in Ozone Data 1980 - 2001
South Coast Air Basin

Year	Stage 1 Smog Alerts (Days)	Maximum One-Hour Ozone Concentration (PPHM)	Annual Average Daily Maximum Ozone	Standard Deviation of Daily Maximum Ozone
1980	102	49	8.47	6.85
1985	83	39	8.3	5.93
1990	42	33	6.91	4.60
1995	14	26	6.31	3.75
1996	7	24	6.04	3.45
1997	2	39	5.61	3.10
1998	12	25	5.82	3.12
1999	0	18	5.49	2.64
2000	0	18	NA	NA
2001	0	19	NA	NA

Table 2
South Coast Air Basin Receptor Zones

Receptor Zone	Location	Routine Monitoring
1	Central Los Angeles County	Yes
2	Northwest Coastal Los Angeles	Yes
3	Southwest Coastal Los Angeles	Yes
4	South Coastal Los Angeles	Yes
5	Southeast Los Angeles County	No
6	West San Fernando Valley	Yes
7	East San Fernando Valley	Yes
8	West San Gabriel Valley	Yes
9	East San Gabriel Valley	Yes
10	Pomona Walnut Valley	Yes
11	South San Gabriel Valley	Yes
12	South Central Los Angeles County	Yes
13	Santa Clarita Valley	Yes
16	North Orange County	Yes
17	Central Orange County	Yes
18	North Coastal Orange County	Yes
19	Saddleback Valley	Yes
22	Norco/Corona	No
23	Metro Riverside County	Yes
24	Perris Valley	Yes
32	Northwest San Bernardino Valley	Yes
33	Southwest San Bernardino Valley	No
34	Central San Bernardino Valley	Yes
35	East San Bernardino Valley	Yes
37	Central San Bernardino Mountains	Yes

Table 3
Ozone Data by Receptor Zones

Receptor Zone	Annual Average Ozone 1980	Annual Average Ozone 1999	Violations of National Standard 1980	Violations of National Standard 1999	Coefficient on Time	t-statistic
1	7.54	4.99	76	2	-0.17	-12.16
2	7.04	4.73	48	1	-0.12	-8.15
3	5.09	5.04	29	1	-0.05	-3.10
4	4.67	4.48	9	1	-0.02	-1.15
5	6.65	4.49	59	2	-0.13	-9.76
6	9.45	5.18	111	0	-0.18	-8.79
7	9.12	5.59	111	5	-0.21	-8.76
8	10.61	5.10	131	5	-0.29	-11.39
9	11.52	5.37	140	21	-0.29	-9.88
10	9.40	4.64	115	8	-0.22	-10.36
11	9.57	5.06	119	3	-0.22	-13.12
12	4.24	4.14	23	3	-0.10	-4.53
13	9.21	5.90	106	9	-0.15	-6.91
16	7.55	4.90	77	2	-0.16	-8.74
17	6.36	3.36	50	0	-0.11	-6.39
18	4.89	4.76	10	0	-0.08	-1.94
19	6.42	5.08	36	0	-0.07	-4.30
22	9.27	4.54	113	7	-0.25	-6.61
23	11.22	6.39	147	14	-0.21	-12.40
24	9.13	5.62	116	2	-0.14	-6.86
32	11.31	6.07	139	18	-0.25	-14.46
33	10.10	5.64	148	15	-0.19	-8.49
34	11.82	6.06	298	41	-0.22	-7.98
35	10.70	6.84	138	33	-0.12	-5.28
37	10.13	7.96	135	56	-0.14	-7.58

Table 4
Variable Definitions --- Distributional Analysis

Variable	Definition	Units of Measurement
Neighborhood Level Attributes		
AGE65	Percent 65 or Older in Census Tract	Percent
BPOV	Percent Below Poverty Level in Census Tract	Percent
PCINC	Per Capita Income in Census Tract	Dollars
MEDINC	Median Income in Census Tract	Dollars
TWORK*	Average Time to Work in Census Tract	Minutes
WHITE	Percent White in Census Tract	Percent
AFAMER	Percent African American in Census Tract	Percent
ASIAN	Percent Asian in Census Tract	Percent
HISP	Percent Hispanic in Census Tract	Percent

Table 5
Summary Statistics – 1980, 1990, 1999

Variable	Mean-1980	Mean---1990	Mean---1999
Neighborhood Attributes			
AGE65	0.095	0.093	0.043
BPOV	0.122	0.137	0.160
PCINC	7819	16268	20291
TWORK	26.42	26.49	28.92
WHITE	0.59	0.46	0.36
AFAMER	0.099	0.089	0.079
ASIAN	0.045	0.102	0.118
HISP	0.249	0.343	0.417
Number of Census Tracts	2211	2345	3017

Table 6
Total Person Violations (in millions)

Population Group	1980	1990	1999	% Change from 1980
White	507.6	313.2	29.6	-94.2
African American	62.3	45.5	6.5	-89.6
Hispanic	212.8	221.0	35.1	-83.5
Asian American	34.4	61.7	7.4	-78.5
Below Poverty	97.8	84.5	13.0	-86.7

Table 7
Pearson Correlations Coefficients
Number of Days Exceeding National Standard and Various Population Sub-Groups
(* indicates significance at the 0.10 level)

Population Group	1980	1985	1990	1995	1999
White	0.17	0.13	0.11	0.06	0.31
African American	-0.27	-.023	-0.17	-0.10	-0.12
Hispanic	0.01	0.01	-0.02	0.01	-0.18
Asian American	-0.37*	-0.22	-0.18	-0.14	-0.42*
Below Poverty	-0.08	-0.08	-0.04	-0.04	-0.10
% Age > 65	0.13	0.08	0.05	0.02	0.15
Minority	-0.16	-0.12	-0.11	-0.06	-0.30
Dissimilarity Index	0.17	0.12	0.11	0.06	0.31

Table 8
Relationship of Census Tract Demographics to Ozone Violations
(Dependent Variable = Number of Violations)

Variable	1980 Coefficient	1990 Coefficient	1999 Coefficient
Intercept	73.01***	6.614***	6.33***
African American	-45.62***	-4.88***	-2.62***
Asian American	-97.13***	-13.14***	-9.11***
Hispanic	17.47***	-2.37***	-0.97
Below Poverty	21.71	0.09	4.46**
R-Squared	0.06	0.03	0.02

***Significant at the 0.01 level

**Significant at the 0.05 level

Table 9
Relationship of Census Tract Demographics to Ozone Violations

Variable	1980 Odds Ratio*	1990 Odds Ratio*	1999 Odds Ratio*
African American	0.99984	1.00011	1.00017
Asian American	0.99977	0.99997	0.99986
Hispanic	1.00002	1.00004	1.00011
Below Poverty	1.00019	1.00009	1.00011

*All coefficients are significant at the 0.01 level

Table 10
Variable Definitions --- Hedonic Price Estimation

Variable	Definition	Units of Measurement
House Level Attributes		
PRICE	Sale Price	Dollars
BATH	Number of Bathrooms	Number
CENTAIR	Presence of Central Air Conditioning	Zero/One
FIRE	Number of Fireplaces	Number
HOUSE AGE	Age of Home	Years
HOUSE CONDIITON	Evaluation of House Condition	Excellent/Good/Fair
HOUSE STYLE	Style of House Construction	Spanish/Contemporary/Modern/
{Not used}		Traditional/Bungalow/Other
LANDAREA	Lot Area	Square Feet (1000)
LIVAREA	Interior Living Space	Square Feet (100)
MONTH	Month of Year Home was Sold	Number (January = 1)
POOL	Presence of Pool	Zero/One
ROOF	Roof Construction Material	Shake/Other
STORIES	Number of Stories	Number
RELATIVE_Elevation	Home elevation relative to tract min	Percent
YEAR	Year Home was Sold	Number (1980 = 1)
Neighborhood Level Attributes		
AGE65	Percent 65 or Older in Census Tract	Percent
BEACHDUM	Location within 5 Miles of Nearest Beach	Zero/One
BEACH	Distance to Nearest Beach	Miles
BPOV	Percent Below Poverty Level in Census Tract	Percent
SCHOOL	Location in Specific School Districts	Zero/One
TWORK	Average Time to Work in Census Tract	Minutes
WHITE	Percent White in Census Tract	Percent
TOPO	Difference in max and min elevation in CT	Meters
Air Pollution Level Attributes		
OZMAX	Annual Average of Daily Maximum Ozone	Parts Per Million
NV	Annual Days Violating Federal Standard	Number
SV	Annual Days Violating State Standard	Number

Table 11
Summary Statistics – 1980, 1990, 1999

Variable	Mean-1980	Mean---1990	Mean---1999
House Attributes			
PRICE (Nominal $)	117,225	245,940	230,856
PRICE (Real $)	140090	180,971	138,986
BATH	2.00	1.96	1.88
CENTAIR	0.31	0.33	0.30
FIRE	0.68	0.66	0.67
HOUSE AGE	41.22	41.01	41.11
HOUSE CONDIITON			
Excellent	0.07	0.03	0.03
Good	0.40	0.33	0.25
LANDAREA	8,843	8,869	8,993
LIVAREA	1,646	1,625	1,571
POOL	0.15	0.14	0.15
SHAKE ROOF	0.31	0.21	0.21
STORIES	1.25	1.23	1.19
RELATIVE_ELEVATION	44.12	44.33	43.90
Neighborhood Attributes			
AGE65	0.08	0.09	0.05
BEACHDUM	0.01	0.01	0.01
BEACH DISTANCE	22.16	24.05	23.06
BPOV	8.39	9.81	11.85
TWORK	26.95	27.13	29.53
WHITE	0.68	0.53	0.43
TOPO	100.9	111.3	102.7
Air Pollution			
OZMAX	8.13	6.34	5.07
NV	81.89	47.91	5.40
SV	121.61	89.58	33.25
Number of Observations	25,583	53,141	113,734

Table 12
Coefficient Estimates of Pollution Terms

Year	NV-Coef	SV-Coef	OZMAX-Coef
1980	-0.00166	-0.00095	-0.03126
1981	-0.00149	-0.00097	-0.03162
1982	-0.00209	-0.00101	-0.0289
1983	-0.00208	-0.0016	-0.03832
1984	-0.00259	-0.0018	-0.05371
1985	-0.00261	-0.00151	-0.05197
1986	-0.00272	-0.00176	-0.05334
1987	-0.00331	-0.00176	-0.06925
1988	-0.0035	-0.00209	-0.07702
1989	-0.00419	-0.00202	-0.05932
1990	-0.00412	-0.00177	-0.05985
1991	-0.00378	-0.00229	-0.07038
1992	-0.00391	-0.00255	-0.09969
1993	-0.00621	-0.00385	-0.12159
1994	-0.00388	-0.00389	-0.10639
1995	-0.00608	-0.00389	-0.13373
1996	-0.00969	-0.00526	-0.13262
1997	-0.01242	-0.00609	-0.1402
1998	-0.01614	-0.0078	-0.19183
1999	-0.0279	-0.00794	-0.17749
2000	-0.03996	-0.01304	NA

All estimates significant at conventional levels.

Table 13
"Premium" Regressions

Year	NV			SV			OZMAX		
	Intercept	nv	R-sq	Intercept	sv	R-sq	Intercept	ozmax	R-sq
1980	0.708057	-0.00419	0.47	0.768243	-0.00355	0.32	1.011119	-0.0817	0.4
1981	0.479209	-0.00282	0.31	0.580584	-0.00274	0.28	0.795606	-0.07014	0.31
1982	0.649129	-0.00409	0.59	0.711251	-0.00332	0.44	1.091114	-0.10152	0.57
1983	0.65512	-0.00398	0.44	0.795422	-0.00387	0.35	1.07879	-0.09459	0.48
1984	0.940478	-0.00531	0.6	1.122546	-0.00496	0.49	1.509558	-0.12777	0.52
1985	0.780939	-0.00536	0.43	0.8829	-0.00439	0.32	1.361936	-0.12797	0.42
1986	1.059444	-0.00298	0.03	0.780018	-6.9E-05	0.01	1.585691	-0.0957	0.04
1987	1.218591	-0.00831	0.63	1.364142	-0.0066	0.48	2.321644	-0.23258	0.61
1988	1.285223	-0.0075	0.63	1.389243	-0.00586	0.43	2.300614	-0.20522	0.6
1989	1.524869	-0.00893	0.71	1.741038	-0.00728	0.56	2.339981	-0.20024	0.58
1990	1.149816	-0.00852	0.6	1.26401	-0.00614	0.5	1.964764	-0.19174	0.59
1991	1.314158	-0.00947	0.64	1.490687	-0.00719	0.58	2.346313	-0.22748	0.62
1992	1.400149	-0.0093	0.68	1.601809	-0.00747	0.61	2.618671	-0.26085	0.72
1993	1.079032	-0.00843	0.75	1.233211	-0.00615	0.65	2.005013	-0.20655	0.72
1994	0.891665	-0.007	0.77	1.061837	-0.00597	0.77	1.737946	-0.18716	0.78
1995	0.948814	-0.01049	0.75	1.129084	-0.00742	0.72	2.223096	-0.26701	0.78
1996	1.141628	-0.01286	0.9	1.300559	-0.00807	0.82	2.361227	-0.27353	0.82
1997	0.88336	-0.01672	0.82	1.065619	-0.00821	0.84	2.062143	-0.26762	0.66
1998	1.350265	-0.01869	0.92	1.529705	-0.01168	0.91	2.936887	-0.347	0.92
1999	1.016582	-0.01858	0.82	1.251775	-0.0093	0.91	2.60415	-0.32795	0.87
2000	1.09578	-0.0639	0.82	1.202111	-0.0143	0.91	NA	NA	NA

Table 14
Premium Rank Regressions

Year	Intercept	sv
1980	17.32797	-0.50678
1981	16.42486	-0.42825
1982	16.05195	-0.39582
1983	20.71797	-0.59369
1984	21.36644	-0.64357
1985	21.68003	-0.66769
1986	17.51	-0.34692
1987	22.46228	-0.72787
1988	22.3586	-0.71989
1989	21.7	-0.66923
1990	20.62793	-0.58676
1991	22.75375	-0.75029
1992	22.9	-0.76154
1993	23.19892	-0.78453
1994	24.10354	-0.85412
1995	23.49404	-0.80723
1996	23.72	-0.82462
1997	23.92761	-0.84059
1998	23.91339	-0.83949
1999	22.84879	-0.7576
2000	23.72738	-0.82518

Table 15
Rank Regressions with Period Lags
Dependent Variable is the Average Rank of Premiums in Period 4 (1996-2000)

Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)
NV (period 3)	-0.835 (-6.42)		-.6849 (-1.21)			
NV (period 2)		-0.787 (-6.12)	-0.149 (-0.27)			
SV (period 3)				-0.864 (-7.94)		-1.139 (-2.19)
SV (period 2)					-0.820 (-6.97)	0.277 (0.54)
Intercept	23.86 (12.51)	23.231 (12.20)	23.83 (12.23)	24.236 (15.08)	23.656 (13.58)	24.206 (14.82)
R-square	.64	.62	.64	.73	.68	0.73

Figure 1
Receptor Areas

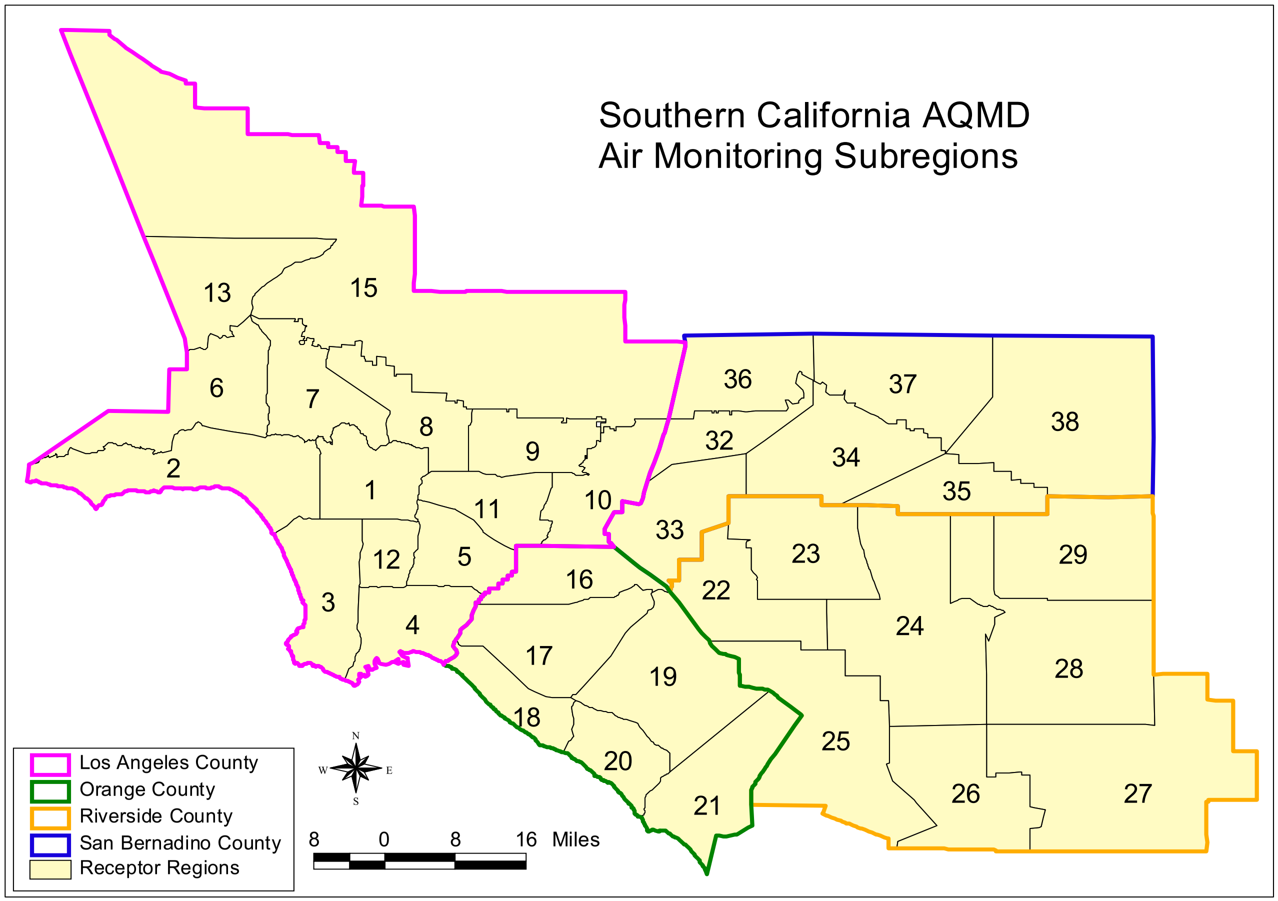


Figure 2
Study Area Receptor Areas

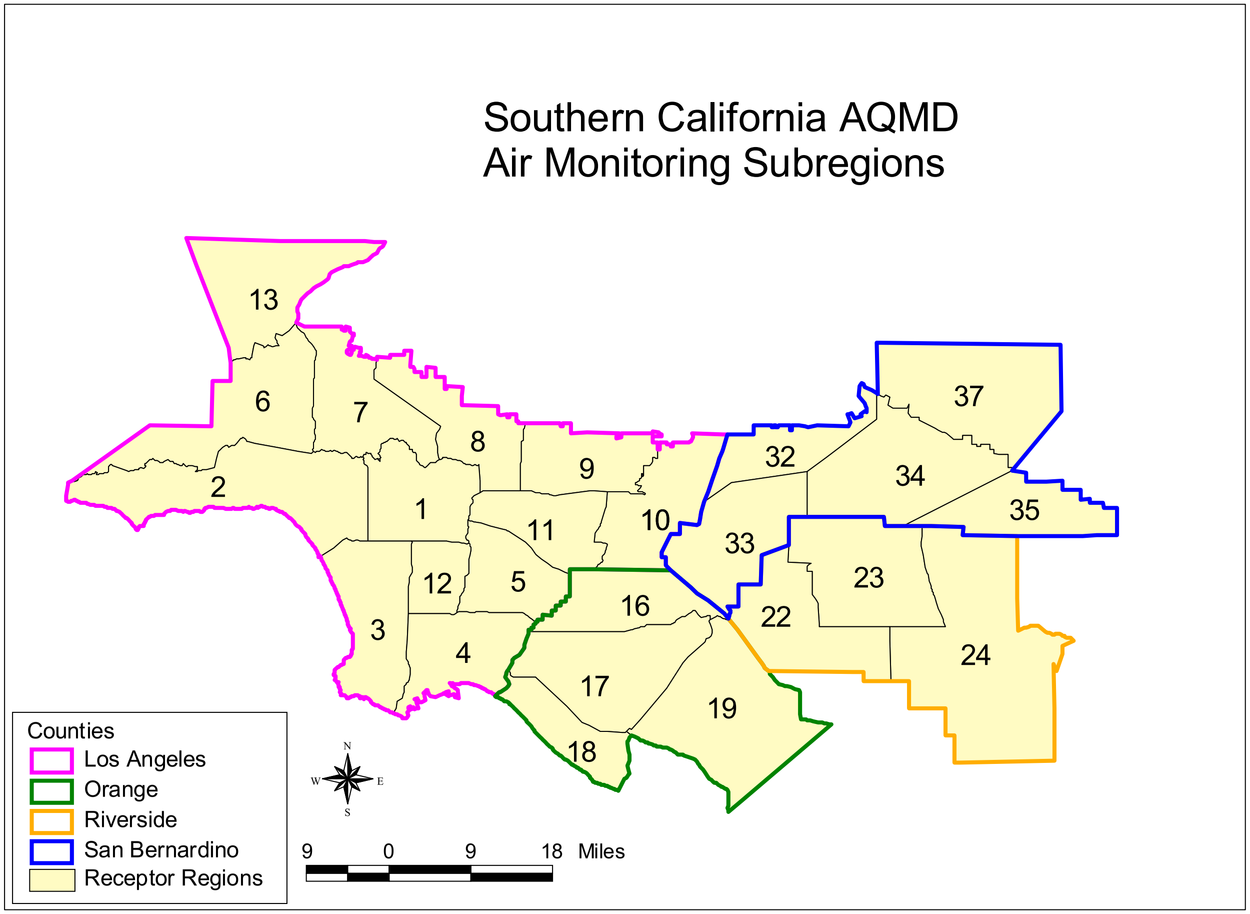


Figure 3.

Convergence in OZMAX

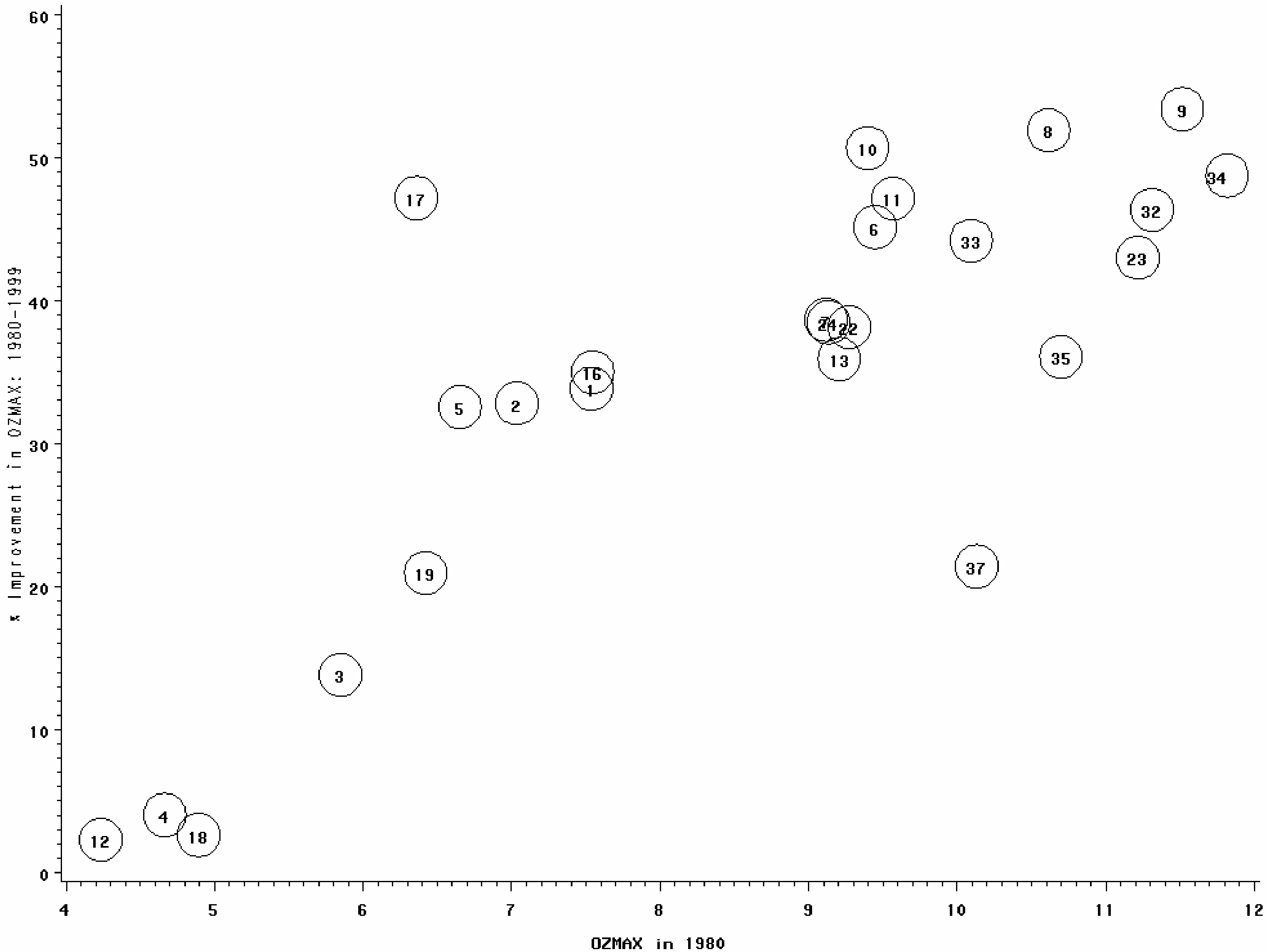


Figure 4.

1999 OZMAX vs 1980 OZMAX

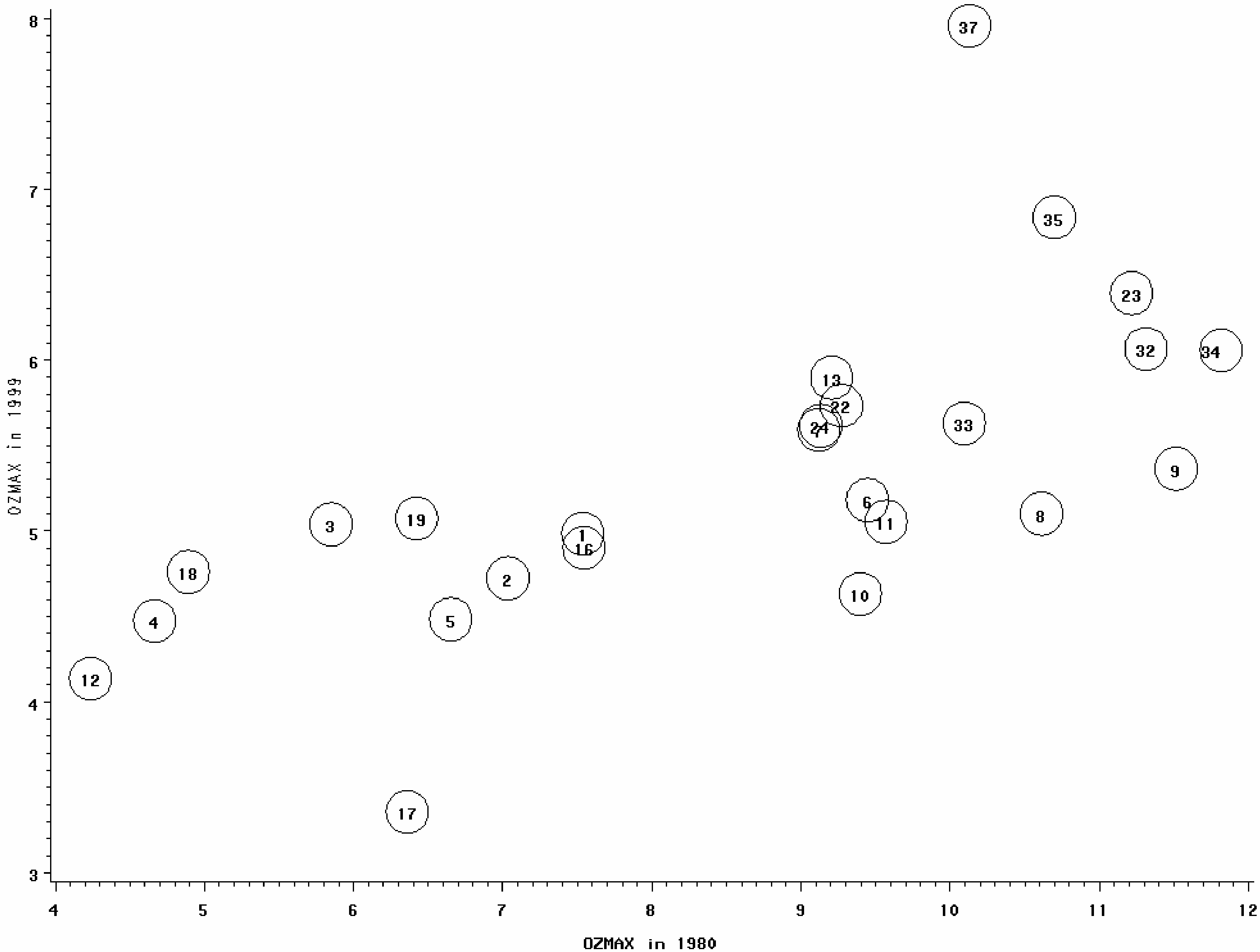


Figure 5.

Convergence in NV

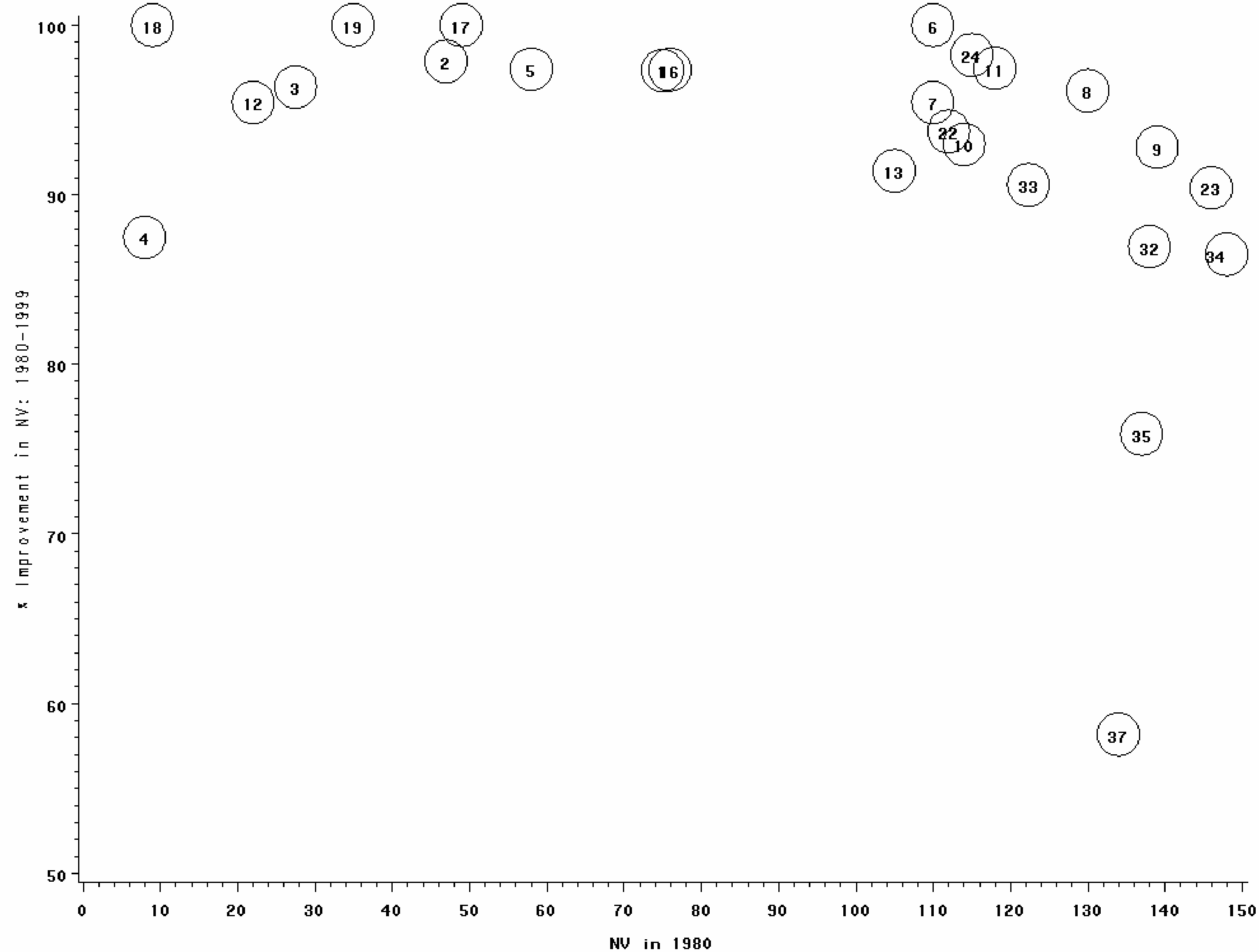


Figure 6.

1999 NV vs 1980 NV

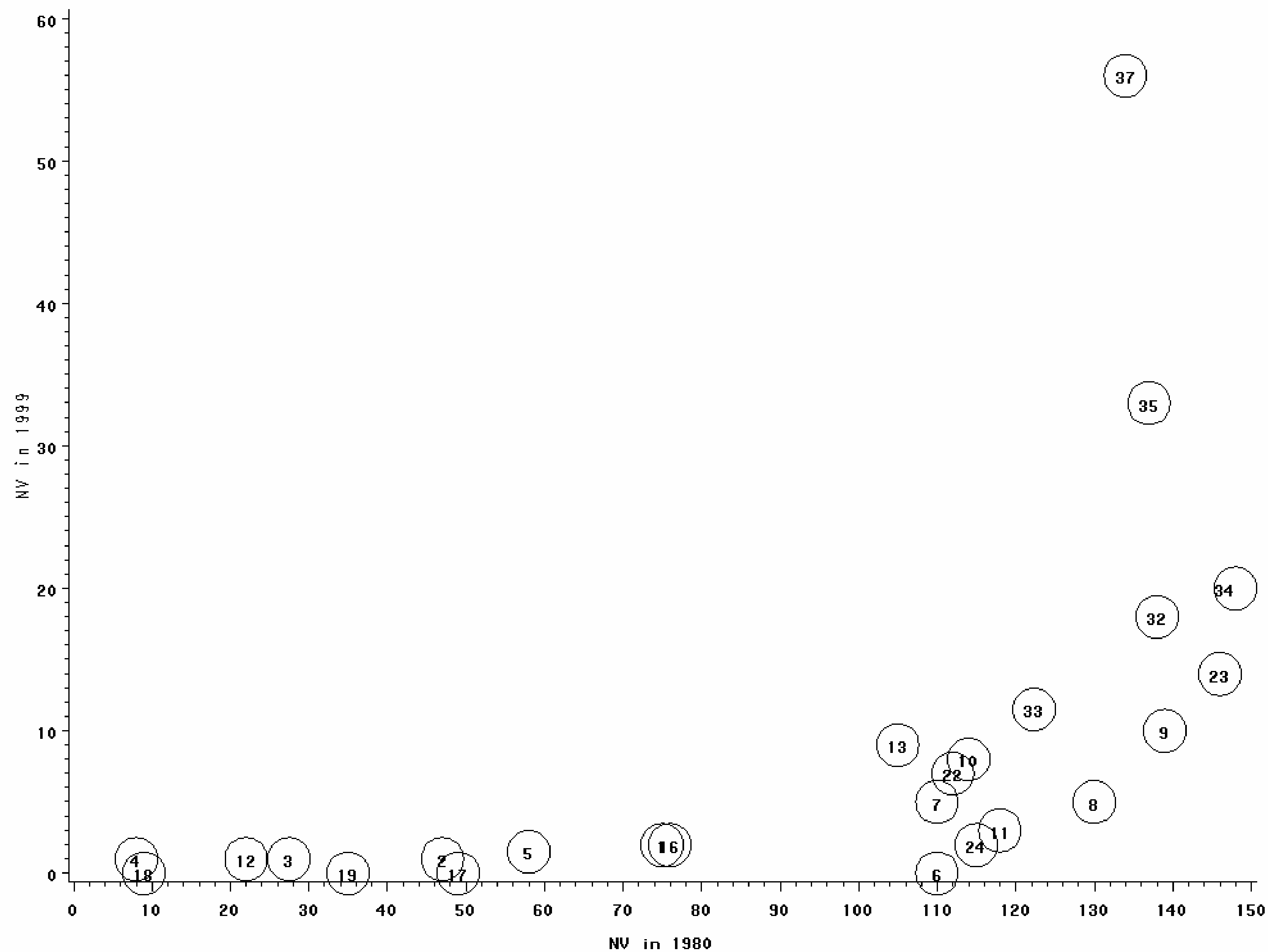


Figure 7.

Convergence in SV

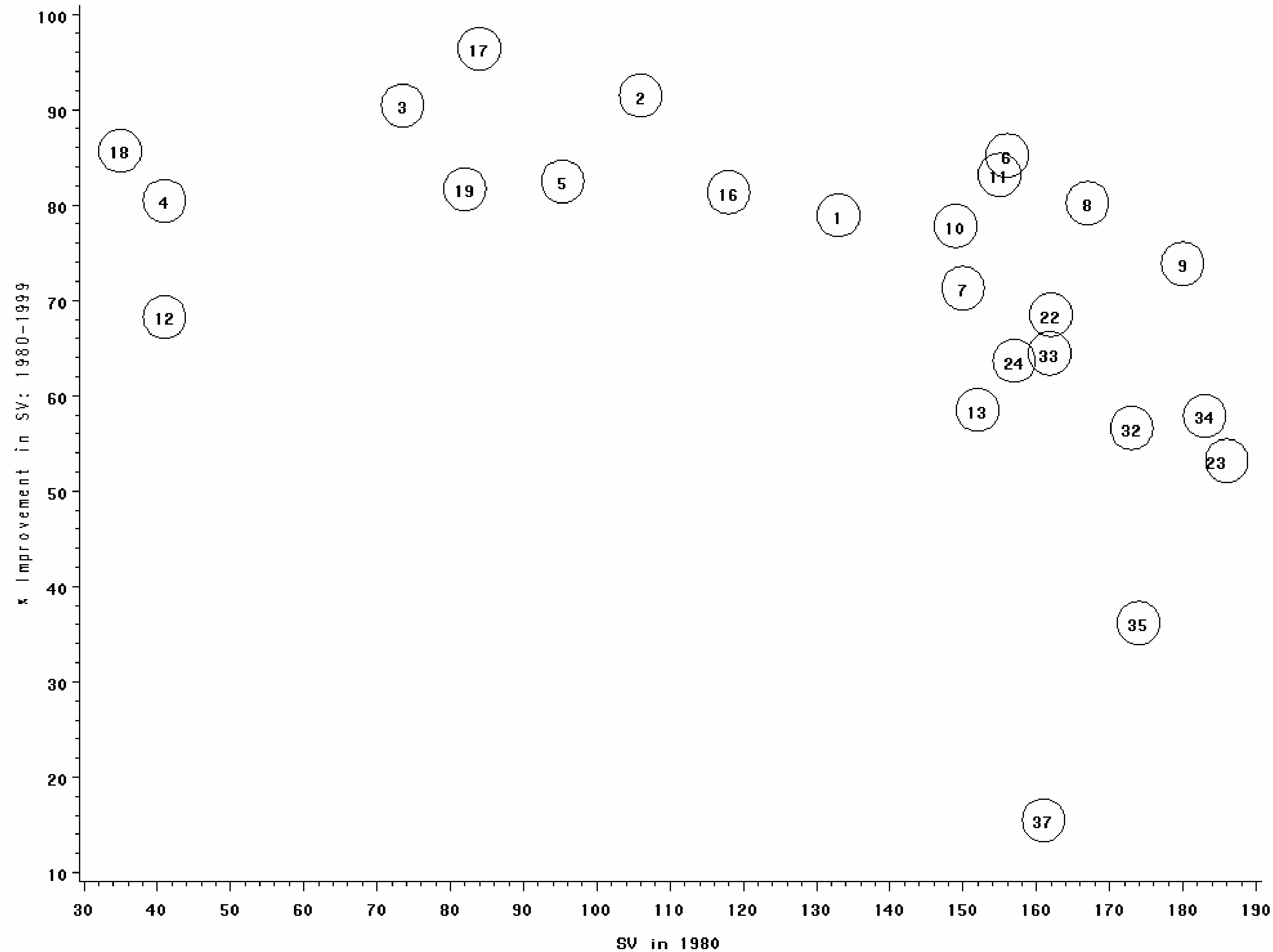


Figure 8.

1999 SV vs 1980 SV

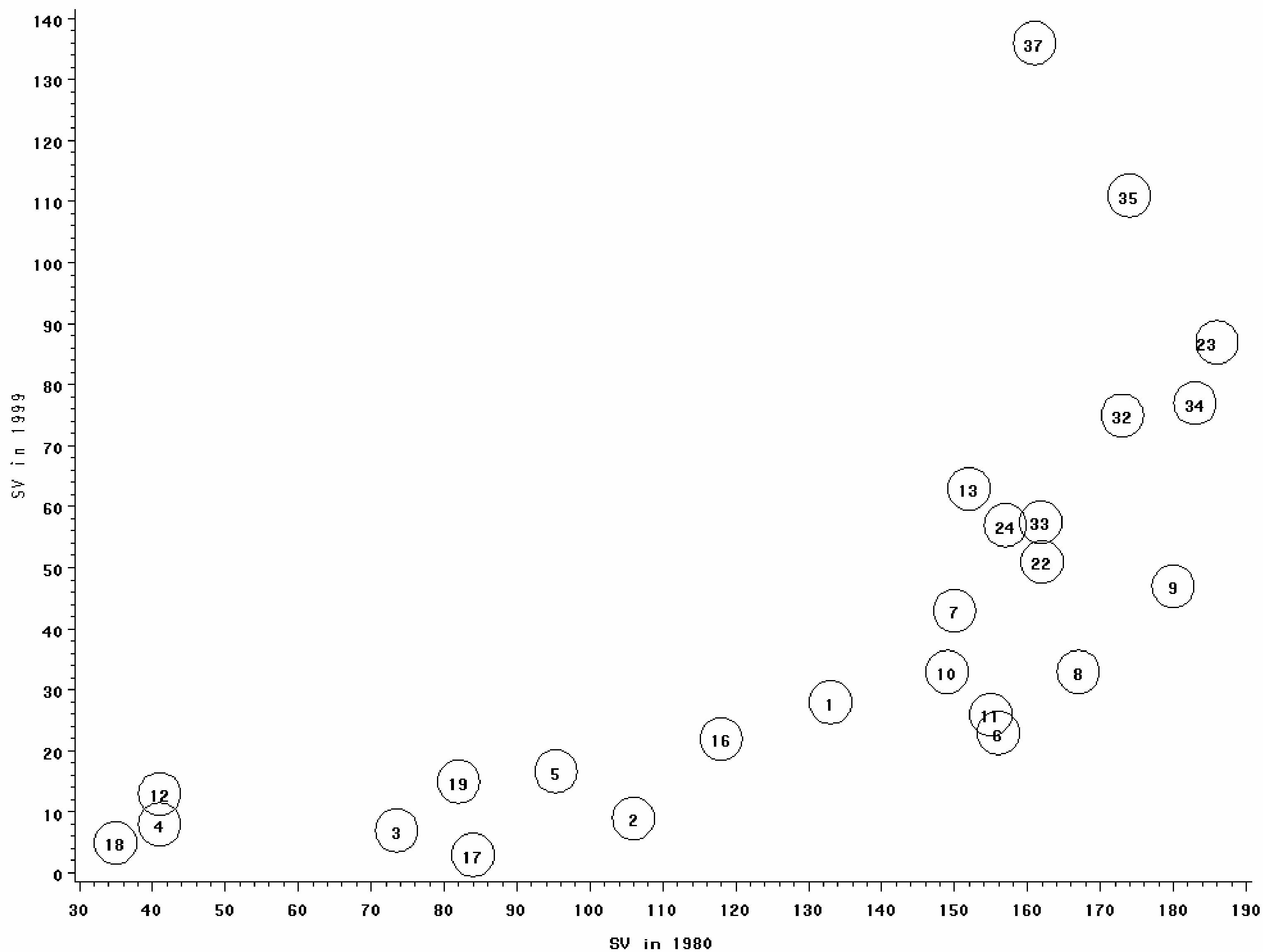


Figure 9
The Spatial Distribution of the Population in the South Coast Air Basin

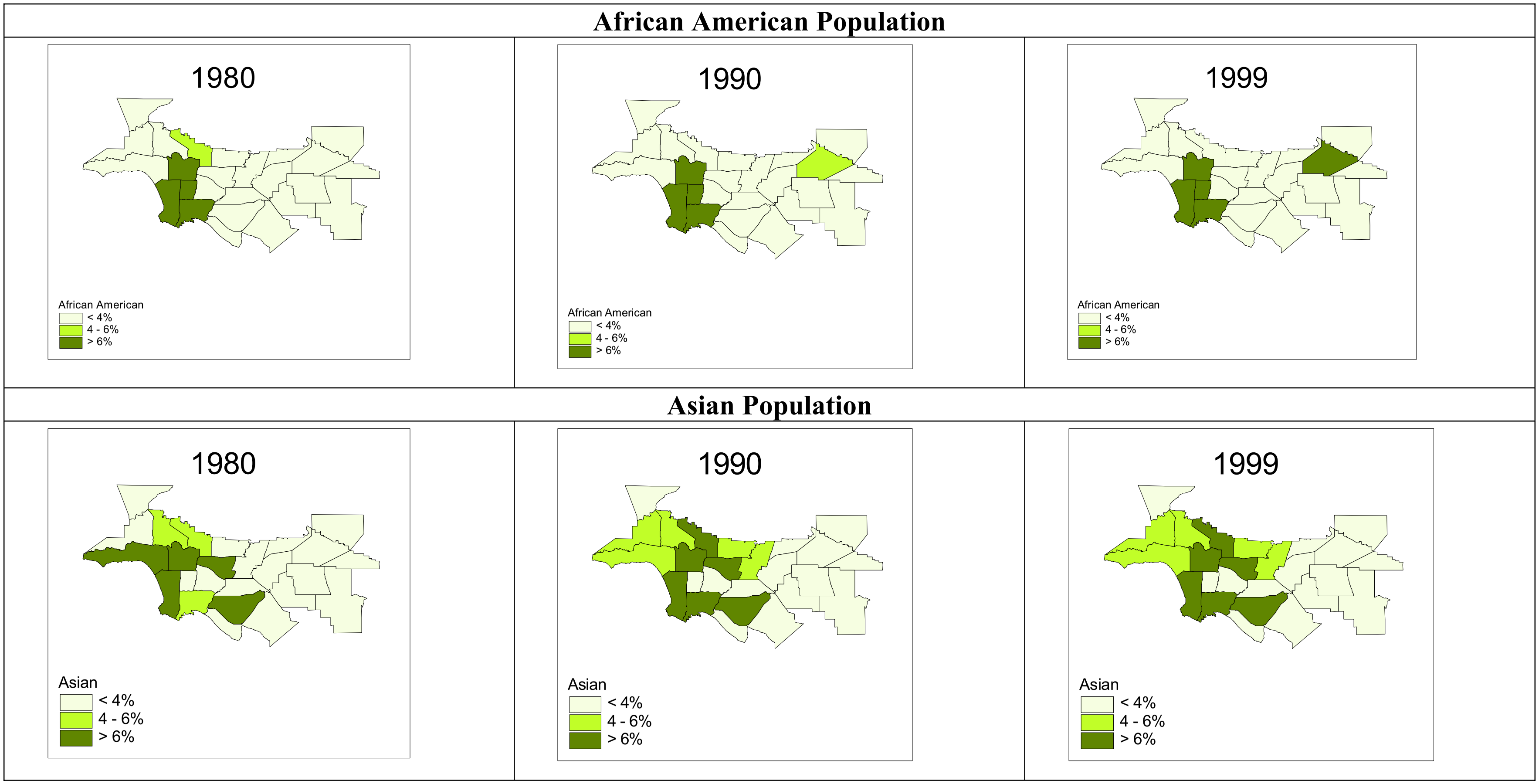
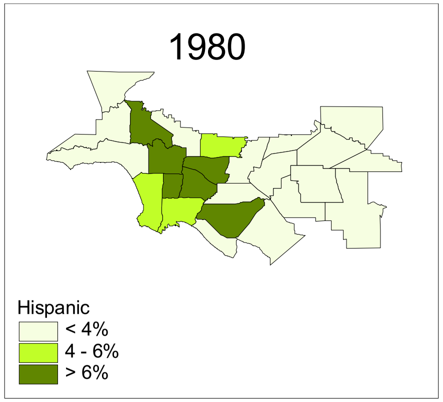
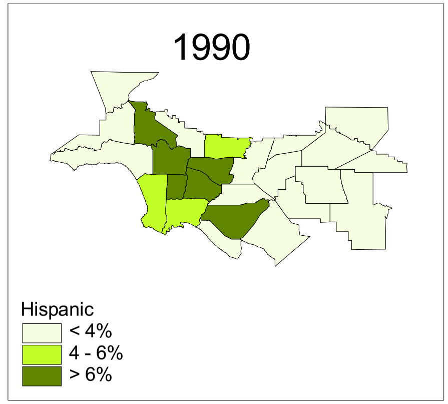
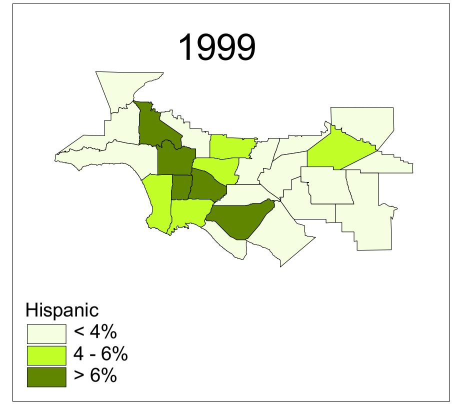


Figure 10
The Spatial Distribution of the Population in the South Coast Air Basin

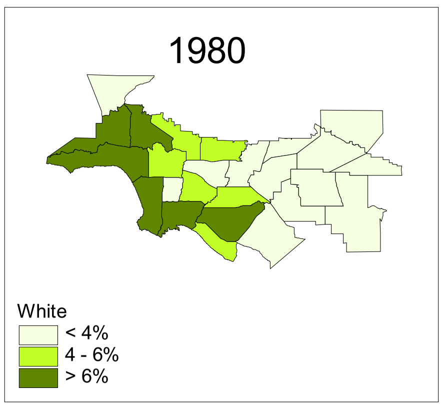
Hispanic Population

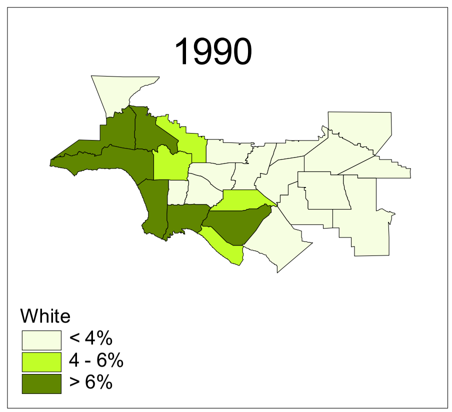






White Population





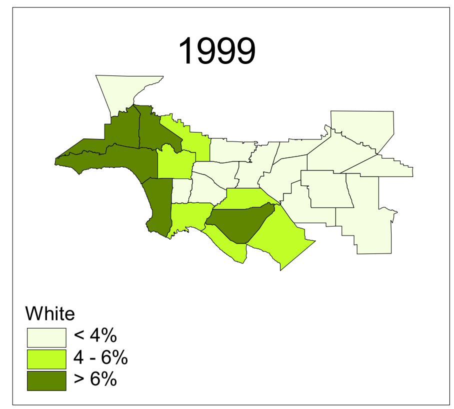
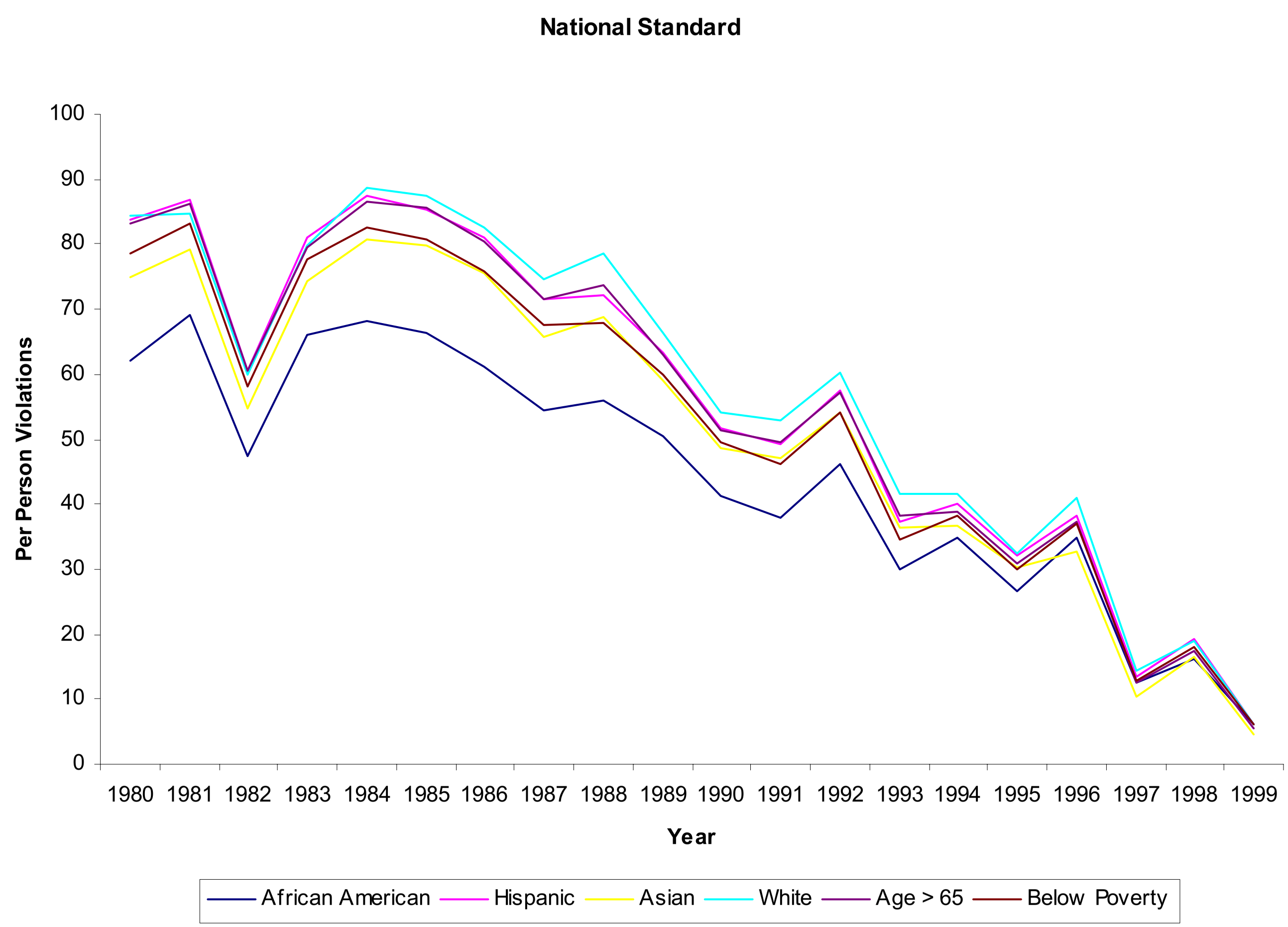
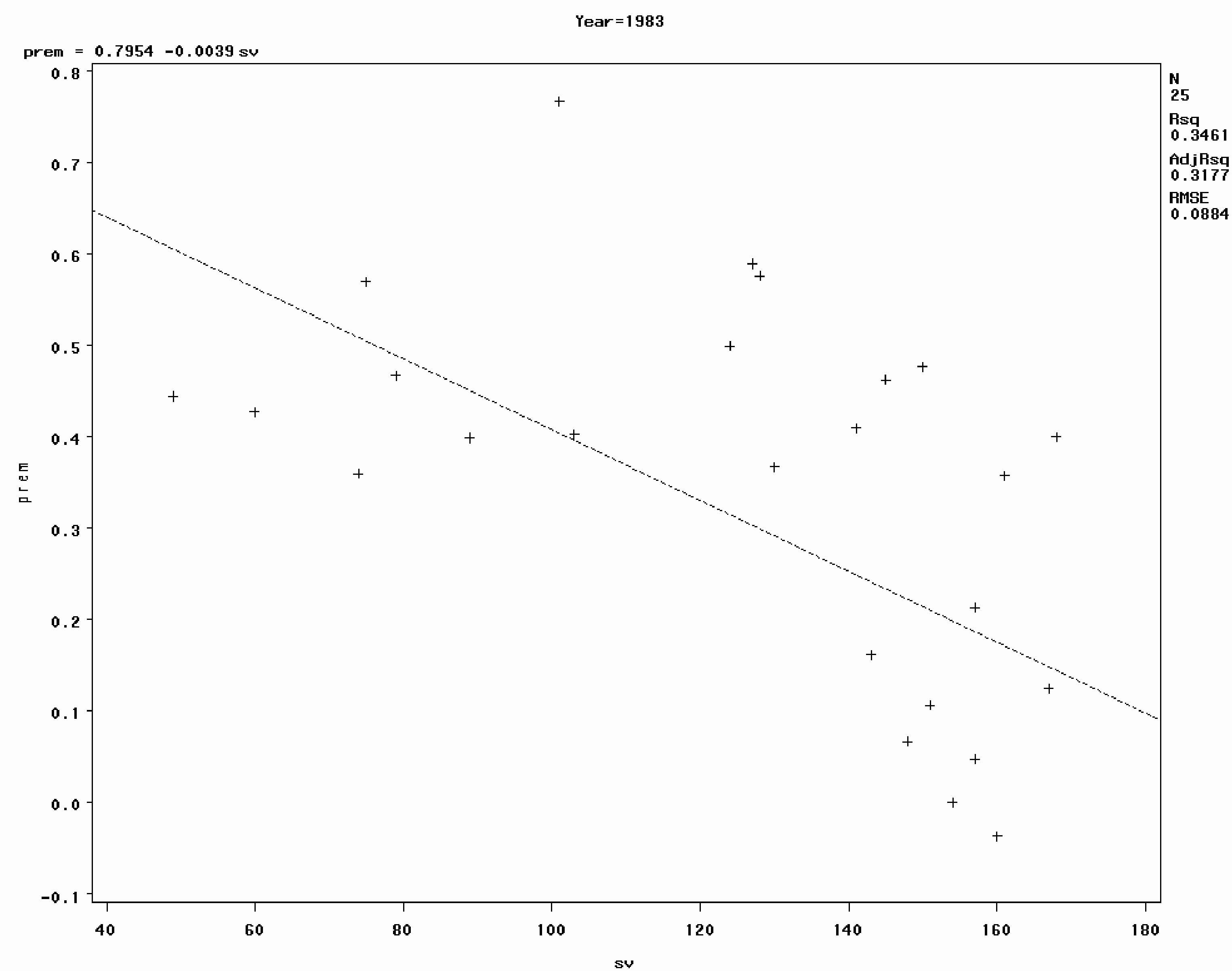


Figure 11
Average Ozone Exposure Over Time by Population Group





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Rsq
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AdjRsq
0.3177
RMSE
0.0884
prem
sv
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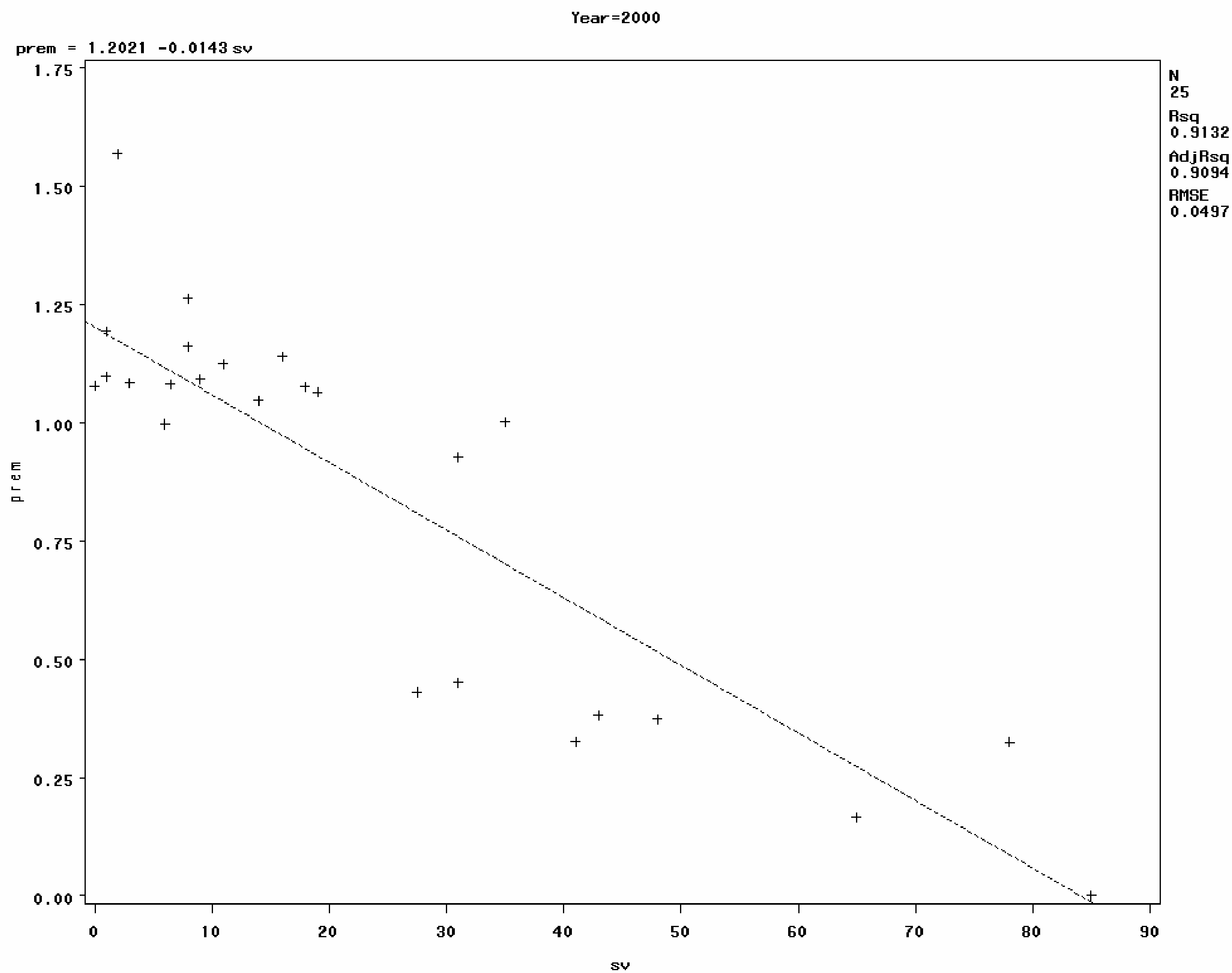
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
40
60
80
100
120
140
160
180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AdjRsq
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RMSE
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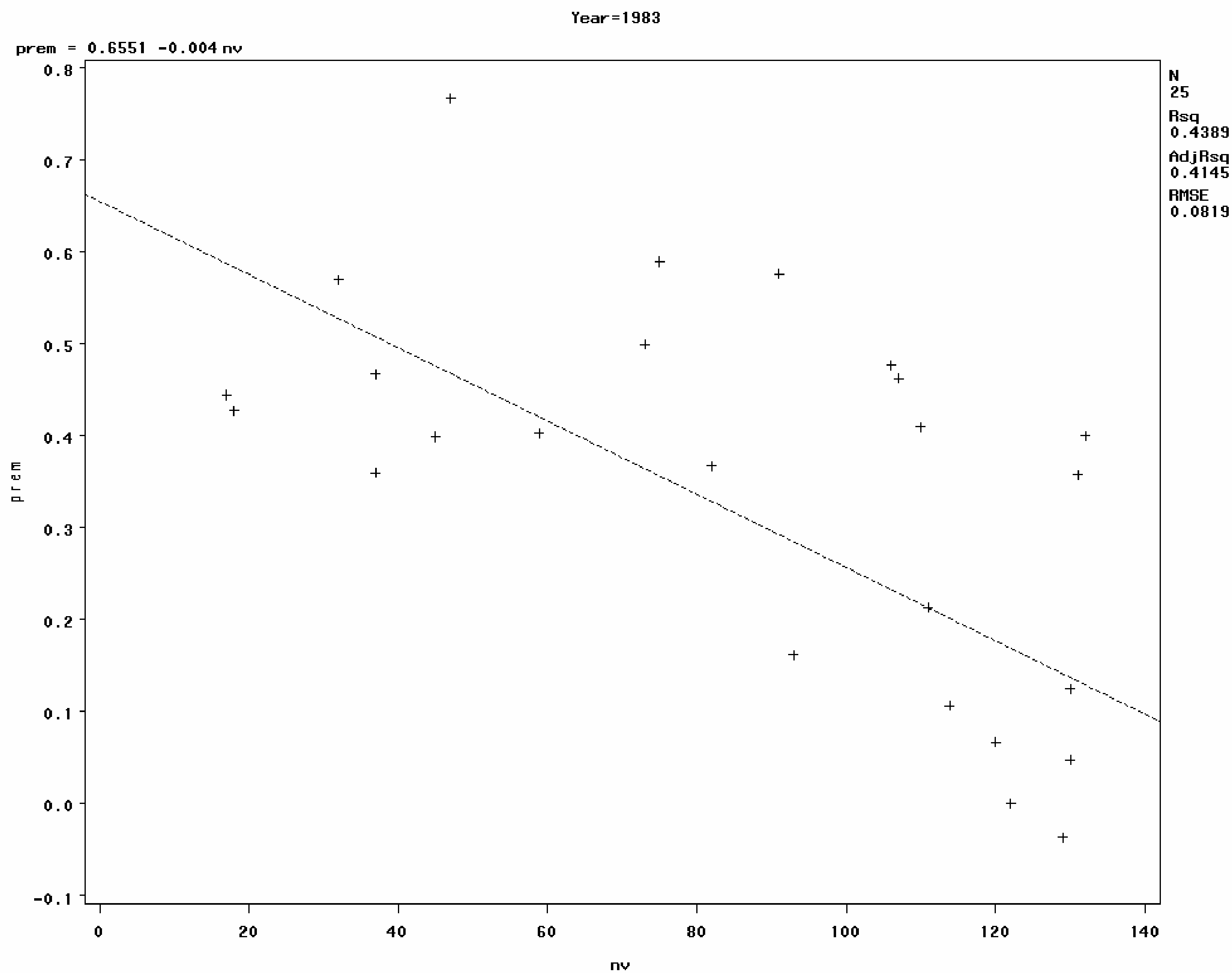
prem
sv
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
10
20
30
40
50
60
70
80
90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AdjRsq
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RMSE
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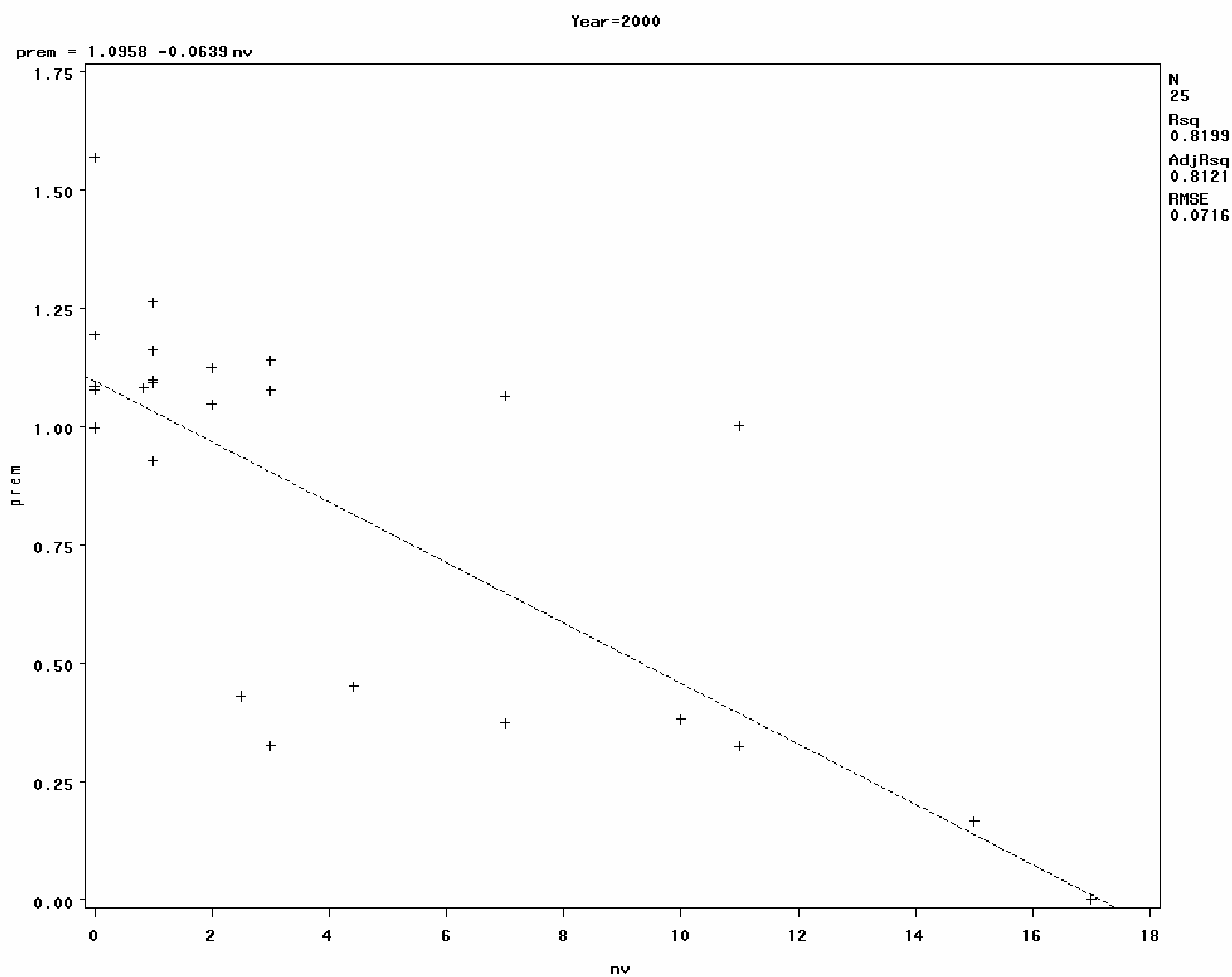
prem
nv
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
20
40
60
80
100
120
140



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1.50
1.25
1.00
0.75
0.50
0.25
0.00
prem
0
2
4
6
8
10
12
14
16
18
nv
N
25
Rsq
0.8199
AdjRsq
0.8121
RMSE
0.0716