CHICAGO JOURNALS

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Author(s): Jeffrey D. Morenoff
Source: *American Journal of Sociology*, Vol. 108, No. 5 (March 2003), pp. 976-1017
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/10.1086/374405
Accessed: 19/02/2014 00:30

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# Neighborhood Mechanisms and the Spatial Dynamics of Birth Weight[1]

Jeffrey D. Morenoff
*University of Michigan*

This study addresses two questions about why neighborhood contexts matter for individuals via a multilevel, spatial analysis of birth weight for 101,662 live births within 342 Chicago neighborhoods. First, what are the mechanisms through which neighborhood structural composition is related to health? The results show that mechanisms related to stress and adaptation (violent crime, reciprocal exchange and participation in local voluntary associations) are the most robust neighborhood-level predictors of birth weight. Second, are contextual influences on health limited to the immediate neighborhood or do they extend to a wider geographic context? The results show that contextual effects on birth weight extend to the social environment beyond the immediate neighborhood, even after adjusting for potentially confounding covariates. These findings suggest that the theoretical understanding and empirical estimation of "neighborhood effects" on health are bolstered by collecting data on more causally proximate social processes and by taking into account spatial interdependencies among neighborhoods.

A long history of research shows that health status (e.g., mortality, morbidity, birth weight) and other aspects of individual well-being and behavior vary strongly across neighborhood ecological settings (Robert 1999; Yen and Syme 1999). Most of this research has been based on aggregate-level relationships between the social and economic characteristics of local community contexts and health-related outcomes. More recently, so-called neighborhood effects studies have shown that these associations persist

[1] I thank Jim House, Robert J. Sampson, and Stephen Raudenbush for their comments on earlier drafts. I gratefully acknowledge support from the National Institute of Child and Human Development (NICHD) through a core support grant (P30-HD10003) to the Population Studies Center, University of Michigan. Direct all correspondence to Jeffrey D. Morenoff, Department of Sociology, University of Michigan, 1225 South University Avenue, Ann Arbor, Michigan 48109. E-mail: morenoff@umich.edu

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0002-9602/2003/10805-0002$10.00



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even after controlling for individual-level socioeconomic status (Diez-Roux 2001; Ellen, Mijanovich, and Dillman 2001; Pickett and Pearl 2001).

Although the cumulative weight of this evidence is impressive, it offers a limited perspective on how the local social environment is related to health. First, previous studies limit their analysis mainly to the association between socioeconomic characteristics of neighborhood environments and health, but they do not consider more proximate contextual mechanisms that might explain why the local socioeconomic environment may be related to health. Second, previous research on neighborhoods and health focuses exclusively on the "internal" properties of neighborhoods but does not consider the possible influences that the wider social environment surrounding a given neighborhood may have on the health of its residents.

Focusing on the phenomenon of low birth weight, this article addresses each of these limitations by showing that the theoretical understanding and empirical estimation of neighborhood effects can be improved through better specification and measurement of proximate contextual factors and broader spatial relationships. Two classes of neighborhood mechanisms are considered: social conditions that foster stress, such as high rates of violent crime; and the informal resources that are generated by social relations and social engagement among neighbors. This article also expands the neighborhood-effects paradigm by considering not only the local neighborhood but also the wider spatial context within which that neighborhood is embedded, and how both the local and more distal social contexts are related to health. Methodologically, this is accomplished by using a combination of multilevel hierarchical models and spatial regression models of birth weight.

Birth weight is an important early-life health outcome that is especially well-suited for studying the effects of neighborhood context because it is sensitive to short-term influences on maternal health during the length of pregnancy. A research design in which characteristics of the neighborhood environment are measured very close in time to the health outcome is more sustainable for birth weight than it is for many other health outcomes. Low birth weight is also an important outcome because it presents considerable risks for children's health and development. For example, Conley and Bennet (2000) find that children born at low birth weights are much less likely to complete high school by age 19, even after controlling for family socioeconomic status and other demographic characteristics. Other studies have linked low birth weight to developmental setbacks in childhood such as illness, subnormal growth, neurological impairment, intellectual and cognitive delays, behavioral problems, the early onset of antisocial behavior (Boardman et al. 2002; Donker et al. 1997; Hack, Flannery, and Schluchter 2002; Hack, Taylor, and Klein 1994; McCormick, Brooks-Gunn, and Workman-Daniels 1992); and also to



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health problems later in life, such as coronary heart disease in adulthood (Barker 1995). Low birth weight could thus be a precursor to health inequalities in childhood and beyond.

## PREVIOUS RESEARCH ON NEIGHBORHOODS AND BIRTH WEIGHT

Current interest in neighborhood effects throughout the social sciences is reflected in a rapid escalation in the number of neighborhood studies published in social science journals during the mid-1990s (Sampson, Morenoff, and Gannon-Rowley 2002). The term "neighborhood effects" generally refers to the study of how local social context influences the health and well being of individuals in a way that is not reducible to the properties of the individuals themselves. One of the hallmarks of this research is its attention to the potentially confounding influences of individual-level attributes in making neighborhood-level inferences, either through the use of multilevel research designs and statistical methods or through randomized experimental designs. Most of this research has focused on social and behavioral outcomes, including child cognitive and behavioral development, school dropout, educational attainment, crime and delinquency, substance use, sexual activity, contraceptive use, childbearing, income, and labor force participation (Gephart 1997; Leventhal and Brooks-Gunn 2000; Sampson et al. 2002).

Until very recently, health had been relatively neglected in this literature, but multilevel studies are now becoming increasingly popular in health research. One review (Pickett and Pearl 2001) identified 25 multilevel studies of local area effects on health, of which 23 reported at least one statistically significant association between health and local social context. This research covers a wide range of health outcomes, including mortality (e.g., all-cause, heart disease, cancer), infant and child health (e.g., birth weight, infant mortality, child illness), adult physical health status (e.g., self-rated health, heart disease, hypertension, chronic conditions, height), mental health (e.g., depression, anxiety, mental disorders), and health behaviors (e.g., smoking, diet and nutrition). This set of studies has garnered wide attention in social epidemiology, as evidenced by the publication of at least four reviews of this literature in the past several years (Diez-Roux 2001; Ellen et al. 2001; Pickett and Pearl 2001; Robert 1999).

A small number of multilevel studies have focused on the association between local area characteristics and birth weight, including city-specific studies of Chicago (Buka et al. 2002; Roberts 1997), Baltimore (O'Campo, Xue, and Wang 1997), Los Angeles (Pearl, Braveman, and Abrams 2001), and New York (Rauh, Andrews, and Garfinkel 2001), one national study



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of the United States (Gorman 1999), and one national study of the United Kingdom (Sloggett and Joshi 1994). All of these studies report significant associations between at least one measure of local area socioeconomic composition and birth weight, after controlling for an individual-level measure of socioeconomic status. However, this evidence is hardly conclusive.

Most of this research focuses exclusively on socioeconomic characteristics of neighborhoods and does not consider mechanisms that might explain why more disadvantaged neighborhoods are associated with lower birth weights. Some studies consider other measures of neighborhood composition drawn from the census, such as racial/ethnic composition (Roberts 1997), immigrant composition (Gorman 1999), and age structure (Roberts 1997). Thus far, very few studies have used non–census-based neighborhood measures of community context (Buka et al. 2002; O'Campo et al. 1997), and none have advanced a coherent theoretical framework that considers the relationships among various neighborhood characteristics and, in turn, how they may be related to birth weight.

As a result, this group of studies has shed very little light on the question of why low birth weight is more common in more disadvantaged neighborhoods. Moreover, much of the evidence they present linking neighborhood disadvantage to low birth weight is questionable on methodological grounds because the findings are based on conventional regression methods that are inappropriate for multilevel data (for two exceptions, see Buka et al. [2002] and Rauh et al. [2001]). Finally, all of these prior studies of birth weight confine their purview to the "internal" properties of local areas and neglect potential effects of social context beyond the geographical boundaries of the neighborhood.

## WHAT MAKES A PLACE (UN)HEALTHY?

Recent developments in the sociology of urban communities provide some guidance for better understanding how neighborhoods come to affect health. First, the sociological literature on neighborhood effects has taken a "process turn" in recent years and has begun to focus more on the mechanisms that explain *why* neighborhoods matter (Sampson et al. 2002). Much of this literature has been driven by interest in social capital, which is generally defined as a resource that is realized through social relationships (Kawachi and Berkman 2000; Portes 1998; Sampson, Morenoff, and Earls 1999). To build on these advances in neighborhood research and bring them to bear on the study of health, I present a conceptual framework for thinking about the relationship between neighborhoods and health, which is outlined in figure 1. Consistent with a stress and adap-



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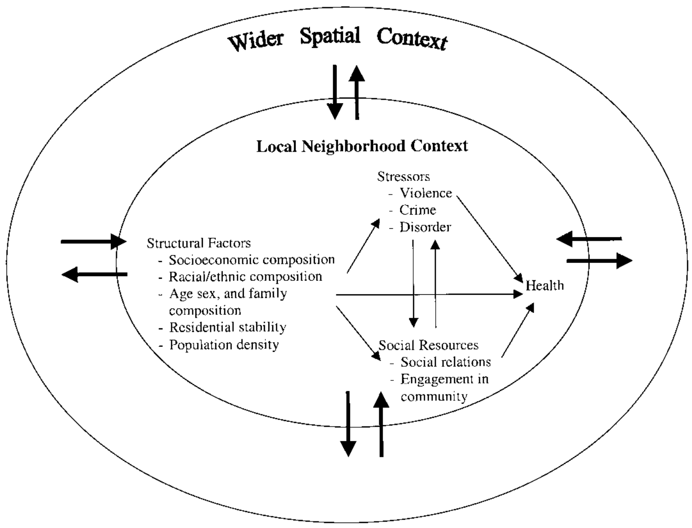


FIG. 1.—Conceptual framework for neighborhood effects on health

tation perspective on how social environments come to affect health (House 2002; Lin and Ensel 1989), this framework highlights the importance of stressful neighborhood conditions that may deleteriously affect the health of mothers and children, and it also highlights the availability of resources from social relationships and collective engagement in community life that may counteract or buffer the impact of contextual stressors on health. Not all possible pathways to health are depicted in figure 1, nor does this conceptual framework serve as an exact empirical model for the analyses that follow. Rather, it is a heuristic device for delineating key dimensions of neighborhood environments and pathways through which they may be related to health.

A second important development has been the increasing popularity of spatial perspectives in social science research (Goodchild et al. 2000). As noted earlier, the conventional approach to studying neighborhood effects focuses solely on the internal properties of neighborhoods, ignoring any influences on health that may emanate from the wider social environment, and it assumes that for analytical purposes neighborhoods can be treated as independent entities. This tendency to abstract the idea of "neighborhood" from its broader spatial context runs counter to the long theoretical tradition in urban sociology, dating back to the Chicago School, that views neighborhoods as spatially interrelated parts of a broader social system that Park and Burgess and their colleagues characterized as a "moving equilibrium of social order" (Park, Burgess, and McKenzie 1967, p. 54).



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Thus far, only a few studies have explored the wider spatial context of neighborhood effects (e.g., Baller, Anselin, and Messner 2001; Morenoff and Sampson 1997; Morenoff, Sampson, and Raudenbush 2001; Sampson et al. 1999; Smith, Frazee, and Davison 2000), and most of these are ecological-level studies that do not control for characteristics of individuals. Before expounding a broader spatial perspective on neighborhood environments and health, it is necessary to elaborate the key theoretical dimensions of neighborhood environments outlined in figure 1.

### Structural Characteristics

Structural characteristics refer to properties of a neighborhood's population or physical infrastructure that are typically measured as aggregations of individual-level attributes. The most commonly analyzed structural factors in previous research are indicators of socioeconomic composition. The geographical concentration of socioeconomic disadvantage is tied to multiple health risks such as dilapidated and overcrowded housing, poor recreational facilities, fewer stocks of nutritional food in local stores, inadequate municipal services and amenities, and exposure to environmental toxins (Sooman, Macintyre, and Anderson 1993; Sooman and Macintyre 1995; Wallace 1990; Williams and Collins 2001). However, the concentration of poor people in a neighborhood does not necessarily make it an unhealthy environment. For example, some disadvantaged neighborhoods may produce social conditions that are more conducive to stress, while others may not. Likewise, some poor neighborhoods may foster informal social resources that offset some of the deleterious effects of stressful conditions and material deprivation.

Another key aspect of neighborhood structure is racial/ethnic composition. Residential segregation imposes multiple health risks on residents of predominantly minority areas, many of which overlap with the health risks associated with concentrated disadvantage. However, segregation imposes an additional psychological toll in the form of racial discrimination, which a growing body of evidence indicates can have adverse consequences for physical and mental health (Jackson et al. 1996; Williams and Collins 2001). On the other hand, some aspects of neighborhood racial/ethnic homogeneity may be health promoting. For example, in a national multilevel study, Gorman (1999) finds that the county-level percentage of foreign-born residents is a protective factor against the risk of low birth weight. There is also some evidence that birth weights to Mexican women are higher in predominantly Mexican immigrant neighborhoods (Morenoff 2000), perhaps because, as some scholars have argued, Mexican culture reinforces healthy behaviors and promotes group resources such as social



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support from family and friends (Balcazar, Aoyama, and Cai 1991; Scribner 1996).

### Stressful Social Conditions

One of the main reasons that lower SES neighborhoods may be unhealthy places to live is that they expose residents to stressful conditions, such as violent crime. Repeated exposure to stress fosters a condition known as allostatic load, which refers to the physiological costs of chronic overactivity or underactivity of systems within the body (e.g., the hypothalamic-pituitary-adrenal axis or the autonomic nervous system) that fluctuate to meet demands of repeated exposure to environmental stressors (McEwen 1998). Geronimus (1992) argues that prolonged exposure to high-stress neighborhood environments can take a cumulative toll on maternal health in the form of "weathering."

There are strong theoretical reasons to believe that violent crime is a primary source of stress in many urban neighborhoods. First, research on the fear of crime shows that people tend to perceive crime largely in geographic terms (Warr 1994), which makes the neighborhood environment a particularly salient context for generating fear and, hence, stress. Moreover, neighborhood crime can be stressful not only for people who perceive high personal risks of victimization, but also for those who fear for the safety of family members and friends, which Warr and Ellison (2000) call "altruistic fear." Women tend to be more fearful of crime than men (Warr 1994), which makes neighborhood crime particularly important for maternal health, and there is some evidence that the risk of low birth weight is greater in high-crime neighborhoods (Collins and David 1997; Zapata et al. 1992). Second, research shows that people who perceive more crime and disorder in their neighborhoods have a higher risk of mental health problems related to stress, such as anxiety, depression, powerlessness, fear, and mistrust (Aneshensel and Sucoff 1996; Cutrona et al. 2000; Geis and Ross 1998; Ross and Jang 2000; Ross, Reynolds, and Geis 2000). By promoting distrust of others, neighborhood crime can also lead to social isolation from close social relationships (Krause 1991), which in turn has been linked to adverse physical health outcomes (Berkman and Glass 2000; House, Landis, and Umberson 1988). Third, research on exposure to violence among children and adolescents has linked repeated encounters with violence (both direct and indirect) to the development of emotional problems, post-traumatic stress syndrome, substance use, and increasing pessimism in one's own ability, and that of health professionals, to improve health (Fick and Thomas 1995; Margolin and Gordis 2000; Selner-O'Hagan, Kindlon, and Buka 1998). Finally, some scholars suggest that in addition to fostering stress, neighborhood crime also promotes



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risky behaviors, such as substance use, because residents of crime-ridden neighborhoods perceive themselves to have relatively short life expectancies, which leaves them less concerned with the long-term health consequences of their actions (Ellen et al. 2001; Ganz 2000).

In figure 1, crime is viewed as a potential mediator of both structural characteristics and social relations/engagement on individual health outcomes. There is a long line of studies on the predictors of crime, most of which focuses on structural factors, such as concentrated disadvantage and racial/ethnic composition and their connection to violent crime rates (e.g., Krivo and Peterson 2000; Land, McCall, and Cohen 1990), but which also includes recent studies of neighborhood social processes (Morenoff et al. 2001; Sampson et al. 1997), as discussed in more detail below. There is also some evidence that perceptions of crime and disorder may mediate the effects of neighborhood structural factors on physical and mental health outcomes (Aneshensel and Sucoff 1996; Cutrona et al. 2000; Geis and Ross 1998; Ross and Jang 2000; Ross and Mirowsky 2001; Ross et al. 2000).

### Social Relations/Engagement

How people adapt to stressful environments depends, in part, on their access to informal resources such as those produced through social relationships and institutions (i.e., social capital). In places where neighbors are more engaged in the social life of their community, residents are more likely to generate informal resources by assisting one another with favors; providing each other with health-related advice and other information; aiding one another with everyday tasks, such as child care; monitoring each others' property; and participating in local voluntary associations, such as block clubs, tenants' associations, and religious organizations.

Thus far, most of the research on social relations/engagement and health has focused on individual-level measures of social ties and social support. A major finding from this research is that social isolation—the relative lack of social relationships—is a risk factor for mortality, with a relative risk ratio comparable to that of cigarette smoking (Berkman and Glass 2000; House et al. 1988; Singer and Ryff 2001). A related line of research finds that participation in voluntary organizations, a form of social engagement, may promote both physical and mental health (Wilson and Musick 1999).

There are relatively few studies that have analyzed the connection between neighborhood-level measures of social relations/engagement and health. These studies have focused mainly on mental health (Aneshensel and Sucoff 1996; Cutrona et al. 2000; Geis and Ross 1998; Ross and Jang 2000; Ross et al. 2000), and most of them characterize neighborhood social



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processes by relying on only a single individual's report of what happens in his or her neighborhood. A more reliable approach to measuring neighborhood social processes is to aggregate the reports of multiple respondents living in the same neighborhood (Raudenbush and Sampson 1999), but this strategy has only been used in a few health studies to date (Buka et al. 2002; Cutrona et al. 2000). Sampson and colleagues use such an approach to measure neighborhood "collective efficacy," defined as the shared willingness of residents to actively cooperate in pursuit of commonly held goals (Sampson et al. 1999; Sampson et al. 1997), but most of their research focuses on crime-related outcomes, not health. This research shows that neighborhoods with higher levels of collective efficacy have lower levels of violent crime (Morenoff et al. 2001; Sampson et al. 1997) and disorder (Sampson and Raudenbush 1999) and that collective efficacy—as well as other social processes, such as reciprocal exchange—is predicted by structural factors, such as concentrated disadvantage and residential stability (Morenoff et al. 2001; Sampson et al. 1999). Thus, in terms of the paths displayed in figure 1, previous research has focused on the association between neighborhood social resources and crime and on the connection between structural factors and social resources, but there has been very little research on the association between neighborhood social relations/engagement and health.[2]

## THE SPATIAL DYNAMICS OF HEALTH

The social environment and context in which individuals live their lives comprises not only their own immediate neighborhood, but also surrounding neighborhoods in which people work, shop, attend school, visit with friends, travel, and so on in the course of their daily lives. Further, the way a person experiences her or his neighborhood may be influenced by the wider context of surrounding neighborhoods. For example, if a neighborhood has a low crime rate but the areas around it all have high crime rates, then crime in the surrounding areas could still be an important source of stress for people who live in the low-crime neighborhood. In this case, there is a spillover effect, whereby crime in surrounding neighborhoods produces a negative "spatial externality" for the low-crime neighborhood (Anselin, in press). Spatial externalities can also be positive, as in the case of social networks and voluntary associations that spread resources to multiple neighborhoods within a geographic area. In general, the point is that neighborhood conditions may be reinforced, exacerbated,

[2] One exception is a recent study of neighborhood support and birth weight in Chicago by Buka and colleagues (2002).



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moderated, or counteracted by the characteristics of adjacent and proximate neighborhoods.

The embeddedness of neighborhoods within a larger social environment is usually neglected in analyses of neighborhood effects on health, even though spatial methods have become more widely used in social science research (Goodchild et al. 2000). A key issue in spatial analysis is how to conceptualize and model the spatial process under study (Anselin 2002; Anselin, in press). Some outcomes diffuse over space, such as acts of violence in one neighborhood that instigate retaliatory acts in nearby neighborhoods, or an infectious disease that is spread from one area to another through social networks (Cohen and Tita 1999). Noninfectious health outcomes, such as low birth weight, do not diffuse over space, because an occurrence of the outcome in one neighborhood does not increase the likelihood that a similar outcome will occur in a geographically proximate area. However, a noninfectious health outcome may still be spatially conditioned—meaning that the occurrence of the outcome in a given place is related to what happens in nearby places—if there are spatial processes operating in the causes of that outcome. For example, a pregnant woman may experience stress from high crime rates in neighborhoods surrounding hers, even if the crime rate in her own neighborhood is relatively low. In this example, high crime rates in surrounding neighborhoods represent negative spatial externalities that, in a sense, spill over neighborhood boundaries and affect health outcomes in adjacent neighborhoods. Thus, there is an important theoretical distinction between *diffusion*, which describes a spatial process intrinsic to a given outcome (e.g., a contagious disease) such that once the outcome occurs in a geographic area it is also likely to occur in surrounding areas, and *spatial externalities*, which are generated by social processes that spill over multiple geographic areas, generating a wider spatial context for risk and protective factors than just the immediate neighborhood. This theoretical distinction has important methodological implications for how to model and interpret spatial effects, which are considered below in greater detail.

## RESEARCH QUESTIONS

The ensuing analysis addresses three central questions about neighborhoods and birth weight. First, do associations between neighborhood structural characteristics—such as poverty, racial/ethnic composition, and residential stability—and birth weight persist after controlling for individual-level attributes in a multilevel model? I examine a broad array of neighborhood characteristics, including measures of neighborhood structure and neighborhood mechanisms related to stress and social resources.



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A related second question is whether or not two hypothesized neighborhood mechanisms, violent crime and social exchange/voluntarism, are associated with birth weight after controlling for both individual- and neighborhood-level confounders, and if they are associated, do they mediate the effects of structural factors such as poverty, racial/ethnic composition, and residential stability?

Third, is there evidence that birth weight is also related to the wider spatial context within which neighborhoods are embedded? I address this question through multilevel spatial models of birth weight. If indeed there is evidence that the health of individuals in a given neighborhood is related to characteristics of adjacent neighborhoods, then it is also important to investigate which characteristics of the surrounding areas are most likely to spill over neighborhood boundaries and produce health-related spatial externalities. Moreover, it is important to know whether such spillover effects are additive or multiplicative—that is, for a given risk/protective factor, is there a statistical interaction between exposure to that factor in the proximal and distal social environment? For example, living in a place where neighbors generate informal resources through social relations and participation in local organizations may offer more protection against low birth weight if that neighborhood is also surrounded by other neighborhoods where neighbors engage in similar practices and thus reinforce this type of behavior. Each of these questions is addressed in the multilevel spatial analysis below.

## RESEARCH DESIGN AND MEASUREMENT

This study uses a multilevel data set that combines individual-level data from the 1995–96 Chicago vital statistics with contextual data from the 1990 U.S. census, 1995 Chicago Police Crime Statistics, and the 1995 Project on Human Development in Chicago Neighborhoods (PHDCN). The two years' worth of cases from the Vital Statistics yield a total sample size of 101,662 live births.[3] For the purposes of this study, "neighborhoods" are defined operationally as the sampling units for the PHDCN Community Survey, which are called neighborhood clusters (NCs) and consist of one or more geographically contiguous census tracts. The PHDCN team cluster analyzed 1990 census data in order to determine which tracts could be combined to form relatively homogenous NCs with respect to

[3] There were 107,346 live births registered in Chicago from 1995 to 1996. Cases of multiple births (2.75%) were dropped from the analysis, as is conventional in birth weight analyses. Cases with missing birth weights (.37%) or missing geographic identifiers (2.55%) were also excluded from the analysis, yielding a final sample size of 101,662 women.



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distributions of racial/ethnic mix, SES, housing density, and family structure. They then fine-tuned these combinations to ensure that the final NC boundaries would be consistent with major ecological barriers (e.g., railroad tracts, parks, and main thoroughfares) and local knowledge of neighborhood borders. Chicago's 865 inhabited census tracts were combined to form 343 NCs.[4]

## Measures of Infant Health

There is disagreement in the health literature over how to construct birth outcome measures. Most studies rely on a dichotomous measure of low birth weight, which is conventionally defined as a birth weight of less than 2,500 grams (5 pounds and 8 ounces). This convention of measuring low birth weight dates back to 1919, when Arvo Ylppo proposed that birth weights of 2,500 grams or less be adopted as a standard because infants born below this weight were not mature enough to survive the first year of life (Kline, Stein, and Susser 1989, p. 166). Ylppo's standard gained wider acceptance in 1950, when it was adopted by a committee of the World Health Organization (Kline et al. 1989). More recent research has shown that low birth weight is only a serious threat to infant health and development when it results from intrauterine growth retardation (IUGR)—the condition of a baby being small in size for her or his gestational age—as opposed to less harmful cases of low birth weight when babies are fully grown for their gestational age but simply born prematurely (Kramer 1987). Thus, some births that are categorized as non–low birth weight can still be "compromised" in terms of the development of the fetus (Frisbie, Forbes, and Pullum 1996), and vice versa.

In this study, I use multiple specifications of birth outcomes. To maintain comparability with previous studies, I use the conventional measure of low birth weight as one outcome. However, to more directly tap into the notion of IUGR, I also use a linear specification of birth weight that adjusts for gestational age.[5] This linear specification of birth weight has

[4] The NC containing O'Hare Airport was dropped from the analysis because the sample size was insufficient to generate reliable neighborhood measures, leaving a total of 342 NCs. The average NC contains 7,950 people. In comparison, the average census tract contains 3,156 people, while the Local Community Area, another commonly used geographic unit in Chicago that is aggregated from census tracts, has an average of 35,415 people. More details about the PHDCN sample design are available in previous publications (e.g., Sampson et al. 1997).

[5] In the interest of showing how robust the findings are across multiple model specifications, I also present results from models of dichotomous low birth weight that are adjusted for gestational age. Thus, the ensuing analysis consists of models for both continuous birth weight and dichotomous low birth weight, with and without controlling for gestational age.



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both substantive and statistical advantages. Substantively, it is a more direct indicator of IUGR than the conventional low birth weight threshold because it captures potentially critical variation across the distribution of birth weights that cannot be explained simply by the length of gestation. Statistically, a continuous specification of birth weight is preferable to the dichotomous measure of low birth weight in a multilevel framework, because low birth weight is a rare outcome (it occurs in 9% of the births in this sample), making it difficult to detect variation even with relatively large within-neighborhood sample sizes (the average neighborhood in this sample contains 297 births).[6] Descriptive statistics for both the continuous and dichotomous measures of birth weight are presented in table 1.

### Measures of Neighborhood Context

Measures of neighborhood context were constructed to reflect each of the categories in the conceptual framework. Descriptive statistics on these variables are also presented in table 1. Indicators of neighborhood structural composition consist of the following census variables: the percentage of neighborhood residents that are African-American, the percentage that are of Mexican origin, the percentage of poor families, the percentage of residents who have lived at the same location for at least five years, and the percentage of homes that are owner occupied.[7] The latter two items are collapsed into a scale of residential stability ($\alpha = .75$), to reduce problems of multicolinearity.

As an indicator of social environmental stress, I use the 1995 violent crime rate, calculated from the Chicago police statistics as the total number of violent crimes (murder, rape, robbery, and aggravated assault) that occurred in a given NC and were reported to the police in 1995, divided by the 1990 census population count for that area.[8] I used the violent crime rate rather than the total crime rate because violent crimes are

[6] One problem with adjusting birth weight for length of gestation in a regression framework is that gestational age is likely brought about by many of the same factors that are causally related to birth weight, making it an endogenous variable. From the standpoint of estimating neighborhood effects on birth weight, this is a conservative strategy, because if gestational length is a pathway through which some neighborhood characteristics affect birth weight, then controlling for gestational age may eliminate or attenuate neighborhood effects on birth weight.

[7] In supplemental analysis, the neighborhood poverty indicator was replaced with a scale of concentrated disadvantage that included not only the family poverty rate but also rates of unemployment, family public assistance, and female-headed families ($\alpha = .98$). Although the results of this analysis were not reported in the tables because this scale was too highly correlated with other predictors discussed below, the results were entirely consistent with the models that are reported.

[8] The official police data were provided to PHDCN by Richard Block.



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TABLE 1
Person- and Neighborhood-Level Descriptive Statistics

| | Mean | SD | Min | Max |
|---|---|---|---|---|
| Birth outcomes: | | | | |
| Birth weight | 3,229.39 | 611.29 | 10 | 6,673 |
| Low birth weight | .09 | .29 | 0 | 1 |
| Neighborhood: | | | | |
| %African-American | 41.21 | 43.67 | .00 | 99.81 |
| %Mexican | 12.92 | 20.03 | .00 | 91.48 |
| %poor families | 20.43 | 17.31 | .23 | 88.18 |
| Residential stability | .00 | 1.00 | −2.07 | 2.32 |
| 1995 violent crime rate (per 1,000) | 65.63 | 42.68 | 4.38 | 237.37 |
| Exchange/voluntarism | .00 | 1.00 | −2.49 | 3.32 |
| Race/ethnicity: | | | | |
| Non-Hispanic white | .20 | .40 | 0 | 1 |
| Non-Hispanic black | .42 | .49 | 0 | 1 |
| Mexican origin | .26 | .44 | 0 | 1 |
| Puerto Rican origin | .05 | .21 | 0 | 1 |
| Other Hispanic origin | .03 | .17 | 0 | 1 |
| Non-Hispanic other race | .04 | .19 | 0 | 1 |
| Foreign born | .33 | .47 | 0 | 1 |
| Sociodemographic: | | | | |
| Maternal age | 25.77 | 6.34 | 12 | 53 |
| Birth order | 2.64 | 1.79 | 1 | 17 |
| Maternal education | 11.72 | 3.02 | 0 | 17 |
| Marital status | .45 | .50 | 0 | 1 |
| Health behaviors during pregnancy: | | | | |
| Smoking | .10 | .30 | 0 | 1 |
| Drinking | .01 | .11 | 0 | 1 |
| *N* of doctor visits | 10.39 | 4.31 | 0 | 80 |
| Weight gain (pounds) | 29.51 | 12.72 | −82 | 186 |
| Biomedical characteristics during pregnancy: | | | | |
| Anemia | .01 | .11 | 0 | 1 |
| Diabetes | .02 | .12 | 0 | 1 |
| Herpes | .00 | .05 | 0 | 1 |
| Hypertension | .03 | .16 | 0 | 1 |
| Previous low-birth-weight baby | .01 | .09 | 0 | 1 |
| Previous pregnancy termination | .26 | .44 | 0 | 1 |
| Female infant | .49 | .50 | 0 | 1 |
| Length of gestation | 38.68 | 2.43 | 18 | 51 |

Note.—Summary statistics for $N = 101{,}949$ women in 342 neighborhood clusters. Data are from 995-96 Chicago vital statistics, the 1990 census, 1995 Chicago police statistics, and 1995 PHDCN Community Survey.

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likely to be more widely publicized and treated as serious threats to personal safety, but the results are consistent with either measure.

I also constructed two indicators of neighborhood social relations/engagement from the PHDCN community survey.[9] The first, reciprocated exchange, is a five-item scale measuring how often neighbors provide mutual support, exchange advice and information, and socialize with one another. Respondents were asked how often (on a four-point scale) they engage in the following activities with their neighbors: exchanging favors for each other, such as watching each other's children, helping with shopping, lending garden or house tools, and other small acts of kindness; watching over each other's property; having parties or other get-togethers where other people in the neighborhood are invited; visiting in each other's homes or on the street; and asking each other advice about personal things such as child rearing or job openings. The second, participation in local voluntary associations, is a six-item index that measures residents' involvement (yes or no) in the following types of associations: local religious organizations; neighborhood watch programs; block groups, tenant associations, or community councils; business or civic groups; ethnic or nationality clubs; and local political organizations. Each of these scales has been used in previous research and has been shown to be highly reliable (Sampson et al. 1999). However, preliminary analysis revealed that the colinearity between these two variables ($r = .60$) produced unstable estimates, and so they were collapsed into a single index, exchange/voluntarism, using factor analysis. Exploratory analysis also suggested that the resulting factor is more predictive of birth weight than either of the two separate scales by themselves.

## Individual-Level Controls

The individual-level variables come from the Chicago vital statistics data and are treated as control variables in the analysis. Descriptive statistics

[9] These scales were constructed using methodology developed by Raudenbush and Sampson (1999) for measuring neighborhood processes with survey data. This method adjusts for measurement error through a three-level model with separate variance components for items in the scale, persons, and neighborhoods. Although these scales are measured with more precision than one constructed by simply averaging responses to survey items across neighborhoods, they nonetheless yield the same results in the analysis of birth weight.



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for these variables are provided in table 1.[10] The individual-level controls are classified into four groups. The first group, indicators of maternal *race, ethnicity, and nativity*, consists of dummy variables for women who are non-Hispanic African-American, of Mexican origin, of Puerto Rican origin, of other Hispanic origin, and non-Hispanic other races (the reference category is non-Hispanic white), and a dummy variable for foreign-born women. Maternal *sociodemographic* characteristics include continuous variables for maternal age, birth parity, and highest grade of education,[11] and a dummy variable for those women who were married at the time of the birth. Measures of *maternal health behavior* include dummy variables for women who smoked or drank during pregnancy, continuous measures of weight gained during pregnancy and the number of visits to the doctor, and a dummy variable for women who had over 20 doctor visits during their pregnancy (the ninety-nineth percentile).[12] Finally, *biomedical* measures include dummy variables for women who experienced anemia, diabetes, herpes, or hypertension during pregnancy, dummy variables for women who reported at least one previous birth resulting in low birth weight or a previous pregnancy termination, and a dummy variable indicating whether the infant was a female.[13]

It is important to note that many of these individual-level covariates could be endogenous in the sense that they may, in part, reflect the effects of prior social context. In other words, it is possible that a woman's sociodemographic characteristics, health behaviors, and biomedical conditions were all influenced by neighborhood environments in which she once lived or perhaps continues to live. In this sense, the associations

[10] Missing values were imputed for the continuous independent variables using stepwise regression procedure (best-subset regressions) in Stata (2001). In the case of categorical variables, separate dummy variables were created for the missing cases on each independent variable. These dummy variables were included as control variables in all of the regression models reported in this article. However, in the interest of parsimony, the coefficients for these missing-data control variables are not reported in the tables.

[11] I considered nonlinear specifications of all the individual-level covariates, such as natural logs, quadratic terms, and dummy variables, and none of these changed the results of the neighborhood-level variables. In the interest of parsimony, only the linear specifications are reported in the tables.

[12] The smoking and drinking dummy variables were constructed from measures of the number of cigarettes and drinks consumed during pregnancy. In these data, less than 1% of all cases had values of zero for either variable, so missing values were also recoded as zero, under the assumption that being missing meant that the mother refrained from the behavior in question. This means that estimates of the prevalence of smoking and drinking from this data set are probably biased downward.

[13] The dummy variable for hypertension is coded as "1" if the birth certificate reports an incidence of chronic hypertension, pregnancy-associated hypertension, or preeclampsia; and "0" if none of these conditions are reported.



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between current neighborhood environments and birth weight could be conservative estimates of the total effects of neighborhood context.

## METHODS

Multilevel analyses for continuous birth weight and dichotomous low birth weight were conducted using hierarchical modeling techniques (Raudenbush and Bryk 2002) realized through HLM software (Raudenbush, Bryk, Cheong, and Congdon 2001). Hierarchical models for multilevel data consist of two equations estimated simultaneously: a level-1 (individual-level) model and a level-2 (neighborhood-level) model. The level-1 model is either a linear model (for continuous birth weight) or a generalized linear model (for low birth weight). The linear model is written as

$$Y_{ij} = \beta_{0j} + \sum_{q} \beta_q X_{qij} + \varepsilon_{ij},$$

where $Y_{ij}$ is the infant's birth weight for mother $i$ in neighborhood $j$; $\beta_{0j}$ is the intercept; $X_{qij}$ is the value of covariate $q$; and $\beta_q$ is the partial effect of that covariate on birth weight. The person-specific error term, $\varepsilon_{ij}$, is assumed to be independently, normally distributed with constant variance $\sigma^2$. The generalized linear model for a binary outcome has the same structure, but it replaces $Y_{ij}$ with the logit link function, $\eta_{ij} = (\frac{\Phi_{ij}}{1-\Phi_{ij}})$, where $\Phi_{ij}$ is the probability that an infant will be born below 2,500 grams and $\eta_{ij}$ is the log-odds (or logit) of low birth weight.

The level-2 model is the same in both cases. The intercept from level 1, $\beta_{0j}$, is allowed to vary randomly across NCs:

$$\beta_{0j} = \gamma_{00} + \sum_{s} \gamma_{0s} W_{sj} + \mu_{0j},$$

where $\gamma_{00}$ is the average birth weight across all neighborhoods, $\gamma_{0s}$ are the neighborhood-level regression coefficients, $W_{sj}$ are the neighborhood-level predictors, and $\mu_{0j}$ is the unique increment to the intercept associated with neighborhood $j$ (i.e., the random effect), assumed to be normally distributed with variance $\tau$.

### Spatial Models

A distinctive methodological feature of this analysis is that it combines multilevel and spatial modeling techniques. Spatial effects on birth weight



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are estimated through an autoregressive process in the dependent variable known as a "spatial lag" model,[14]

$$Y = \rho WY + X\beta + \varepsilon, \tag{1}$$

where $\rho$ is the spatial autoregressive parameter, $W$ is a weights matrix that expresses a form of spatial association among each pair of neighborhoods (in the analysis below it is a binary contiguity matrix), $X$ is a matrix of exogenous explanatory variables with an associated vector of regression coefficients $\beta$, and $\varepsilon$ is a vector of normally distributed, random error terms.

Because equation (l) has an endogenous variable on the right-hand side, $WY$, it must be estimated using either a maximum likelihood (ML) or two-stage least squares (2SLS) approach (Anselin 1988; Anselin 1995*b*), neither of which can currently be estimated in HLM. However, using a two-step procedure, it is possible to approximate a hierarchical spatial model of either continuous birth weight or dichotomous low birth weight by first constructing a neighborhood-level birth weight measure that is adjusted for the potentially confounding effects of individual-level covariates using coefficients from multilevel models, and then regressing this adjusted neighborhood birth weight score on neighborhood-level covariates and a spatial lag term in a spatial regression model.[15]

The spatial lag model is commonly interpreted as a diffusion model, wherein the value of $Y$ at one location is related to values of $Y$ in contiguous neighboring locations through $\rho$. This interpretation is problematic for two reasons. First, diffusion is a process that unfolds over time and cannot be captured with cross-sectional data. Second, the $\rho$ coefficient not only captures the effects of spatial proximity to $Y$ in other locations, but also spatial proximity to the observed and unobserved *covariates* of

[14] There is also a spatial error model, in which the autocorrelation process is modeled in the error term, as follows: $Y = X\beta + \lambda\varepsilon + \xi$, where $X$ is a matrix of exogenous explanatory variables with an associated vector of regression coefficients $\beta$, $\lambda$ is the autoregressive coefficient, $\varepsilon$ is a vector of error terms, and $\xi$ is a random error term (Anselin 1988; Anselin 1995*b*). Anselin (1995*b*) has developed regression diagnostic tests to determine whether spatial dependence is better captured by a lag or error process.

[15] The hierarchical model of birth weight used in the first step contains only individual-level covariates, which are all centered around their neighborhood means in order to derive their *within* neighborhood estimates (Raudenbush and Bryk 2002, p. 33), using the following equation: $Y^* = Y_j - \bar{Y} - [\sum \beta_{wp} \times (X_{pj} - \bar{X}_p)]$, where $Y_j - \bar{Y}$ represents the deviation of $Y$ in neighborhood $j$ from the overall sample mean; $X_{pj} - \bar{X}_p$ represents the deviation of $X$ in neighborhood $j$ from the sample mean; and the $\beta_{wp}$ are the HLM within-neighborhod slope parameters from a regression where the $X_{pj}$ covariates are centered around their *group*$_j$ means. In short, this process adjusts the value of $Y$ for neighborhood $j$ according to the biasing effects of *individual-level* covariates, weighted by the neighborhood's relative composition on those covariates.



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$Y$. This point rests on a subtle but very important interpretation of equation (1), which is that if values of $Y$ in a "focal" neighborhood are a function of $Y$ in its first-order neighbors (i.e., the neighbors of the focal neighborhood), then it follows that values of $Y$ in the first-order neighbors are, in turn, functions of $X$ and $\varepsilon$ in the first-order neighbors and of $Y$ in the second-order neighbors (i.e., the neighbors of the first-order neighbors). This process—known as a "spatial multiplier" (Anselin, in press; Morenoff et al. 2001)—continues to expand until it reaches the border of the city, because $Y$ in a given neighborhood is always a function of $X$ and $\varepsilon$ in that neighborhood and as $Y$ in its neighbors (which in turn is a function of $X$, $\varepsilon$, and neighboring values of $Y$, etc.). The spatial multiplier process can be expressed mathematically by rewriting equation (1) in its reduced form (where all endogenous variables are written as functions of exogenous variables):

$$Y = X\beta + \rho WX\beta + \rho^2 W^2 X\beta + \ldots + \rho^m W^m X\beta + \varepsilon + \rho W\varepsilon + \rho^2 W^2 \varepsilon + \ldots + \rho^m W^m \varepsilon, \quad (2)$$

where $m \rightarrow \infty$. This equation clearly shows that the spatial effect represented by $\rho$ in equation (1) actually operates through the observed $X$ variables and the unobserved error term, $\varepsilon$. Thus, the spatial lag effect in equation (1) is consistent with any of the following mechanisms: (*a*) spatial externalities from the observed $X$ variables, (*b*) spatial externalities from unobserved factors that are not in the model (i.e., the error term), or (*c*) a feedback or diffusion effect in $Y$ (which is conceived as an unobserved process that is captured by the error term).

In the case of birth weight, diffusion is not a theoretical possibility, so the interpretation of the spatial lag term hinges on the operation of spatial externalities. These externalities can be estimated more directly with a less frequently used model in which all spatial effects operate through the $X$ variables (or a subset thereof) (Anselin, in press):

$$Y = X\beta + \rho WX + \varepsilon, \quad (3)$$

which is identical to equation (1) except that $WX$ is substituted for $WY$. This model assumes that spatial effects operate only through the observed $X$ variables, whereas the spatial lag model in equation (1) allows the spatial process to operate through either observed or unobserved variables.[16] Whether equation (3) is more appropriate than equation (1) is an empirical question that can be resolved by examining diagnostic tests for residual spatial autocorrelation (Anselin 1995*b*, in press).

[16] Another important difference between eqq. (1) and (3) is that unlike $WY$, $WX$ is not endogenous, so eq. (3) can be estimated directly in HLM.



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## RESULTS

The results of the multilevel analysis for continuous birth weight are presented in table 2. The neighborhood-level variables in all of the models have been standardized around a mean of zero and a standard deviation of one to place the coefficients on a common metric. Models 1 and 2 estimate neighborhood effects before adjusting for individual-level covariates. The reason for showing unadjusted neighborhood estimates is that many of the individual-level controls (introduced in model 3) may actually be reflecting the effects of prior neighborhood conditions, and so the unadjusted neighborhood coefficients represent, in a sense, an upper bound on the estimates of neighborhood effects. Model 1 includes only structural characteristics and shows that neighborhood racial composition (%African-American), poverty, and residential stability are all significantly related to birth weight in the expected direction. Model 2 adds the two hypothesized neighborhood mechanisms: violent crime and exchange/voluntarism. Both crime and exchange/voluntarism are significantly related to birth weight in the expected direction, and their inclusion in the model reduces the effects of poverty and residential stability to nonsignificance. Adding crime and exchange/voluntarism also reduces the effect of percentage black (although it remains statistically significant) but increases the percentage Mexican coefficient, which becomes significant in model 2.[17]

Adding individual-level controls in model 3 reduces the effects of all the neighborhood structural characteristics to nonsignificance. Birth weight's association with violent crime, though also reduced, remains significant, as does its association with exchange/voluntarism. These results support the theoretical argument that indicators of neighborhood stress and social resources are more causally proximate to birth weight than are structural compositional factors. Although these effects are relatively small in substantive terms (e.g., a 1-SD increase in violent crime is associated with only a 10.4 gram decrease in birth weight), some of the individual-level controls included in model 3 (e.g., smoking and drinking) may themselves be affected by prior neighborhood conditions, and in this sense, some true contextual effects could be attributed to individual-level factors when these controls are introduced. Hence, the estimates of neighborhood effects in model 3 are arguably lower bound estimates.

There are substantial correlations among some of the independent variables in model 3—as detailed in the correlation matrix provided in the

[17] The protective effect of Mexican neighborhoods is enhanced in model 2 because Mexican neighborhoods tend to have relatively high rates of violent crime (compared to white neighborhoods) and low levels of exchange/voluntarism. After adjusting for these risk factors, Mexican neighborhoods appear to be more protective.



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TABLE 2
NEIGHBORHOOD- AND PERSON-LEVEL PREDICTORS OF BIRTH WEIGHT FROM HIERARCHICAL LINEAR MODELS

| | 1 | | 2 | | 3) | |
|---|---|---|---|---|---|---|
| INDEPENDENT VARIABLES | Coefficient | *t*-ratio | Coefficient | *t*-ratio | Coefficient | *t*-ratio |
| Neighborhood: | | | | | | |
| %African-American | −112.18 | −24.12*** | −81.88 | −15.57*** | .71 | .18 |
| %Mexican | 2.04 | .72 | 10.35 | 4.18*** | 2.92 | 1.58 |
| %poor families | −24.24 | −5.25*** | −8.25 | −1.93 | 3.15 | 1.01 |
| Residential stability | 12.52 | 3.42*** | −2.09 | −.62 | 3.29 | 1.33 |
| ln violent crime rate | | | −41.24 | −7.36*** | −10.41 | −2.80** |
| Exchange/voluntarism | | | 13.04 | 4.00*** | 6.71 | 2.81** |
| Race/ethnicity: | | | | | | |
| Non-Hispanic black | | | | | −134.02 | −18.36*** |
| Mexican origin | | | | | −5.92 | −.97 |
| Puerto Rican origin | | | | | −83.61 | −10.51*** |
| Other Hispanic origin | | | | | −29.43 | −2.94** |
| Non-Hispanic other race | | | | | −173.28 | −21.04*** |
| Foreign born | | | | | 2.77 | .52 |
| Sociodemographic characteristics: | | | | | | |
| Maternal age | | | | | 2.74 | 7.00*** |
| Birth order | | | | | 22.20 | 15.82*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Maternal education | | | | | 1.19 | 1.77 |
| Marital status | | | | | 47.69 | 12.90*** |
| Maternal behaviors: | | | | | | |
| Smoking | | | | | −188.92 | −34.60*** |
| Drinking | | | | | −123.00 | −8.23*** |
| *N* doctor visits | | | | | 4.90 | 12.46*** |
| > 20 doctor visits | | | | | −107.55 | −5.72*** |
| Weight change during pregnancy lbs | | | | | 6.05 | 47.91*** |
| Biomedical characteristics: | | | | | | |
| Anemia | | | | | −14.35 | −1.24 |
| Diabetes | | | | | 197.20 | 13.84*** |
| Herpes | | | | | −26.62 | −1.11 |
| Hypertension | | | | | −104.89 | −10.24*** |
| Previous low birth weight baby | | | | | 29.78 | 1.52 |
| Previous pregnancy termination | | | | | −25.36 | −5.99*** |
| Female infant | | | | | −112.97 | −37.99*** |
| Length of gestation | | | | | 149.07 | 195.24*** |
| Intercept | 3,231.90 | 1,197.23*** | 3,232.67 | 1,327.55*** | 3,231.08 | 1,922.55*** |
| %Variance explained: | | | | | | |
| Neighborhood level | 93.45 | | 95.96 | | 98.49 | |
| Individual level | NA | | NA | | 45.72 | |

SOURCE.—1995-96 Chicago vital statistics, 1990 census, 1995 Chicago police statistics, and 1995 PHDCN Community Survey.
* $P < .05$.
** $P < .01$.
*** $P < .001$.

appendix—which could produce multicolinearity and thus distort some of the estimates. Violent crime, for example, is highly correlated with both percentage poor ($r = .76$) and percentage African-American ($r = .75$), and exchange/voluntarism is correlated with residential stability ($r = .58$). A series of robustness checks revealed that both violent crime and exchange/voluntarism remain significant predictors of birth weight when any of the other independent variables (or combinations of them) are removed from the model.[18] These correlations become particularly problematic in trying to disentangle the effects of violent crime on birth weight from those of percentage poor and percentage African-American. Figure 2 provides more intuitive evidence that higher crime is associated with lower birth weight even after holding levels of neighborhood poverty and racial composition constant. The top portion of figure 2 shows that within almost every poverty quartile, the mean birth weight decreases significantly at higher levels of violent crime, and the bottom portion of figure 2 shows that the same association between crime and birth weight holds within most quartiles of percentage African-American.

The same sequence of models was run on a dichotomous measure of

[18] In supplemental analysis, I used a "propensity score" approach, which some statisticians argue is a better way to control for potentially confounding covariates in estimating a "treatment" effect because it eliminates the correlation between the treatment variable(s) and the error term (Winship and Morgan 1999). In this case, neighborhood violent crime and exchange/voluntarism (both measured in 1995) are conceived as treatments, and structural characteristics from the 1990 census are "pretreatment" covariates. The strategy behind the propensity score approach is to control for the propensity of a neighborhood to have a given level of crime or exchange/voluntarism in estimating these so-called treatment effects. To do this, I regressed each treatment variable on a wide array of neighborhood-level covariates from the U.S. census that might affect levels of crime and social resources, including additional census variables that are not used in the birth weight models, such as population density, the ratio of children to adults, the proportion of vacant houses, the percentage of adults employed in professional and managerial occupations, and the percentage of adults who have graduated from college. The predicted values from these first-stage regressions (i.e., the propensity scores) were then included as neighborhood controls in the birth weight equation. Because these first-stage regressions explained much of the variance in crime and exchange/voluntarism (the $R^2$ was .88 for violent crime and .60 for exchange/voluntarism), it is reasonable to assume that when the propensity scores are included as predictors in the birth weight equation, any remaining unobserved neighborhood factors that predict birth weight are probably not highly correlated with either violent crime or exchange/voluntarism, thus eliminating the correlation between the treatment and the error term. The results showed that both violent crime and exchange/voluntarism remain significant predictors of birth weight even after controlling for propensity scores (where propensity scores are specified either as continuous variables or as dummy variables marking quartiles of each propensity measure to allow for nonlinear effects). This same procedure was used to test each of the models presented in subsequent tables and any significant changes to coefficients are reported below.



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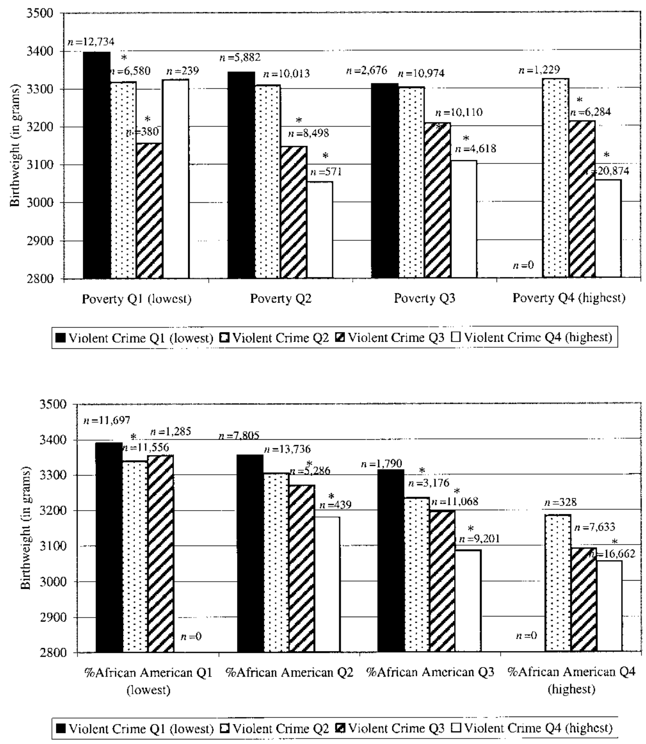


FIG. 2.—The top chart represents neighborhood mean birth weight by quartiles of violent crime and poverty. The bottom chart represents neighborhood mean birth weight by quartiles of violent crime and racial composition. The asterisk (*) signifies that mean birth weight is significantly lower ($P < .01$, Bonferroni test) compared to first (or lowest) quartile of violent crime within the same quartile of %poor (top chart) or %African-American (bottom chart). $N = 0$ indicates that category contains no neighborhoods.

low birth weight, and the results are displayed in table 3.[19] The coefficients in table 3 are presented as odds ratios, obtained by exponentiating the raw logistic coefficients. The neighborhood-level results for low birth weight are similar to those from the continuous birth weight models, but with two main differences. First, although violent crime is significantly associated with low birth weight before adjusting for individual-level covariates, in model 2, the association does not remain significant after introducing the individual-level controls in model 3. Exactly the opposite is true for exchange/voluntarism, which is nonsignificant before adjusting

[19] Table 3 reports a percentage of variance explained statistic for each model at the neighborhood level but not the individual level because the individual-level variance component heteroscedastistic in nonlinear models (Raudenbush and Bryk 2002, p. 298).



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TABLE 3
NEIGHBORHOOD- AND PERSON-LEVEL PREDICTORS OF LOW BIRTH WEIGHT FROM HIERARCHICAL GENERALIZED LINEAR MODELS

| INDEPENDENT VARIABLES | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|
| | Odds Ratio | *t*-ratio | Odds Ratio | *t*-ratio | Odds Ratio | *t*-ratio |
| Neighborhood: | | | | | | |
| %African-American | 1.50 | 19.44** | 1.36 | 11.06*** | 1.01 | .26 |
| %Mexican | .98 | −1.00 | .96 | −2.54* | 1.04 | 1.75 |
| %poor families | 1.07 | 3.77*** | 1.02 | 1.00 | .98 | −.57 |
| Residential stability | .97 | −1.67 | 1.01 | .74 | 1.00 | .20 |
| ln violent crime rate | | | 1.16 | 4.52*** | 1.05 | 1.12 |
| Exchange/voluntarism | | | .98 | −1.38 | .96 | −1.95* |
| Race/ethnicity: | | | | | | |
| Non-Hispanic black | | | | | 1.58 | 5.97*** |
| Mexican origin | | | | | .75 | −3.95*** |
| Puerto Rican origin | | | | | 1.24 | 2.57** |
| Other Hispanic origin | | | | | .89 | −1.11 |
| Non-Hispanic other race | | | | | 1.59 | 5.81*** |
| Foreign born | | | | | .99 | −.12 |
| Sociodemographic characteristics: | | | | | | |
| Maternal age | | | | | 1.02 | 5.95*** |
| Birth order | | | | | .93 | −6.93*** |
| Maternal education | | | | | .99 | −1.56 |
| Marital status | | | | | .76 | −7.12*** |
| Health behaviors during pregnancy: | | | | | | |
| Smoking | | | | | 2.06 | 15.09*** |
| Drinking | | | | | 1.68 | 5.05*** |
| *N* doctor visits | | | | | .98 | −4.94*** |
| > 20 doctor visits | | | | | 1.85 | 4.31*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Weight gain (in pounds) | | | | | .98 | −19.44*** |
| Biomedical characteristics during pregnancy: | | | | | | |
| Anemia | | | | | .91 | −.87 |
| Diabetes | | | | | .49 | −5.74*** |
| Herpes | | | | | .84 | −.72 |
| Hypertension | | | | | 2.18 | 11.84*** |
| Previous low-birth-weight baby | | | | | 1.50 | 3.14** |
| Previous pregnancy termination | | | | | 1.17 | 4.18*** |
| Female infant | | | | | 1.35 | 10.21*** |
| Length of gestation | | | | | .50 | −67.68*** |
| Intercept | .09 | −695.57*** | .09 | −688.23*** | .04 | −148.62*** |
| % variance explained: | | | | | | |
| Neighborhood level | 92.94 | | 94.61 | | 93.57 | |

Note.—Data are drawn from 1995-96 Chicago vital statistics, 1990 census, 1995 Chicago police statistics, and the 1995 PHDCN Community Survey.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

for individual-level covariates, in model 2, but becomes significant after the controls are added, in model 3.[20] As was the case with continuous birth weight, introducing violent crime and exchange/voluntarism in model 2 mediates the effect of neighborhood poverty, and none of the structural predictors remain significant once the individual-level controls are introduced. Thus, the evidence for neighborhood mechanisms affecting low birth weight is somewhat weaker than was the case with continuous birth weight, probably because the dichotomous measure of low birth weight has a low variance and is perhaps also less reliable.[21]

## Spatial Analysis

The analysis up to this point has restricted the exploration of contextual effects to the immediate neighborhood environment and ignored the wider spatial context within which neighborhoods are embedded. This stage of the analysis begins with an examination of birth weight maps. If spatial context does matter, then maps should reveal evidence of birth weight clusters, such that neighborhoods next to each other have similar levels of birth weight—that is, positive spatial association. If the maps show that birth weight is not spatially clustered, then there would be very little support for the spatial externalities hypothesis.

To indicate the extent of significant spatial clustering of similar values around a given observation, Anselin (1995*a*) has developed the local Moran statistic, part of a larger set of statistics called local indicators of spatial association.[22] In addition to testing the significance of spatial clus-

[20] Further analysis revealed that the increase in the exchange/voluntarism coefficient in model 3 is related to the introduction of individual-level controls for race/ethnicity. One potential explanation for why exchange/voluntarism only becomes significant after introducing these controls is that Mexican women have the lowest rate of low birth weight of any racial/ethnic group but also live in neighborhoods with relatively low levels of exchange/voluntarism.

[21] When model 3 is rerun using the propensity score approach described in n. 18, the effect of exchange/voluntarism becomes nonsignificant. Thus, the neighborhood-level results are somewhat weaker and less clear in the case of dichotomous low birth weight than they were with continuous birth weight.

[22] The local Moran statistic is defined as $I_i = (z_i/m_2)\sum_j w_{ij}z_j$ with $m_2 = \sum_j z_i^2$, where the observations $z_i$ and $z_j$ are standardized values of $y_i$ and $y_j$ expressed as deviations from the mean (Anselin 1995*a*). I use Anselin's (1995*b*) conditional randomization approach to estimate the local Moran statistic, where the value of $z_i$ at location $i$ is held fixed, and the remaining values of $z_j$ over all other neighborhoods in the city are randomly permuted in an iterative fashion. With each permutation, a new value of the quantity $\sum_j w_{ij}z_j$ is computed, and the statistic is recalculated. This permutation operationalizes the null hypothesis of complete spatial randomness. A test for pseudo significance is then constructed by comparing the original value of $I_i$ to the empirical distribution that results from the permutation process (Anselin 1995*a*).



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tering, the local Moran statistic can be used in tandem with the so-called Moran scatterplot typology to provide information on the nature of spatial association around any given neighborhood (Anselin 1995*a*, 1995*b*). The Moran scatterplot classifies each neighborhood based on whether it is above or below the mean on a variable, $Y$, and its spatial lag, $WY$ (in this case, the weighted average value of $Y$ in the adjacent neighborhoods), yielding the following categories: (1) "low-low" neighborhoods with low (i.e., below the mean) levels of $Y$ that are surrounded by neighborhoods with low levels of $Y$ (i.e., $WY$ is also below the mean); (2) "low-high" neighborhoods with low levels of $Y$ that are surrounded by neighborhoods with high levels of $Y$ (i.e., $WY$ is above the mean); (3) "high-low" neighborhoods with high levels of $Y$ (i.e., $Y$ is above the mean) surrounded by neighborhoods with low levels of $Y$; and (4) "high-high" neighborhoods with high levels of $Y$ that are also surrounded by neighborhoods with high levels of $Y$.

Figures 3–5 display maps of the Moran typology for birth weight, violent crime, and reciprocal exchange, respectively. Figure 3 shows that birth weight is strongly clustered—in fact, it has the most significant clustering of the three variables. The map is dominated by large low-low and high-high neighborhoods, both of which are forms of positive spatial association.[23] Figure 4 shows that there is also a strong pattern of positive spatial association in violent crime and that many of the so-called crime hot-spots (high-high crime areas) are in the same neighborhoods as the low-low birth weight clusters from figure 3. In fact, 91% of the neighborhoods that are in the significant high-high category on the violent crime map—the so-called crime "hot-spots"—are also in the significant low-low category on the birth weight map, while 77% of the significant low-low crime neighborhoods are also significant high-high clusters of birth weight. Figure 5 shows that reciprocal exchange is less clustered spatially than birth weight and violent crime, but there are still many significant local clusters. Also, exchange/voluntarism clusters do overlap with birth weight clusters (particularly the high-high categories of each variable), but not as much as was the case with violent crime.

There could be several reasons why birth weight is so strongly spatially clustered in figure 3. One possibility is that birth weight appears to be spatially clustered only because its predictors are also spatially clustered. For example, two adjacent neighborhoods could each have low mean birth weights because they also have high crime rates, and thus the apparent clustering in birth weight would be an artifact of the clustering

[23] Using neighborhood rates of low birth weight instead of mean birth weight generated a very similar spatial pattern. I only present the results for mean birth weight in the interest of parsimony.



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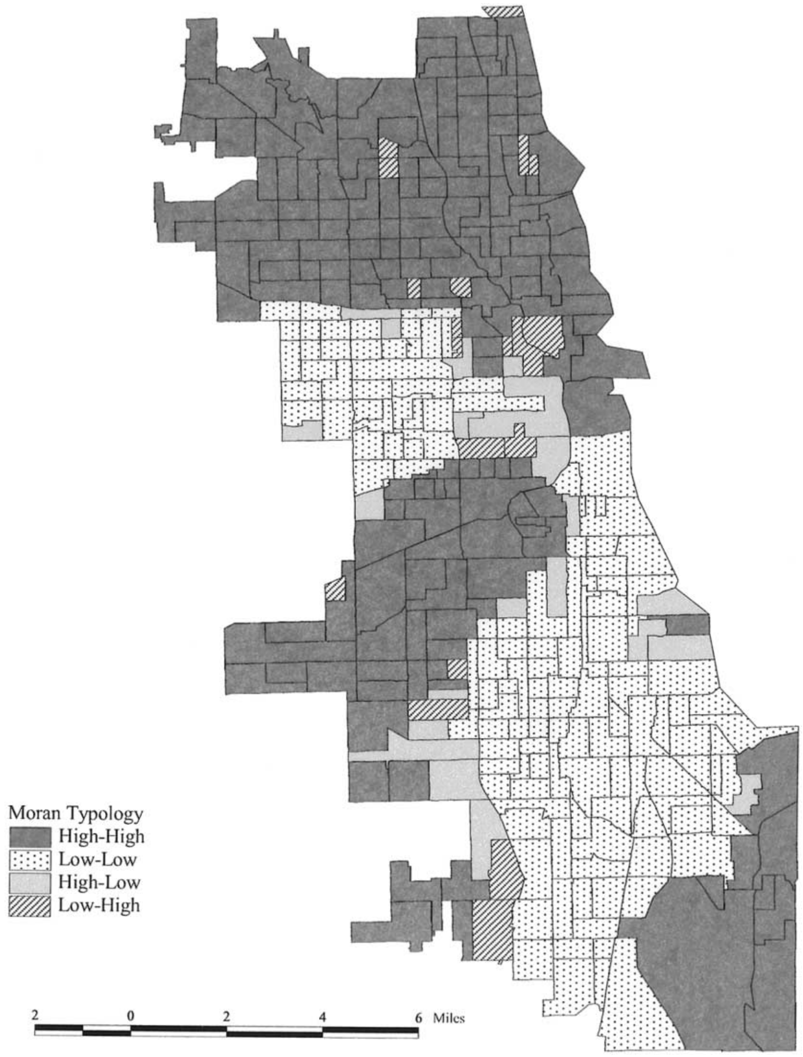


FIG. 3.—Local Moran for birth weight

of crime. This hypothesis suggests that after controlling for the effects of crime and other individual- and neighborhood-level covariates in a regression model, there should no longer be significant spatial autocorrelation in birth weight. An alternative hypothesis is that even after controlling for potentially confounding neighborhood predictors in a spatial regression framework, birth weight will still be significantly spatially autocorrelated because the spatial clustering observed in figure 3 is driven by



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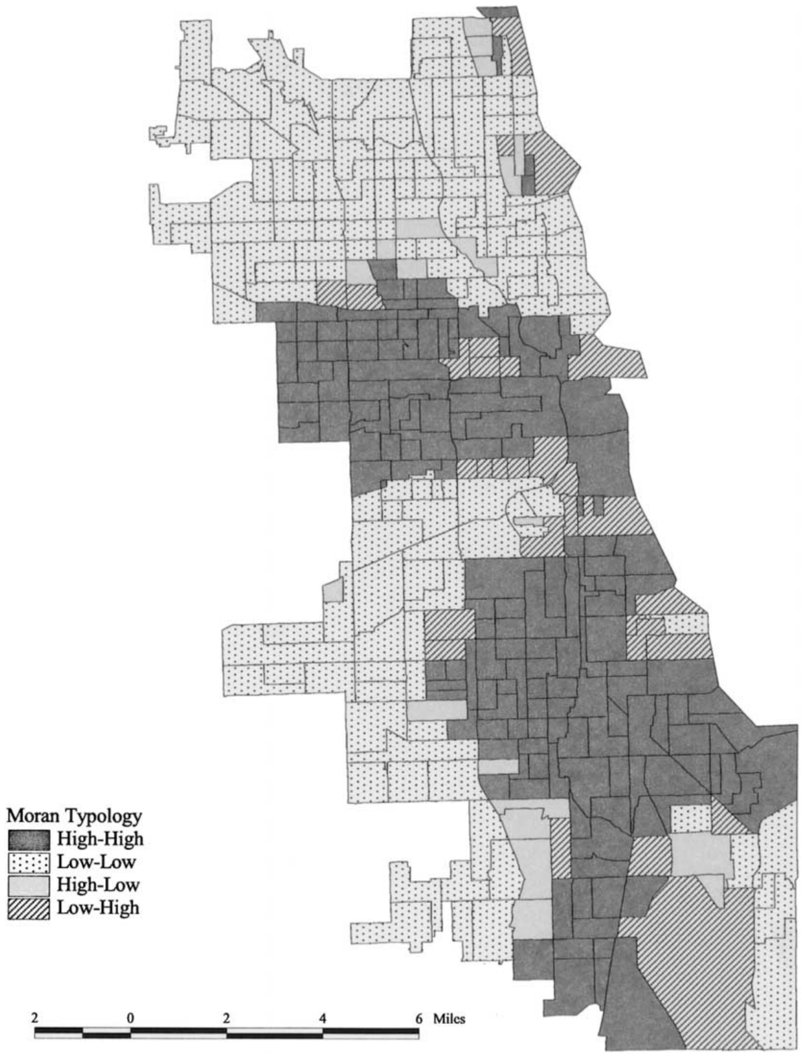


FIG. 4.—Local Moran for ln violent crime rate

true spatial processes, such as externalities. Thus, the two adjacent neighborhoods described above may have similar levels of birth weight because crime in one of the neighborhoods actually creates stress (a negative externality) for women living in the other neighborhood, regardless of whether the latter neighborhood has a high crime rate.

These competing explanations for the spatial clustering of birth weight are tested in spatial lag regression models presented in table 4. Both the



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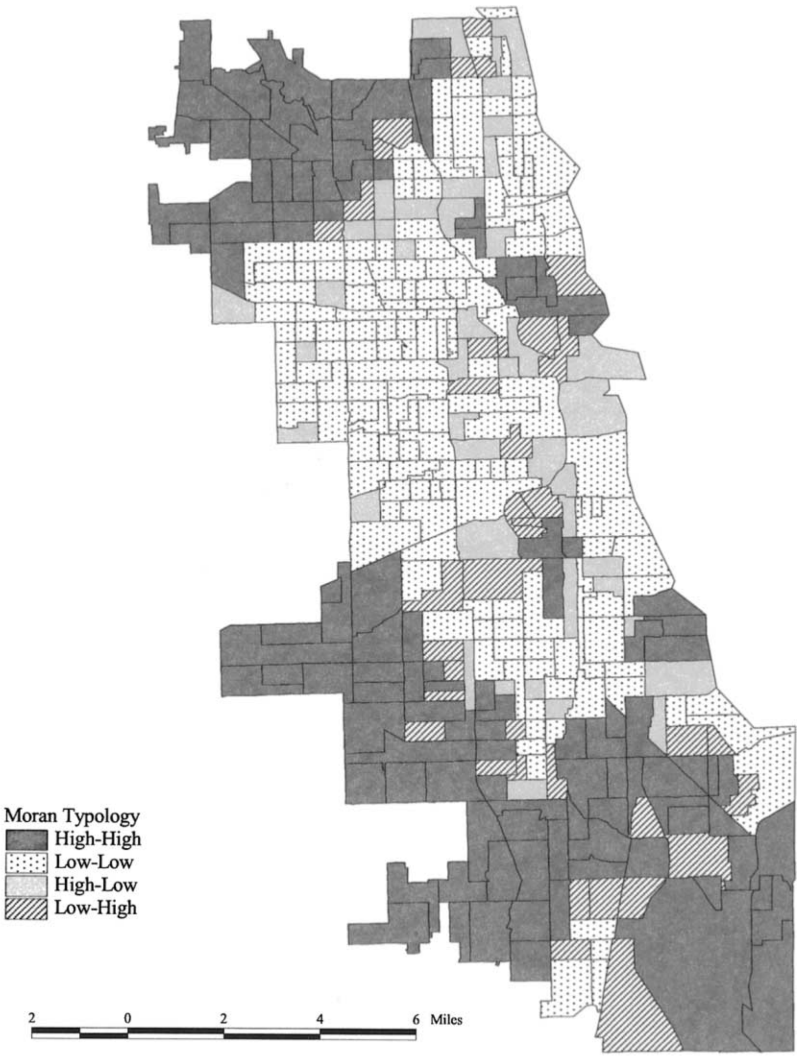


FIG. 5.—Local Moran for exchange/voluntarism

ML and 2SLS estimates are presented for the continuous birth weight model, but only the 2SLS approach is used for the low birth weight model because the ML approach assumes normality, and diagnostic tests revealed that the adjusted neighborhood mean for low birth weight was nonnormal. The ML estimates of spatial lag dependence for continuous birth weight in model 1 confirm that there are significant spatial effects on birth weight even after adjusting for individual-level covariates (using



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TABLE 4
COEFFICIENTS FROM SPATIAL LAG REGRESSION MODELS OF CONTINUOUS BIRTH WEIGHT AND LOW BIRTH WEIGHT (ADJUSTED NEIGHBORHOOD MEANS)

| | CONTINUOUS BIRTH WEIGHT | | | | LOW BIRTH WEIGHT | |
|---|---|---|---|---|---|---|
| | ML (1) | | 2SLS (2) | | 2SLS (3) | |
| INDEPENDENT VARIABLE | Coefficient | SE | Coefficient | SE | Coefficient | SE |
| %African-American ...... | 2.43 | 3.36 | 2.58 | 3.38 | −.02 | .03 |
| %Mexican ................ | 3.01 | 2.04 | 2.89 | 2.05 | .02 | .02 |
| %poor families ........... | 1.73 | 2.64 | 1.02 | 2.77 | −.02 | .02 |
| Residential stability ...... | 2.37 | 2.28 | 1.55 | 2.43 | .00 | .02 |
| ln violent crime rate ..... | −9.16 | 3.57* | −7.50 | 3.96 | .04 | .03 |
| Exchange/voluntarism ... | 6.30 | 2.30** | 5.46 | 2.47* | −.02 | .02 |
| Spatial lag term ($Wy$) .... | .33 | .07*** | .53 | .21* | .69 | .35* |
| Intercept .................. | 74.69 | 8.18*** | 52.91 | 23.42* | −.08 | .09 |
| $R^2$ .......................... | .24 | | .29 | | .18 | |

NOTE.—ML is maximum likelihood and 2SLS is two-sided least squares. Data are from 1995-96 Chicago vital statistics, 1990 census, 1995 Chicago police statistics, and the 1995 PHDCN Community Survey.
* $P < .05$.
** $P < .01$.
*** $P < .001$.

the procedure described in note 15) and neighborhood-level covariates. Violent crime and exchange/voluntarism are the only significant neighborhood predictors of birth weight other than the spatial lag term. When the same model is estimated using the 2SLS approach, in model 2, the spatial lag effect becomes 59% larger ($\rho = .53$) and remains significant, while the violent crime rate becomes marginally nonsignificant ($P = .06$).[24] When the spatial lag term is introduced into the low birth weight model, as shown in model 3, none of the other neighborhood covariates remain significant. Nonetheless, the spatial effect is quite large in model

[24] The 2SLS approach is used to remove the correlation between $WY$ and the error term of the birth weight equation. In the first-stage regression, the spatial lags of the $X$ variables, $WX$ serve as instruments for $WY$. Anselin (1995*b*) argues that the $WX$ variables make ideal instrumental variables because they are strongly related to the endogenous variable, $WY$ (i.e., if $X$ is related $Y$ in the focal neighborhood, then $WX$ is related to $WY$ in first-order neighbors), but they are uncorrelated with the error term in the birth weight equation because the $X$ variables are already assumed to be uncorrelated with the error term, and the $WX$ variables are nothing more than the $X$ variables in the first-order neighbors. The 2SLS estimates are less efficient than the ML estimates, as evidenced by their higher standard errors (particularly on the spatial lag coefficient) in model 2 compared to model 1.



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3 ($\rho$ = 0.69), indicating that spatial externalities for low birth weight accrue mainly from unobserved factors in surrounding areas.[25]

The $\rho$ coefficient for the spatial lag term, $WY$, represents the change in a focal neighborhood's birth weight associated with a one-unit change in the birth weight of adjacent neighborhoods, and it is constrained to be between 0 and 1. The $\rho$ coefficient also conveys information about the strength of spatial externalities, as shown in equation (2), the so-called spatial multiplier process. For example ($\rho \times \beta$) represents the effect of a one-unit change in $WX$ on the mean birth weight of the focal neighborhood. In substantive terms, the $\rho$ coefficient represents the rate at which spatial externalities—i.e., effects from the observed and unobserved characteristics of adjacent neighborhoods—contribute to birth weight in the focal neighborhood. For continuous birth weight, $\rho$ is estimated to be between 0.33 (using ML) and 0.53 (using 2SLS), meaning that the total effects of observed and unobserved neighborhood-level causes of birth weight are about one-third to one-half larger when we take into account the effects of externalities from surrounding areas. For low birth weight, the effects of observed and unobserved causes in adjacent neighborhoods is an astounding 69% as large as it is in the focal neighborhood.

One drawback of the spatial lag regression model is that the $\rho$ coefficient combines spatial effects from all of the $X$ variables with those from the error term. To isolate the contribution that specific $X$ variables make toward spatial externalities, it is possible to run a model that contains $WX$ variables but no $WY$, as described in equation (3). However, since most of the independent variables are highly correlated with their corresponding spatial lag terms, multicolinearity is a big problem in these models.

Table 5 presents the neighborhood-level results from multilevel models of birth weight that contain a spatial lag term for exchange/voluntarism. The spatial lag for violent crime could not be included in this model because it was very highly correlated with the unlagged violent crime rate ($r$ = .87), so these models include only the spatial lag for exchange/voluntarism (the correlation between exchange/voluntarism and its spatial lag is 0.67).[26] The results in model 1 show that although the level of

[25] When the models in table 4 are rerun using the propensity score approach described in note 18, the effects of violent crime and exchange/voluntarism are reduced (the latter becomes nonsignificant in models 1 and 2), but the spatial effects remain strong and significant.

[26] Adding the spatial lag of crime to either continuous or low birth weight model does not change the significance of any of the coefficients. The effect of lagged crime is nonsignificant, but the sign on its coefficient is in the opposite direction of violent crime in the focal neighborhood, an indication that colinearity is a problem. It was not possible to reliably estimate potential spatial externalities from any of the other neighborhood variables due to multicolinearity.



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TABLE 5

NEIGHBORHOOD-LEVEL PREDICTORS AND SPATIAL EFFECTS FROM HIERARCHICAL MODELS OF CONTINUOUS BIRTH WEIGHT AND LOW BIRTHWEIGHT

| | CONTINUOUS BIRTH WEIGHT | | | | LOW BIRTH WEIGHT | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | | (2) | | (3) | | (4) | |
| INDEPENDENT VARIABLE | Coefficient | *t*-ratio | Coefficient | *t*-ratio | Odds Ratio | *t*-ratio | Odds Ratio | *t*-ratio |
| Neighborhood: | | | | | | | | |
| %African-American | .93 | .23 | 1.16 | .29 | 1.01 | .30 | 1.01 | .20 |
| %Mexican | 3.86 | 2.15* | 4.19 | 2.27* | 1.05 | 2.08* | 1.03 | 1.48 |
| %poor families | 2.50 | .80 | .36 | .11 | 1.00 | .04 | 1.00 | −.09 |
| Residential stability | 1.36 | .53 | −.71 | −.27 | 1.01 | .43 | 1.02 | .94 |
| ln violent crime rate | −8.50 | −2.38* | −5.86 | −1.59 | 1.05 | 1.10 | 1.03 | .59 |
| Exchange/voluntarism: | | | | | | | | |
| Focal NC | 4.28 | 1.67 | 4.37 | 1.78 | .96 | −1.64 | .96 | −1.86 |
| First-order neighbors | 6.86 | 2.55* | 5.61 | 2.11* | .98 | −.85 | .99 | −.48 |
| Focal NC × first − order neighbors | | | 6.98 | 3.63*** | | | .95 | −2.10* |
| Intercept | 3,231.19 | 1,946.91*** | 3,231.05 | 1,961.00*** | .04 | −147.44)*** | .04 | −147.88*** |
| %variance explained: | | | | | | | | |
| Neighborhood level | 98.64 | | 98.77 | | 93.56 | | 93.55 | |

NOTE.—Data are from 1995–96 Chicago vital statistics, 1990 census, 1995 Chicago police statistics, and the 1995 PHDCN Community Survey.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

exchange/voluntarism in the focal neighborhood is not significantly associated with birth weight, the spatial lag of exchange/voluntarism has a positive and significant effect on birth weight, meaning that proximity to social resources is a protective factor, above and beyond the level of resources in the focal neighborhood. Model 2 adds an interaction between exchange/voluntarism and its spatial lag to the model, and it is also significant, which indicates that spatial proximity to social resources is most important when the neighborhood itself has a high level of exchange/voluntarism. Adding this interaction term to the model also reduces the effect of violent crime to nonsignificance. Models 3 and 4 present the same models for dichotomous low birth weight. Although more neighborhood variables are significant in these models, the findings on the spatial context of exchange/voluntarism remain very similar: proximity to higher levels of social resources is protective against low birth weight, and this protective effect is stronger when the focal neighborhood is also high in exchange/voluntarism.

The results from table 5 add more insight into the spatial dynamics of birth weight, by showing more clearly that neighborhood social processes produce positive spatial externalities for birth weight and that the protective effects on birth weight are multiplicative when social resources are abundant in both the focal neighborhood and surrounding areas. However, analysis of the residuals from the models in table 5 revealed that there was still residual spatial autocorrelation, meaning that the spatial lag of exchange/voluntarism does not fully capture all of the spatial processes that were estimated by the $\rho$ coefficients in table 4.

## DISCUSSION AND CONCLUSION

The results suggest that neighborhood mechanisms and spatial externalities are both important for understanding the influence of the social environment on maternal and infant health. One major finding is that violent crime and the combined scale of reciprocal exchange and participation in voluntary associations are the two most robust neighborhood predictors of birth weight, even after controlling for the potentially confounding individual-level covariates. These neighborhood mechanisms also appear to mediate the effects of structural factors, such as poverty and residential stability. The frequent occurrence of violent crime in a neighborhood may provoke fear and concern for safety that could induce stress among neighborhood residents, while social resources that accrue from relations among neighbors and collective engagement in local organizations provide a means of adapting to stressful aspects of neighborhood life. This is not to say that structural factors, such as the con-



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centration of disadvantage, do not matter for health, but rather that they are important precursors that create conditions in which sources of stress and modes of adaptation differentially flourish.

Another major finding is that there are significant and quite strong spatial effects on both continuous and low birth weight. Even after adjusting for potentially confounding covariates at both the individual and neighborhood levels, the correlation between the mean birth weight of a focal neighborhood and that of its adjacent neighbors was estimated to be as high as 0.53 for continuous birth weight and 0.69 for low birth weight. This suggests that analysts who focus only on properties of a person's immediate neighborhood are missing potentially strong contextual influences from the wider social environment. It is difficult to pinpoint which neighborhood factors produce the strongest spatial externalities, in part because of the multicolinearity that results from strong correlations between the characteristics of a focal neighborhood and its surrounding areas, but also because some of the spatial effect is attributable to spatial externalities from unobserved factors. There is, however, evidence that neighborhoods with reciprocal exchange and participation in local voluntary associations do produce positive spatial externalities that are beneficial for the health of women not only in those areas, but also to those living in adjacent neighborhoods. Moreover, there is evidence of an interaction between the proximal and distal social environment in that the protective effect of neighborhood social processes is strongest when women are exposed to it both in their neighborhood and in surrounding areas.

These findings of both proximate and distal social environmental influences on health have three major implications for future research. First, this study calls into question the conventional strategy for analyzing social environmental effects on health, which is to collect data, usually from the census or administrative sources, on the structural composition of neighborhoods and to focus exclusively on the internal properties of a given place. These results suggest that collecting more data on neighborhood mechanisms and expanding the scope of the analysis to take geographic location more seriously would enhance our understanding of the social environment and health and perhaps lead to stronger evidence that social context does indeed matter for infant and maternal health. The same logic extends to other forms of individual health, well-being, and behavior.

Second, although the finding that there are strong spatial effects on birth weight is intriguing, more needs to be learned about spatial externalities both from a research and a public health perspective. From a research perspective, the results indicate that there are spatial processes not only in the observed $X$ variables, but also in the error term, which suggests that there are potentially important sources of spatial externalities



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for health that are currently unobserved. The findings also suggest something important about what these unobserved factors may be: characteristics of a wider spatial region rather than a particular area. Perhaps if we had more data on environmental features that span multiple neighborhoods—such as the physical environment, proximity to medical care, and the quality of local services, stores, institutions, and infrastructure, and social networks that cut across geographic neighborhoods—we might be able to explain more of these spatial effects, which should ultimately be the analytical goal. From a public health standpoint, understanding how and why spatial externalities occur may be critical in designing community intervention strategies. One major implication for public policy is that treating neighborhoods as "islands unto themselves" for the purposes of intervention is potentially misguided. However, the findings also have promising implications for neighborhood intervention efforts, because they suggest that if interventions can foster social processes that are protective against adverse health outcomes, they may spawn positive spatial externalities that could benefit the health of individuals in a wider geographic area.

Finally, although there have been many calls for neighborhood research to give greater attention to the microcontext of neighborhood environments, primarily by using smaller units of analysis to operationalize the idea of a neighborhood (Bond Huie, Hummer, and Rogers 2002), these findings are a reminder that research must also not neglect more macrolevel concerns about the interdependence of neighborhoods and how entire regions of the city are shaped by broader social forces, such as residential segregation. In short, the idea that health outcomes in a given neighborhood may be affected by what happens in the neighborhood next door suggests new research directions that could combine both micro- and macrolevel perspectives on neighborhood environments and could add new meaning to the old real estate adage that "location matters."

## APPENDIX

TABLE A1
Correlations among Neighborhood-Level Covariates

| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. %African-American | . . . | | | | | |
| 2. %Mexican | −.45* | | | | | |
| 3. %poor families | .54* | .02 | | | | |
| 4. Residential stability | .10 | −.18* | −.39* | | | |
| 5. ln violent crime rate | .75* | −.10 | .76* | −.29* | | |
| 6. Exchange/voluntarism | −.22* | −.19* | −.55* | .58* | −.53* | . . . |

* $P < .001$.



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