A Tale of Two Counties: Childhood Lead Poisoning, Industrialization, and Abatement in New England*

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Abstract: We examine spatial variation in childhood lead poisoning within two industrial counties in New England: Worcester County, Massachusetts, and Providence County, Rhode Island. The findings suggest that lead exposure is linked to the differential patterns of urbanization and industrial activity and that a history of abatement can reduce lead exposure. Lead exposure in census tracts with minority neighborhoods varies in complex ways between the counties. We conclude that attention to local context forms an essential component of understanding how public health interventions will continue to affect the geography of childhood lead poisoning.

Keywords: childhood lead poisoning, industrial history, abatement, medical geography.

Lead poisoning is often cited as the nation's most preventable childhood public health problem (for example, ATSDR 1988). Children absorb lead more readily than adults and suffer longer-term health insults, which include reading problems, learning disabilities, and reductions in the intelligence quotient and in attention span (Centers for Disease Control 1991). Children with high blood lead levels require costly medical treatments, including chelation therapy. In the long term, the fiscal costs to society of childhood lead poisoning include increased medical expenses, lost productivity, and lost tax revenues.

The recent and dramatic reduction in blood lead levels in the United States has been hailed as a major public health success. Results from nationwide samples suggest a 75 percent decline in geometric mean blood lead levels between 1976 and 1991 (Brody et al. 1994; Mahaffey et al. 1982). Such gains to public health are linked to the reduction of lead in gasoline and food cans, the removal of lead from household paint, screening and abatement programs in some states, and the widespread publicity surrounding the problem of lead poisoning, particularly among children (Centers for Disease Control 1991).

Not all children or all places have been winners. Indeed, childhood lead poisoning remains a significant public health issue in New England, in part because of its industrial history and in part because children there and in the Middle Atlantic states are at a greater risk of lead poisoning than are children in other areas (Bailey et al. 1994).
Can significant geographic variation within an industrialized region shed light on the ways historical industrial processes are related to contemporary lead levels? Furthermore, can some of this geographic variation be traced to public health interventions (especially screening and abatement)? Because recent work in medical geography and environmental justice suggests that the outcome of public health interventions depends on local, neighborhood context (McLafferty and Tempalski 1995; Bullard 1994), we use the neighborhood as the unit of analysis here.

We have two goals in this paper. First, we examine spatial variations in lead poisoning in two industrial counties of New England (Worcester County, Massachusetts, and Providence County, Rhode Island). Second, we compare the correlates of lead exposure among the neighborhoods of a county with 19 years of abatement experience (Worcester County) to the correlates of lead exposure among the neighborhoods of a county with no abatement experience (Providence County). Although both counties are among the oldest industrial counties in the United States, they differ in the way in which their respective state governments have promulgated health policy. In fact, Massachusetts remains one of the most progressive states in the nation with respect to reducing lead in the environment. The comparison reveals important insights into the complex links among industrial heritage, urbanization, demography, and public health policy at a time when screening and abatement policies are being adopted in most other states.

Toward an Ecological Analysis of Lead Exposure, Industrialization, and Abatement

Much of our current understanding of spatial variations in lead poisoning derives from micro-level research, which focuses on the experiences of individuals and the condition of their current and immediate living space (for example, Amital, Brown, and Graef 1981; Farfel and Chisholm 1990). Such studies downplay the importance of neighborhood context (McLafferty 1992). Here we sketch out the case for neighborhood-scale analysis of lead exposure, particularly as the need to assess the impacts of public health interventions rises.

Lead is only a hazard when it is concentrated in the built environment by processes of industrialization and urbanization. Major point sources of lead exposure include industry (for example, lead smelting (Maizlish et al. 1980)), water distribution systems, and soil and dust near old highways (Hunter 1976). Because of their industrial histories, some areas also have a large stock of old homes containing lead-based paint (Chisholm, Mellits, and Quaskey 1985). Although the manufacture of lead-based paint for interior use was made illegal in 1978, some paint manufacturers stopped adding lead to paint in the 1950s. Ecological analyses consistently report statistical associations between neighborhood lead exposure and the age of the housing stock (Sargent et al. 1993, 1997).

A disproportionate number of the estimated 1.7 million children in the United States with blood lead levels in excess of the Centers for Disease Control (CDC) minimum threshold of concern (10 mcg/dL) are from poor and minority households (Lambhear, Weitzman, and Eberly 1996; Billick, Curran, and Shier 1970). Children living in inner-city neighborhoods have higher blood lead levels than children from suburban residences (Daniel et al. 1990). Children living in poverty are at high risk because of diet, reduced access to information and health care, and the increased likelihood that they live in old housing and in areas of general environmental degradation. Minority children are more likely to be living in poverty than nonminority children, and their poverty contributes to elevated lead levels (Mielke et al. 1984; Carter-Pokras et al.
Minority children's elevated blood lead levels have also been linked to biological and cultural factors, including the use of products (for example, medicines and cosmetics) that contain lead, consumption of food from lead-soldered cans, and, for immigrants, exposure to lead prior to arrival in the United States (Sprinkle 1995). Access to lead-free public housing may also explain why some minority groups have lower lead levels than others (Centers for Disease Control 1991).

Increasingly, spatial variations in lead exposure are influenced by the outcomes of public health interventions, which include screening programs and the abatement of lead-based paint from interior and exterior structures (Farr and Dolbeare 1996; Kraft and Scheberle 1995). According to the Residential Lead-Based Paint Hazard Reduction Act of 1992 (P.L. 102-550), abatement covers measures designed to permanently eliminate lead-based paint hazards. This can include the removal of lead-based paint and lead-contaminated dust, the permanent containment or encapsulation of lead-based paint, and the replacement of lead-painted surfaces or fixtures. Prior to the passage of the 1992 Act (Title X), the most common response to childhood lead poisoning was the complete removal of lead-based paint. Uneven compliance and the significant financial cost of full abatement have prompted broader strategies. A Housing and Urban Development (HUD) task force argued for extending protection beyond federally assisted housing by using HUD and the Environmental Protection Agency funds to target housing units that pose the greatest risk of lead exposure to children.

Because of income- and race-based residential segregation, neighborhoods are likely to differ in their rates of lead exposure. Two interconnected factors put minority neighborhoods at greater risk of lead exposure. First, abatement activities occur in the presence of functioning housing markets (Farr and Dolbeare 1996).

Because some minority neighborhoods are impoverished and subject to discrimination from money lenders (Massey, Gross, and Shibuya 1994; Bradbury, Case, and Dunham 1989), abatement may be less likely. Certainly, local capital shortages and disinvestment can reduce access to health care and even worsen health (Polednak 1996). Second, public health interventions may be less rigorously enforced in minority areas with little political clout (Bullard 1994).

However, our expectations about neighborhood-scale effects on lead poisoning are complicated by two counter arguments. First, lead exposure may be reduced via place-based strategies facilitated by the spatial concentration of certain groups, which can lead to the sharing of information about health risks, prevention, and screening (Dyck 1995). Second, screening activity and the dissemination of information about lead hazards may reflect local knowledge of where poisoned children have been located before. Because residential segregation persists in urban areas, we propose that minority neighborhoods may have lower rates of lead poisoning, ceteris paribus.

To summarize, working at the neighborhood scale enables us to investigate both individual and contextual factors. We argue that a neighborhood-level analysis of spatial variation in lead exposure has to be sensitive to established markers of environmental risk (housing age, industrial history), demography (race, ethnicity, nativity, poverty), and public health intervention (screening and abatement). Differences in the geography of lead poisoning between the two counties can be attributed to differences in environmental risk, in demography, and in the way abatement and screening modifies associations among environmental risk, demography, and lead exposure.
Industrialization and Urbanization in Worcester and Providence Counties

Worcester County and Providence County are industrially based regions each dominated by one urban center (Table 1). However, industrialization has given each county a distinctive urban structure (see Vance 1990, 338–61). Providence’s standing as a colonial port contributed to the capitalization of Samuel Slater’s famous textile mill in 1791, which spun off rapid industrialization along the Blackstone Valley, which joins Providence with Worcester. The relatively low-intensity labor process, which featured putting-out and family and child labor, combined with a general lack of suitable water power along the river to promote the growth of small, dispersed industrial villages (Kulik and Bonham 1978). Worcester County’s earliest industrial settlement also followed this “Providence” model, perhaps best seen along the Blackstone Valley which connects the two cities. Industrial development in Worcester County in the middle part of the nineteenth century featured purpose built industrial communities that provided permanent residence for workers (that is, the Walcham system (Vance 1990, 341)). As a result, large stocks of working class homes were constructed both in Worcester City and in the outlying areas of the county.

Although neither county was ever home to a lead smelter, some industries thought to pose point-source hazards have been present, notably paint manufacturing, boots and shoes, and jewelry (Centers for Disease Control 1991). Significant innovation in the textile industry as early as the 1820s prompted the development of the machine tool industry in Providence and later in Worcester. Boots and shoes, among other things, were produced in Worcester City, furniture in Gardner and Fitchburg, metal goods in Clinton, paper in Leominster, and wool in Dudley (Leblanc 1969).

<table>
<thead>
<tr>
<th>Characteristics of Study Sites, 1990</th>
<th>Providence County</th>
<th>Worcester County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>596,270</td>
<td>709,705</td>
</tr>
<tr>
<td>Kids under age 5 (%)</td>
<td>6.9</td>
<td>7.5</td>
</tr>
<tr>
<td>African American (%)</td>
<td>5.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Hispanic (%)</td>
<td>6.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Below poverty (%)</td>
<td>11.9</td>
<td>8.3</td>
</tr>
<tr>
<td>Housing units owner occupied (%)</td>
<td>48.8</td>
<td>57.1</td>
</tr>
<tr>
<td>Structures built 1950 or before (%)</td>
<td>40.0</td>
<td>37.4</td>
</tr>
</tbody>
</table>


Ten companies made paint in Providence in the early 1970s (U.S. Bureau of the Census 1972). The United States Guilla Percha Paint Company, for example, was established in 1906, built a factory that occupied an entire Providence central city block along Dudley Street, and featured (for a world market) a number of lead-based paints, including “Rice’s Crown German White Lead” (Rhode Island State Bureau of Information 1930, 224). This corner of Providence was also home to seven large companies that stored and distilled gasoline and oil products. These included the Pennsylvania Petroleum Products Company, which boasted the state’s first drive-in filling station in 1924. Additionally, Providence has a history of shipbuilding and repair dating to the early 1800s (Greene 1977) and a thriving jewelry industry (266 plants in 1910 (Kulik and Bonham 1978)) that specialized in the production of inexpensive consumer items and used local networks of suppliers. Finally, we have no evidence to suggest significant differences in aerosol lead or lead-containing dust close to highways in the two counties (see Earickson and Billick (1985) and Hunter (1976) for a discussion of these pathways).

With differing industrial histories, the counties may have been differently affected by boom-bust cycles and processes of deindustrialization in recent decades (Knight and Barff 1987). Indeed,
Providence County, with its greater contemporary concentration of apparel companies, has seen higher unemployment rates and higher incidences of poverty than Worcester County (Bradbury 1993). For example, the number of persons below poverty grew 4.3 percent in Providence County between 1980 and 1990, while declining 0.03 percent over the same period in Worcester County (U.S. Bureau of the Census 1990). The rate of poverty is higher in Providence than Worcester (Table 1). These cycles reverberated through the housing markets in both places, which have experienced periodic scarcity of affordable low-income units (Bordeleau 1989; Hanson and Pratt 1995).

Although both counties witnessed substantial increases in their foreign-born populations during the 1980s, more immigrants arrived in and were living in Providence by 1990. The Hispanic community grew 63 percent in Providence between 1980 and 1990 and 44 percent over the same period in Worcester. Puerto Ricans form an important component of the Hispanic community in both counties, although Worcester’s Puerto Ricans have lived on the mainland longer (Rivera 1993). Several Providence neighborhoods contain large populations of Dominicans, Central Americans, and South Americans. In addition, a number of Hmong families were settled in Worcester County during the 1980s and received refugee assistance from federal and state governments. Overall, Providence County has a larger minority population than Worcester County (Table 1).

Public Health Interventions and Lead Poisoning in Massachusetts and Rhode Island

Massachusetts established a statewide childhood lead screening program as early as 1973. Targeted screening was especially prevalent in communities with known high prevalence of lead poisoned children (for example, Worcester City (P. Hunter, Massachusetts Department of Public Health, pers. comm., 20 October 1997)). Although the state’s first abatement law applied to all residential property with children under age six present, in practice abatement was triggered only by the identification of an exposed child. In this case the child’s residence and the surrounding homes were tested for paint containing more than 0.5 percent lead by dry weight. Abatement strategies included dry scraping, permanently covering or replacing exposed and accessible mouthing surfaces, and the removal of any peeling paint. Denselying contractors were not licensed or regulated, dust containment was not required, and dust lead was not collected following abatement. In 1975 about 100,000 children were screened (about 20 percent of the eligible population) and 5,000 houses were abated.

Following the Benscome v. Kokoris court decision in Massachusetts in 1984, which awarded substantial damages to a poisoned child, homeowners in Massachusetts became liable for the exposure of children to lead. Preventative abatement was further boosted by the linking of liability insurance to a homeowners’ letter of compliance with the lead-safe mandate. By this time the designation of rental properties as federally assisted units (that is, Section 8 housing) was also tied to evidence of lead-safe interiors. In 1989 the screening rate was 50 percent of the eligible population and more than 10,000 abatements occurred. The abatement law was modified in that year to regulate dust containment and removal practices and to apply to all lead-painted surfaces up to a height of 1.52 meters (5 feet). A year later Massachusetts began requiring mandatory lead screening for children.

Rhode Island offers, by contrast, something of a control situation. Prior to 1992 the state had no lead paint housing regulations. Suits brought against property owners by plaintiffs were settled out of court, thus reducing the potential for preventa-

Data

Both states require that children under age five be regularly screened for blood lead. In addition, both states collect these data in a central office. In Rhode Island, screening samples are sent to the state laboratory, and the results are collated and maintained by the Rhode Island Childhood Lead Poisoning Prevention Program. Individual child records also contain information on street address, date of blood test, and result. The Massachusetts Childhood Lead Poisoning Prevention Program collects similar data on lead levels in Worcester County.

A total of 17,956 children aged 0–59 months were screened in Providence County between 1 May 1992 and 30 April 1993. In the few children for whom multiple lead tests were conducted during the year, we chose the first venous test or the last capillary test. We matched street address with 1990 U.S. census tracts, discarding records that could not be matched. We also deleted two tracts from the analysis because they contained few or no children under age five. We calculated screening rates for each of the remaining 136 census tracts by dividing the number of children with a lead test result in a tract by the census count of children under age five in that tract in 1990. Screening ranged from 16 percent to 100 percent.

A total of 9,757 children between the ages of 0 and 59 months were screened between 1 May 1992 and 30 April 1993 in Worcester County. Most samples were collected using capillary tests, although 25 percent of the sample was venous. We followed the same procedures and excluded tracts with few or no children in 1990. Among the remaining 136 tracts, screening rates ranged from 4 percent to 80 percent. Although these rates of screening are lower than in Providence, we have no reason to believe that the group of children screened in identical tracts in Providence and Worcester would be any different (that is, the underlying public health guidelines are very similar). If anything, markers of lead exposure would be biased upward in Worcester County.

We select two outcome measures of lead exposure for the descriptive portion of this research. First, we calculate the mean blood level for all screened children in each census tract. This is normally distributed across the tracts of each state. Second, we calculate the percentage of a tract's screened children under age five who have a blood lead level above 10 mcg/dL. This measure is of particular interest to clinicians who seek to identify neighborhoods with many at-risk children and health officials who wish to target resources accordingly.

Spatial and Demographic Variations in Lead Exposure

Both outcome measures reveal higher lead exposures in the neighborhoods of Providence County than in those of Worcester County. The arithmetic mean calculated from the mean blood level of each of the 136 Providence tracts (8.26 mcg/dL) is 49 percent higher than the corresponding arithmetic mean from the 156 tracts in Worcester County (Table 2). Similarly, a typical Providence tract has almost one-third (28.8 percent) of its children under age five exhibiting blood lead levels greater than 10 mcg/dL. In Worcester County this figure is 12.5 percent of screened children. The frequency distribution of mean blood lead levels for Providence tracts is bimodal, with 43 percent of tracts having 30 percent or more children above the Centers for Disease Control critical threshold. By contrast, neighborhoods in Worcester exhibit a slight positive skew, and only 5.8 percent of Worcester’s neighborhoods have 30 percent or more children with lead levels above 10 mcg/dL. t-tests confirm the statistical significance of Providence’s higher lead exposure levels.
Lead exposure exhibits different patterns of spatial variation in the two counties. Figures 1 and 2 classify the pooled distribution of percentage of children with blood lead levels exceeding 10μg/dL from both counties into quintiles and use the same choropleth convention to facilitate comparison. Spatial variation in lead exposure in Providence corresponds closely to the distribution of urban places there (Fig. 1). All tracts of central Providence, Pawtucket, and Woonsocket (except two) fall into the top quintile. By contrast, only four of Worcester County’s tracts fall into this top quintile, and none of these is located in Worcester City (Fig. 2). From south to north, neighborhoods in Webster, Westboro, and Fitchburg have the highest lead exposure values. Both Leominster and Dudley contain some tracts with lead exposure levels in the second quintile, as do more rural communities (for example, Bolton and Boylston). In comparison to Providence County, Worcester County exhibits more spatial variation in lead exposure.

We next explore the association between the income and minority characteristics of neighborhood populations and local lead exposure levels. We identify high-poverty tracts as those where the proportion of the population receiving public assistance falls in the top quartile for the county. We define tracts with African American neighborhoods as those where at least 10% African Americans reside. In the same way, we bifurcate tracts according to presence/absence of Puerto Rican, non–Puerto Rican Latino (that is, other Latino), and Asian neighborhoods. Sample size permits no further decomposition.

Poverty neighborhoods in both states have statistically higher percentages of children with blood lead levels above 10μg/dL compared to all other tracts. In fact, our measure of poverty is the only population characteristic significant in both states. In Providence County, tracts with African American, Puerto Rican, other Latino, and Asian neighborhoods all have statistically higher lead exposures when compared to respective reference groups. In Worcester County, the minority characteristics of tract populations do not appear to be associated with lead exposure.

### Multivariate Analysis of Childhood Lead Poisoning

#### Dependent Variable

For the balance of the paper we use the percentage of a tract’s screened children who have blood lead levels above 10μg/dL as the marker of lead exposure in each census tract. This ratio variable is normally distributed across the tracts of both counties. Knowledge of the prevalence of lead poisoning is particularly important in light of the calls for targeted abatement in areas of strategic need (Gellert et al. 1993). Below we introduce ten independent variables that predict between-tract variation in elevated lead levels and can be used to identify high-risk neighborhoods.

#### Independent Variables

Our predictor variables are drawn from 1990 census STF-3A files and historical sources summarized above. Five measures describe demographic conditions. The percentage of a tract’s population receiving public assistance (PUBLIC ASSIS-
TANCE) best captures socioeconomic standing. Other potential indicators of poverty (for example, per capita income and the percentage of female-headed households) do not perform as well in the multivariate model because of a nonnormal frequency distribution or collinearity with other variables.

Four major non-Anglo population groups live in the two counties: African Americans, Puerto Ricans, other Latinos, and Asians. The highly skewed distribution of these populations across census tracts mitigates against using simple counts or proportions. To indicate the presence or absence of one of these population groups in a neighborhood we thus follow the logic of Table 3 and define four dummy variables. AFRICAN AMERICAN NHHD takes the value one in tracts with at least 100 African Americans, and zero otherwise. PUERTO RICAN NHHD, NON-PR LATINO NHHD, and ASIAN NHHD are similarly defined. We justify separate consideration of Puerto Rican neighborhoods on account of the size of this group and the preferential access Puerto Ricans have (compared to other Latinos) to employment, housing, and public assistance. Further population disaggregation is not possible because of small sample sizes, although it is useful to note that Dominicans form the majority Latino population in Providence County and Hmong refugees form a significant part of the Asian population in Worcester County.

Four variables measure housing conditions and neighborhood structure. The percentage of housing units built before 1950 (PRE-1950 HOUSING) is consistently reported as being positively associated with lead exposure (Daniel et al. 1990). Abatement activity may reduce this association. Similarly, we anticipate that a mea-
Figure 2. Percentage of children with blood lead levels exceeding the Centers for Disease Control threshold: Census tracts of Worcester County.

The presence of vacant housing stock (PUB-1950 VACANT HOUSING) will have a positive coefficient, although its effect may be dampened in heavily abated areas. A housing tenure measure (OWNER OCCUPIED) will be negatively associated with lead exposure, again subject to the dampening influence of abatement. The number of bus commuters (BUS COMMUTERS) captures proximity to relatively high-density transport corridors which may have high levels of soil lead from previous traffic patterns (Mielke et al. 1984; Hunter 1976). It also provides an indication of lead exposure in working poor neighborhoods. The anticipated positive association may be reduced by the presence of public housing projects along many bus lines in both counties (public housing contains less lead paint than rental housing (Chisholm, Mellits, and Quaskey 1985)).

Finally, we include a surrogate dummy variable to assess the impact of the earliest wave of industrialization in both counties upon lead exposure. As discussed above, small-scale industrial villages sprang up along the Blackstone Valley in both counties in the early 1800s. We test the influence of this early "rural" industrialization by defining the dummy variable BLACKSTONE=1 for tracts outside Providence City and Worcester City that abutted the Blackstone River, 0 otherwise. We have no reason to link the industrial activities of such communities (typically textiles) to increased lead exposure. In fact, given the quite rural nature of the contemporary landscape we foresee a negative association between residence in the Blackstone and lead exposure. Particularly interesting is how abatement activities along the Massachusetts section of the Blackstone might modify this relationship.

Means and standard deviations for each variable (Table 4) confirm the earlier profile of the two counties (Table 1). Both counties have tracts with significant stocks of old housing, and Providence County has a higher incidence of poverty and rental housing compared to Worcester County.
Table 3
Average Lead Exposure for Tracts Grouped by Demographic Structure

<table>
<thead>
<tr>
<th>Demographic Structure</th>
<th>Providence County</th>
<th>Worcester County</th>
</tr>
</thead>
<tbody>
<tr>
<td>High poverty</td>
<td>41.5*</td>
<td>20.7*</td>
</tr>
<tr>
<td>All others</td>
<td>21.5</td>
<td>10.2</td>
</tr>
<tr>
<td>Probability t-test</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>African American</td>
<td>38.2*</td>
<td>11.9</td>
</tr>
<tr>
<td>All others</td>
<td>20.5</td>
<td>12.7</td>
</tr>
<tr>
<td>Probability t-test</td>
<td>.000</td>
<td>.024</td>
</tr>
<tr>
<td>Puerto Rican</td>
<td>41.2*</td>
<td>12.9</td>
</tr>
<tr>
<td>All others</td>
<td>22.8</td>
<td>12.3</td>
</tr>
<tr>
<td>Probability t-test</td>
<td>.000</td>
<td>.384</td>
</tr>
<tr>
<td>Non-PR Latino</td>
<td>36.4*</td>
<td>13.5</td>
</tr>
<tr>
<td>All others</td>
<td>20.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Probability t-test</td>
<td>.000</td>
<td>.194</td>
</tr>
<tr>
<td>Asian</td>
<td>41.2*</td>
<td>12.1</td>
</tr>
<tr>
<td>All others</td>
<td>24.6</td>
<td>12.6</td>
</tr>
<tr>
<td>Probability t-test</td>
<td>.000</td>
<td>.357</td>
</tr>
</tbody>
</table>

Source: Authors' calculations from public health data.
* Significant at 0.01.

While three times as many Providence tracts are home to non-Puerto Rican Latino clusters and almost twice as many Providence tracts have African American neighborhoods, Worcester County has more tracts with Puerto Rican neighborhoods. The distribution of Asian neighborhoods is similar in the two counties. Finally, Providence County has more bus riders (consistent with the spatial and demographic structure) and more vacant properties (consistent with the recent history of economic change).

Model Specification

The above variables meet appropriate distributional assumptions for Least Squares regression, and none correlates with another above 0.69. However, ecological analyses involve assumptions about heteroskedasticity and spatial autocorrelation, and we use common practices to assess and correct for these concerns. Tables 5 and 6 report Weighted Least Squares (WLS) estimates of lead exposure for the tracts of Providence and Worcester counties, respectively.

We also have reason to believe that, at the neighborhood level of analysis, the underlying risk factors may exhibit a degree of spatial concentration (for example, clustering of low-income people or old housing). Further, the tract scale of analysis may miss other scales of variation present in these data. Residuals may thus retain vestiges of spatial structuring—that is, spatial autocorrelation. We evaluate this by

Table 4
Descriptive Statistics for Independent Variables

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Providence County</th>
<th>Worcester County</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>PUBLIC ASSISTANCE</td>
<td>10.12</td>
<td>8.34</td>
</tr>
<tr>
<td>AFRICAN AMERICAN NHD</td>
<td>0.35</td>
<td>0.45</td>
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<td>PUERTO RICAN NHD</td>
<td>0.23</td>
<td>0.42</td>
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<tr>
<td>NON-PR LATINO NHD</td>
<td>0.53</td>
<td>0.50</td>
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<tr>
<td>ASIAN NHD</td>
<td>0.36</td>
<td>0.44</td>
</tr>
<tr>
<td>PRE-1900 HOUSING</td>
<td>51.12</td>
<td>22.87</td>
</tr>
<tr>
<td>PRE-1900 VACANT HOUSING</td>
<td>76.66</td>
<td>71.92</td>
</tr>
<tr>
<td>OWNER OCCUPIED</td>
<td>35.79</td>
<td>34.65</td>
</tr>
<tr>
<td>BUS COMMUTERS</td>
<td>59.61</td>
<td>54.80</td>
</tr>
<tr>
<td>BLACKSTONE</td>
<td>0.84</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Note: See text for definitions of variables.
mapping residuals from the WLS regressions and discuss these below.

**Model Parameters and Residuals**

WLS estimates (Tables 5 and 6) suggest county-specific patterns of variation in lead exposure. Lead exposure in Providence County is significantly and positively associated with receipt of public assistance, old housing stock, vacant old housing, and the number of bus riders. Lead exposure is negatively and significantly associated with home ownership rates and location along the Blackstone River. Lead exposure in Worcester County is significantly and positively associated with receipt of public assistance, presence of an Asian neighborhood, old housing stock, and vacant old housing. Lead exposure is negatively and significantly associated with the presence of a Puerto Rican neighborhood, the presence of other Latino clusters, the number of bus commuters, and location along the Blackstone Canal.

Each model accounts for a large and significant part of the overall variation in lead exposure, but examination of residuals suggests the presence of further systematic variation in these data. Three tracts in Providence County are substantially underpredicted—that is, the observed percentage of poisoned children is 10 percent or more than the predicted value. One adjoins the former location of the Gutta Percha paint factory, one straddles a ship-

Heteroskedasticity results from the violation of the homoskedasticity assumption of no relation between variation in the error term and one or more of the independent variables. Failure to include appropriate control variables and suspected endogeneity of the process being modeled can contribute to such violations. The Breusch and Pagan Lagrange Multiplier tests finds evidence of heteroskedasticity in Ordinary Least Squares formulations. Because we anticipate some endogeneity among public health interventions (screening activity and abatement), housing market conditions, and lead exposure, we correct for this problem by weighting estimates with the best available measure of intervention, the screening rate.

building area near Norwood, and one is located in the former industrial center of North Providence. Overpredicted tracts are more randomly distributed but are especially prevalent in the central city areas of Pawtucket and Woonsocket. Most underpredicted tracts in Worcester County are located in industrial towns established in the mid-1800s (for example, Webster, Dudley, Fitchburg, and Leominster).

**Discussion**

The results confirm that lead poisoning is more prevalent in areas with a history of industrial development. Mean blood lead levels for the tracts of both counties exceeded the NHANES III (Third National Health and Nutrition Examination Survey) national geometric mean (2.8 μg/dL), by a factor of two in Worcester County and almost three in Providence County. If these two counties are typical of broader conditions in the region, as we believe they are, then childhood lead poisoning is indeed a continuing public health concern in New England. As is the case nationally, poverty and old (vacant) housing emerge as common risk factors in both counties. However, our results—particularly for Worcester County—suggest nuances to the contemporary geography of lead poisoning that we link to intercounty differences in demography, public health intervention, and patterns of industrialization. First, industrialization in Worcester County took place in dispersed industrial communities, many of which contain high rates of lead poisoning today. The primary exception to the industry-lead exposure link, Worcester City, has had a particularly strong commitment to lead prevention and is considered to have some of the highest rates of abatement in the county (P. Hunter, Massachusetts Department of Public Health, pers. comm., 20 October 1997).

Second, by 1992-93 Worcester County had had almost 20 years of experience with

*For example, Worcester City employs five full-time lead inspectors.*
lead abatement and screening programs. Differences in parameter estimates for Worcester and Providence counties are consistent with our expectation that public health interventions reduce overall levels of lead exposure (Table 2). As we discuss below, abatement may also affect the geography of lead poisoning in minority neighborhoods. In particular, Providence neighborhoods with high rates of public
assistance, high proportions of rental housing, and high mass transit usage have higher proportions of poisoned children than similar neighborhoods in Worcester County.\(^3\) Taken together, and notwithstanding the additional caveats below, these findings suggest the positive impact intervention has had over the long run. Of course, much remains to be done, as evidenced by the above-national-average lead levels that persist in both counties.

The relationship between race/ethnicity/nativity and lead exposure varies in complex ways between counties. Once environmental and demographic factors have been considered, we find no significant relationship between the presence of an African American neighborhood and elevated lead in either county. Although individual-level analyses reveal that African American children have higher blood lead levels than white children, the neighborhood-scale analysis suggests that abatement programs in public housing have reduced lead exposure in African American neighborhoods. Puerto Ricans also enjoy eligibility for public housing in both states, and we see insignificant (Providence) and negative and significant (Worcester) associations between Puerto Rican neighborhoods and lead exposure. Demographically, Puerto Ricans resident in Worcester County have spent longer in the United States, are less likely to be in poverty, and are clustered in Worcester City, which has modest rates of lead exposure.

Non-Puerto Rican Latino tracts are likewise significantly less likely to have elevated lead exposure in Worcester County, once we control for other factors, but are insignificantly related to lead exposure in Providence County. We believe that the combination of demographics (Providence's population is more recently arrived, and more impoverished) and public health interventions in Worcester County explains this intercounty difference. Interestingly, another state program, refugee resettlement, may be implicated in the positive and significant association between Asian tracts and lead exposure in Worcester County. Because the composition of the Asian populations of the two counties is different, we cannot dismiss explanations that link increased lead levels in Worcester to the exposure of (Hmong) children to lead in their former places of residence or to culturally specific practices. Health practices differ, as do the ways information about health risks is processed by different communities (Dyck 1995). However, at least some of Worcester County's Asian community were part of refugee resettlement programs that clustered their clients in low-rent, central areas of small industrial communities like Webster and Fitchburg. Clearly, more needs to be done to better understand the complex links between presence of a minority community and health outcomes.

Summary and Conclusions

This ecological analysis reports significant differences in the level and correlates of lead exposure among the children of two adjoining industrial counties in New England. The analysis focuses on explanations based on differences in industrialization, demographics, and experience with public health interventions. At least some of the variation we report may also arise because of differences in the impact of a recession that was felt more heavily in Providence than in Worcester just prior to the study and to the emphasis Rhode Island officials were placing upon the targeting and screening of at-risk children at the time of data collection. Certainly, blood lead levels have come down sharply in Rhode Island between 1992–93 (the time of our study) and 1994–95 (Mayes et al. 1995), lending some support to the last hypothesis. The substantial gap between lead levels in the two counties, however, suggests that broader processes are operating.

\(^3\) Parameters have lower elasticities (PUBLIC ASSISTANCE) or are insignificant (RENTAL HOUSING) in Worcester, or change signs (WORKING POOR).
We conclude with three main findings. First, the pattern of industrialization informs our understanding of geographic differences in lead poisoning more elegantly than, for example, the traditional surrogate of population density. Second, public health interventions, including abatement, seem to reduce lead levels, perhaps most dramatically in tracts with Latino neighborhoods. Our results align with other recent findings that fail to find environmental racism at work in public policy (Bowen et al. 1995) and lend tentative support to the counter proposition that public health officials use local knowledge to target resources to areas of persistent lead hazard. Third, we call for careful analysis of the complex relations between race, ethnicity, nativity and health outcomes (Carter-Pokras et al. 1990). Our findings suggest that the neighborhood plays an important mediating role, over and above that suggested by explanations based on individual-level research designs. Additional research, some of it ethnographic, could usefully focus on the importance of neighborhood-scale processes.

Finally, given the likely importance of targeted abatement in continued efforts to reduce the nation's stock of lead, we feel more research on the neighborhood consequences of such policies, designed in an explicitly longitudinal manner, would be helpful (Diermayer, Hedinburg, and Fleming 1994). For example, what are the broader housing market implications of sustained abatement? Although rent levels did not differ significantly between the two study counties (U.S. Bureau of the Census 1992), many towns in Worcester County did have long waiting periods for Section 8 (federally assisted) housing (the waiting list is 2–3 years in Fitchburg, 3–4 years in Gardner, and closed in Worcester City (HOME Coalition 1995)). We close with a call for situating health and policy analyses in their local, urban, and cultural context.

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