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Homicide as Infectious Disease: Using Public Health Methods to Investigate the Diffusion of Homicide

April M. Zeoli, Jesenia M. Pizarro, Sue C. Grady and Christopher Melde

This study examined the spatial and temporal movement of homicide in Newark, New Jersey from January 1982 through September 2008. We hypothesized that homicide would diffuse in a similar process to an infectious disease with firearms and gangs operating as the infectious agents. A total of 2,366 homicide incidents were analyzed using SaTScan v.9.0, a cluster detection software. The results revealed spatio-temporal patterns of expansion diffusion: overall, firearm and gang homicide clusters in Newark evolved from a common area in the center of the city and spread southward and westward over the course of two decades. This pattern of movement has implications in regards to the susceptibility of populations to homicide, particularly because northern and eastern Newark remained largely immune to homicide clusters.

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The theoretical and practical implications of the findings, as well as recommendations for future research, are discussed.

Keywords homicide; public health; gangs; firearms

Introduction

The public health approach to homicide emphasizes the identification of populations at-risk for involvement, trends in behavior, and primary prevention. A particularly interesting application of a public health model to this crime type is the hypothesis that violence acts like an infectious disease (see, e.g. Huesmann, 2012). If homicide is infectious, it should diffuse through communities, infecting those susceptible, and that diffusion should be detectable. Homicide may beget homicide through retaliation (Kubrin & Weitzer, 2003), the arming of people with firearms (Fagan, Wilkinson, & Davies, 2007), through a greater willingness to use lethal violence to save face or protect oneself (Pizarro & McGloin, 2006), and as a mechanism of social control (i.e. self help) (Black, 1983) to govern the behavior of others when formal legal processes are not practical (Kirk & Papachristos, 2011). We may be able to prevent homicide, then, by tracking and predicting its movement through communities using public health methods, and halting its movement via public health-informed primary prevention strategies (see US Office of the Surgeon General, National Center for Injury Prevention & Control, National Institute of Mental Health & Services, & Center for Mental Health Services, 2001), which can supplement traditional deterrence-based approaches (i.e. pulling levers and incapacitation).

The purpose of this study is to investigate the diffusion of homicide in Newark, New Jersey, a city that historically has had a homicide rate over three times greater than that of the USA. We examine the possible diffusion of homicide incidents that occurred from 1982 through 2008 by using spatio-temporal clustering techniques from the field of medical geography. The main hypothesis behind the concept of diffusion as applied to homicide is that the spatio-temporal distribution of homicide is not random. If homicide spreads through diffusion-like processes, then researchers and practitioners in public health and criminal justice may predict its spread and employ the principles of infectious disease control to reduce the incidence of this crime.

In the following sections, we explain the process of diffusion and apply it to homicide, with a focus on gang and firearm homicide. Next, we briefly examine methodologies that criminologists have employed to investigate diffusion. A description of the research site, methodology, and findings follows. Finally, the theoretical and practical implications of the findings as well as recommendations for future research are discussed.

The Diffusion Process

Spatial diffusion describes the movement of a phenomenon, such as a disease or type of violence, from a point of origin across geographical areas. A phenomenon may either spread from its point of origin to other areas, while remaining at its origin (i.e. expansion diffusion), or it may leave its point of origin as it spreads to other geographic areas (i.e. relocation diffusion) (Haggett, 2000). While it is often simply referred to as spatial diffusion, there is necessarily a temporal feature, as movement takes time.

Although homicide is an act of violence and does not fit the medical definition of a disease, the elements required for disease diffusion may be relevant for the movement of homicide through communities.[1] According to Haggett (2000), these elements are as follows: (1) a source or infectious agent; (2) a mode of transmission; and (3) a population susceptible to transmission. The first required element is a *source* of disease or *the infectious agent* that causes the disease. The source of homicide may be portrayed as those conditions that increase the likelihood that interactions will lead to homicide. Interactions, such as drug transactions or disputes aimed at saving face, that do not lend themselves to resolution through the legal system are disproportionally related to homicide in areas with high homicide rates (see Papachristos, 2009). The lethality of these interactions increases in the presence of crime facilitators such as firearms, drug markets, and gangs (Pizarro, 2008).

The second element required for disease spread is a *mode of transmission* by which people come into contact with the source of disease or infectious agent. Homicide may spread through social networks via direct contact from person to person (e.g. from the crime facilitator within a gang to another gang member) or through changes in social interactions, more generally. For example, a single homicide of a gang member may precipitate multiple more homicides as the initial death is avenged, which in turn may lead to additional retaliatory homicides (Kubrin & Weitzer, 2003; Papachristos, 2009; Pizarro & McGloin, 2006). Fear of homicide in nearby areas may precipitate arming by individuals who believe they must use lethal force to defend themselves because they perceive others are willing to resort to lethal measures, and they do not trust law enforcement's ability to protect them (e.g. Griffiths & Chavez, 2004; Kirk and Papachristos, 2011). As Rosenfeld, Baumer, and Messner (2007, p. 124) concluded, "social trust is associated with criminal homicide … and that homicide rates and firearm prevalence appear to be mutually reinforcing." Importantly, this research demonstrates that homicide can spread without direct contact between parties involved in particular precipitating events, but also through the lasting impact of prior homicides on social interactions.

Finally, for homicide to spread as a disease, a *population susceptible to transmission* must be present. For homicide, the population most susceptible

1. While we do not intend a literal application, drawing parallels between the elements of disease diffusion to known risk factors for homicide is instructive in understanding how homicide may move through communities and what factors may be appropriate for prevention and intervention efforts.

is young minority males who reside in economically disadvantaged areas (Pizarro, Zgoba, & Jennings, 2011). Anderson (1999) and Wilson (1996) present theoretical models that explain population group susceptibility to homicide and possible modes of transmission. They suggest that high crime and violence in inner city communities emerged with the disappearance of blue-collar work-related industries. That is, the closing of industries that employed a high number of low-skill workers in well-paying jobs sparked citizen out-migration from city centers, resulting in the most disadvantaged residents, who were predominantly minority members, being left behind. Poor police relations with racially segregated and economically disadvantaged communities left many citizens feeling vulnerable and unprotected by law enforcement (Sampson & Jeglum-Bartusch, 1998). The lack of legitimate work opportunities and distrust of agents of formal social control resulted in the proliferation of illegal behaviors associated with black markets, such as drug dealing and stolen goods fencing. Consequently, over time, residents adopted attitudes and behaviors consistent with Black's (1983) notion of self-help to ensure survival, including aggressive behaviors (Anderson, 1999; Wilson, 1996) and the reliance on firearms for self-preservation (Kirk & Papachristos, 2011).

Not everyone in the susceptible population engages in homicide or violence, however. Numerous individuals are exposed to the knowledge of a specific homicide, but only some may be at risk of committing homicide. Researchers have identified individual- and community-level factors that may increase an individual's susceptibility to homicide perpetration. For example, gang members and those who live criminal lifestyles may be uniquely susceptible (Pizarro et al., 2011). For instance, Decker and Pyrooz suggested, "gang homicide rates are estimated at up to 100 times that of the broader population" (2010, p. 129).

Empirical evidence suggests that gangs may, indeed, play a role in the diffusion of homicide. Cohen and Tita (1999) used police record data annually from 1991 to 1995 to detect spatial diffusion of drug- and gang-related homicide in Pittsburgh census tracts. To examine dynamic changes over time, Cohen and Tita (1999) used an innovative method of comparing changes in homicide levels of local-neighbor pairs of census tracts to determine if "transitions that are compatible with diffusion … are more likely than expected based on the prevalence of other transitions to the same local-neighbor outcome" (p. 474). While they hypothesized that drug markets increased the risk of diffusion of homicide, the analysis found no evidence that drug-related homicides spread throughout the community. However, their evidence suggested that "particular patterns of rivalries among gangs might underlie the spread of gang-related homicides among apparently disjoint spatial units" (Cohen & Tita, 1999, p. 491).

Rosenfeld, Bray, and Egley (1999) also used police data to examine the spatial diffusion of gang-motivated, gang-affiliated, and nongang youth homicides in St Louis from 1990 to 1995. Analyses suggested that homicides were not randomly placed, but instead were clustered in block groups with socioeconomic disadvantage and high percentages of African-American residents. Only gang-motivated homicides were found to spread across block groups beyond what

would be expected given disadvantage and racial composition alone (Rosenfeld et al., 1999). This study, therefore, did not suggest that diffusion processes were present for homicide more generally; indeed, the research results suggest that systematic movement of crime types across space may not be applicable to nongang crime outcomes.

The Examination of Diffusion in Criminology

In addition to the studies mentioned above, researchers have long studied spatial variations in the locations of crime in specific areas (see Groff, Weisburd, and Yang (2010) for a brief overview of this literature) and spatio-temporal patterns of crime. For example, Ratcliffe and Rengert (2008) found evidence of a near-repeat pattern of shootings in Philadelphia and suggested that these events could be motivated by a need for retaliation in communities and circumstances in which redressing wrongs could not be done through legal means. Overall, this line of research, which demonstrates that crime locations often cluster systematically (Groff et al., 2010), generates questions that have implications for diffusion, such as whether high-crime areas cluster together, and whether and how the crime densities of neighboring areas affect each other (Cohen & Tita, 1999; Harries, 2006). However, while existing studies are suggestive of or have implications for crime diffusion (e.g. Cohen & Tita, 1999; Cork, 1999; Griffiths & Chavez, 2004; Harries, 2006; Mears & Bhati, 2006; Messner et al., 1999), most do not adequately track spatio-temporal distributions. This is partially due to the large size of the unit of analysis used (Tita & Greenbaum, 2009), and the use of analytic techniques that do not capture the dynamic processes of movement through space and time as "model identification often [became] impossible when both types of dependency [were] present" (Tita & Cohen, 2004, p. 172).

Homicide is a rare event, and large spatial or temporal units of analysis are often used to create aggregated homicide counts large enough to overcome problems of count instability or low statistical power. These large units of spatial analysis (i.e. counties and cities) may obscure changes in local patterns of diffusion that could be important for prevention efforts. Despite this aggregation, however, advances have been made that provide insight into the movement of homicide. For example, Messner et al. (1999) estimated clusters of homicide rates in counties in three Missouri Metropolitan Statistical Areas for the aggregated time periods of 1984-1988 and 1988-1993, and found that the clusters differed from period to period, suggesting movement. Cork (1999) used annual, city-level data from 1976 to 1996 to better detect temporal trends in an investigation of the diffusion of youth firearm homicide associated with the spread of crack markets across the USA. Cork found that growth in crack markets precipitated the growth in youth firearm homicide, and that these trends appeared to start on the coasts and then move to the interior of the country (1999).

More recently, researchers have analyzed crime and/or homicide trends in smaller spatial units, such as census tracts (Griffiths & Chavez, 2004), socially

meaningful communities (Mears & Bhati, 2006), and "micro" spaces, such as street segments (Braga, Papachristos, & Hureau, 2010; Groff et al., 2010; Weisburd, Bushway, Lum, & Yang, 2004). In addition, advancements in modeling the spatial and temporal distributions of crime have been made. Researchers have modeled the temporal trajectories of homicide and crime within defined spaces and analyzed whether certain trajectory types clustered together (Braga et al., 2010; Griffiths & Chavez, 2004; Groff et al., 2010; Weisburd et al., 2004). For example, Griffiths and Chavez (2004) studied the trajectories of firearm, nonfirearm, and total homicide in Chicago's census tracts using annual data from 1980 to 1995. They found patterns suggestive of diffusion, such as the tendency of tracts with low nonfirearm homicide trajectories to be more likely to have high or increasing firearm homicide trajectories when tracts with both high firearm and nonfirearm homicide trajectories were nearby (Griffiths & Chavez, 2004). The authors indicated that this provided support for "defensive diffusion," whereby those in spaces with low nonfirearm trajectories may have armed themselves with firearms for fear of spillover of violence from nearby spaces. While these studies utilized novel methodologies to understand homicide and crime trajectories in spatial units, they were not able to determine whether homicide or crime clusters move into, or encompass, spaces outside of their predefined units. As a result, we attempt to fill this void in the literature with the current study.

The Present Study

This study was designed to detect whether homicide clusters, and to determine whether those clusters moved through space and time. In other words, did homicide diffuse through Newark? In doing this, we hypothesize that *homicide diffused in a similar process to an infectious disease with firearms and gangs operating as the infectious agents*. We therefore tested for spatio-temporal clusters of overall homicides, gang-related homicides, and firearm homicides to determine whether (1) homicide, in general, diffused throughout Newark; (2) whether gang-related and firearm homicides diffused throughout Newark; and (3) whether the diffusion of gang-related and firearm homicide was different from overall homicides.

This study extends the literature in three ways. First, we use an analytic technique from the field of medical geography that examines *both* spatial and temporal trends concurrently and allows us to detect clusters of homicides of varying geographic size (in spatial units of census tracts) and length (in temporal units of months). By using this analytic technique, we are able to show the movement of homicide clusters across Newark throughout the study period.

Second, we examine a relatively long time period, from January 1982 through September 2008 (almost 27 years), allowing us to detect both short-term and long-term movement. This is beneficial since while retaliation may be a relatively quick process (see Ratcliffe & Rengert, 2008), cultural changes

that make homicide increasingly likely take time to occur (see Fagan et al., 2007; Kirk & Papachristos, 2011; Rosenfeld et al., 2007). Also, the diffusion process of homicide may be lengthened as those resistant to homicide become susceptible. Cork (1999) used the Bass model of innovation diffusion to investigate the diffusion of crack markets and gun homicide through cities. This model suggests that diffusion begins as "innovators" adopt the behaviors in question. These innovators influence others to adopt the behaviors, who in turn influence even more people to adopt the behaviors. Eventually, the behavior reaches saturation in the population of potential adopters and the diffusion process ends. Theoretically, then, the diffusion process may last as long as there exists an adequate number of susceptible people (potential adopters) to comprise new cases.

Finally, we utilize the relatively small spatio-temporal unit of analysis of the census tract-month. The examination of smaller spatio-temporal units reduces the likelihood that spatio-temporal patterns are obscured by aggregation within larger units such as cities and counties, and that the characteristics of the areas and time periods vary considerably (Braga et al., 2010; Cohen & Tita, 1999). It is imperative to acknowledge that despite the benefits of using census tracts as the spatial unit of analysis, this approach also has limitations. Some criminologists posit that socially significant neighborhoods are a more useful unit of analysis (Tienda, 1991) because for many people a neighborhood is not necessarily a geographic space, and living arrangements tend to be flexible and fluid—one can have an official address of residence but spend most of the time in an another place. Because census tracts are still large enough to contain areas with diversity in terms of population, socioeconomic status, and risk of violence (Groff et al., 2010), other criminologists instead suggest further disaggregating spatial units and examining street segments (e.g. Braga et al., 2010) and block groups (Taylor, 1997).

Some criminologists posit, however, that the size of the unit of analysis may not be important in the examination of the spatial dynamics that lead to crime because the patterns exhibited in smaller units are a partition of larger social structural spatial processes (Sampson, Morenoff, & Gannon-Rowley, 2002). Sampson et al.'s (2002, p. 446) review of the neighborhood effects literature suggests,

> empirical results have not varied much with the operationalization of unit of analysis. The place stratification of local communities by factors such as social class, race, and family status is a robust phenomenon that emerges at multiple levels of geography, whether local community areas, census tracts, political districts, and other neighborhood units.[2]

2. Given our temporal unit of months, using census tracts as the spatial unit resulted in 28,890 spatio-temporal observations. Due to the complexities of the analytic strategy employed, a smaller spatial unit would have been more intensive to model.

Furthermore, while a smaller spatial unit than census tracts may be more reliable in distinguishing safe places in unsafe neighborhoods and unsafe places in safe neighborhoods, for example, we decided to use census tracts due to the uncommonness of homicide and to ensure an adequate case and population size for our analytic technique while maximizing the potential for homicide rate stability.

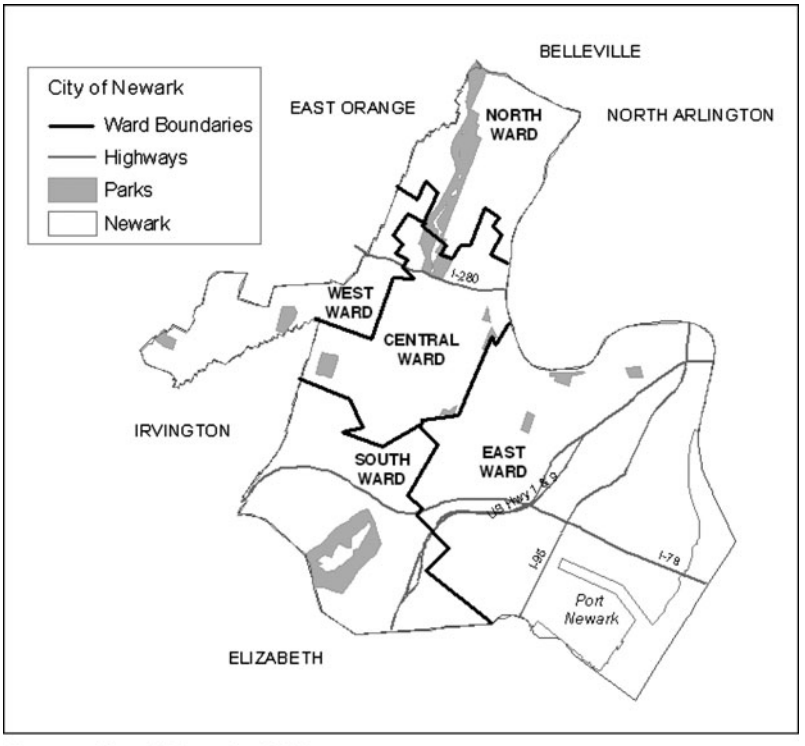
Methods

The city of Newark

Newark is the largest city in the state of New Jersey. Geographically, it covers approximately 24 square miles and houses roughly 277,000 people (US Census Bureau, 2010), or 11,000 per square mile. Approximately 84% of the population is nonwhite with the predominant minority racial/ethnic groups being African-American (50%) and Hispanic (34%). Five political wards, which have an evenly distributed population and appear to be racially segregated, make up the city (City of Newark, 2004) (See Appendix A). The mainly residential North Ward is predominantly inhabited by Hispanic residents. The highly residential East Ward contains numerous ethnic neighborhoods, predominantly composed of European immigrants. The Central Ward, while geographically the smallest of the five wards, has historically been the most densely populated because it contains most of Newark's major public housing complexes. The majority of Central Ward residents are African-American. The West and South Wards are largely similar: African-Americans, followed by Haitians and Hispanics, comprise the majority of their populations (Figure 1).

Newark was once regarded as one of the major transportation, manufacturing, and financial centers of the USA. However, this started to change in the 1950s after businesses began migrating to neighboring suburbs, resulting in a spiral of economic depression and citizen out-migration. Consequently, Newark's population declined from approximately 405,000 in 1960 to approximately 277,000 in 2010. Since the 1960s, the city has continued to face multiple social problems. In 1999, for example, approximately 25% of families earned an income below the poverty line and the median household income was 26,913 dollars (US Census Bureau, 2000). There is also a high rate of family disruption, with approximately 25% of all families headed by single mothers. Furthermore, 38% of the population over 25 years old have completed less than a high school degree, and 9% of the population 16 years and older are unemployed (US Census Bureau, 2000). Newark also has a high homicide rate; the average homicide rate during the study period (1982-2008) was 30.5 per 100,000 (See Figure 2). This rate is over four times higher than the average national homicide rate.

Police investigation and intelligence files suggest that the recognition of a gang problem did not occur until the late 1990s. Prior to this, Newark police recognized the existence of crews, organized by neighborhoods throughout the



Source: City of Newark, 2004

Figure 1 Reference map of Newark wards.

city, who controlled the drug trade. Law enforcement were aware of gangs, such as the Latin Kings and Ñetas, within the city's borders, but these groups were not considered a problem because their involvement in violence was both rare and targeted at members of their own gangs. In the mid-1990s, however, a Blood gang member from the west coast migrated to Newark to recruit new members. He claimed existing drug territories in the city for the Bloods and required individuals who wanted to sell drugs in the area to become members. Individuals who did not adhere to his request had to relocate their drug territories or were killed. Soon after this, competing neighborhood crews began adopting rival gang names. For example, the crews from the city's New Community low-income housing project located in the Central Ward began to call themselves Bloods, while their rival crew from the Prince Street housing projects, also in the Central Ward, began to call themselves Crips.

The first recorded gang-related homicide involving a Blood occurred in August 1997 in the South Ward of the city. Investigation files suggest that after these incidents, Bloods were responsible for all of the gang-related murders in the city until 1999. It was not until mid-1999 that the first recorded homicide involving a Crip occurred, as well as a handful of homicides involving Latin Kings and Ñetas in the North Ward of the city. However, most of these incidents also involved Blood members as either perpetrators or victims.

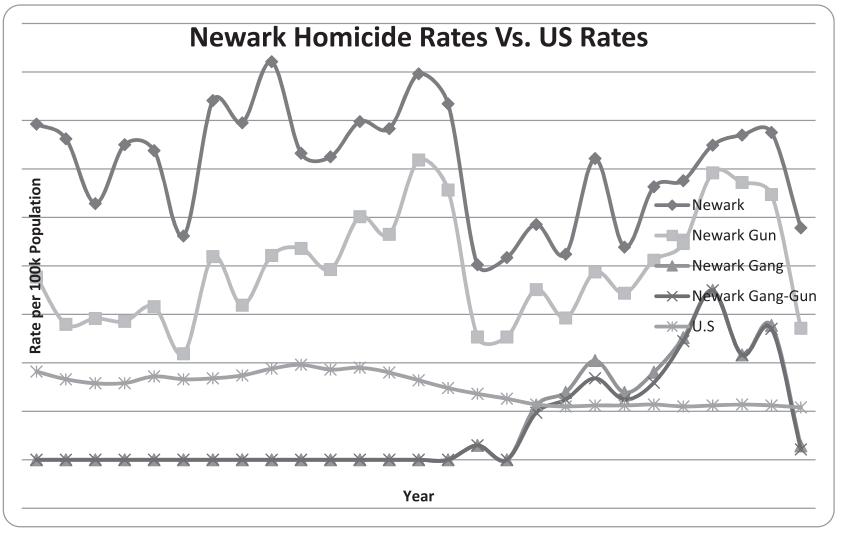


Figure 2 Newark and the US homicide rates from 1982 through 2008.
Note. 2008 data on rates per 100 k population for Newark Firearm, Newark Gang, and Newark Gang-Firearm reflect the period of 1 January 2008 through 30 September 2008. Data for the overall homicide rate for 2008 were obtained from the Uniform Crime Report (UCR).

Homicide Data

Data for this study were obtained from the Newark Police Department's Homicide Unit. Researchers collected homicide information for a total of 2,366 homicide incidents from incident log sheets and investigation files compiled by detectives who investigated each case from 1 January 1982 to 30 September 2008. The investigation files contained detailed information on the homicide incident and characteristics of victims and offenders, which have been described elsewhere (see Pizarro, 2008). The majority of both victims and offenders were African-American males (66% of victims and 78% of offenders). Victims were on average 30.8 years of age (s.d. = 14) and offenders were an average age of 26 years (s.d. = 10). In this study, we focused on the date and location of the homicide incident, the weapon used, and whether the victims or offenders were gang-affiliated.

Because we relied solely on Newark Police Department intelligence and investigation data, there is a possibility that we do not have data on every homicide that occurred in Newark; some homicides may not have come to the attention of the police or been classified as a homicide. In addition, because police have not identified all of the homicide offenders or all of the gang members in the city, one can assume that there is an undercount of gang-related incidents in the data. Related to this, because we do not have data on homicides outside Newark, we are neither able to examine whether homicides that occurred in Newark sparked a diffusion process that generated homicides in neighboring

jurisdictions, nor are we able to detect whether homicides in Newark were in response to a diffusion process originating in a neighboring jurisdiction.

Homicide incidents were coded as gang-related if either the victim or suspect were identified by law enforcement as being a member of a gang, consistent with the Los Angeles Police and Sheriff's Departments' categorization as described by Klein and Maxson (1989). Firearm homicides are cases in which the victim died from a gunshot wound. Overall, 64% of the homicides were committed with a firearm, while 11.3% were gang-related. Interestingly, firearms are overrepresented in gang homicides, as approximately 94% of these incidents were committed with a firearm. Although gang-related homicides appear to be only a small percentage of the incidents in Newark, it is important to note that this may be due to the police department not recognizing the presence of gangs in the city until mid-1997. Since their identification, however, gang-related homicides comprise approximately 31% of all the homicide incidents that occurred from 1997 to mid-2008.

Statistical Techniques

This study retrospectively detected space-time clusters, based on census tract-months, of overall, gang-related and firearm homicide in Newark from January 1982 through September 2008 using the cluster detection software SaTScan v.9.0 (Kulldorff, 2011a).[3] SaTScan has been used in many health studies as a surveillance tool to explore clusters of disease in space, time, and space-time (Kulldorff, 2011b), and has also been used in a limited number of studies to explore crime clusters, including spatio-temporal clusters of homicide in Brazil (Ceccato, 2005). A discrete Poisson model was used in SaTScan in which the number of homicides in each census tract was assumed to be Poisson-distributed, according to the underlying population at risk. In this study, the population at risk referred to the population in the census tract in the decennial census closest in time to the actual homicide (US Census Bureau, 1980, 1990, 2000).[4] SaTScan is operated by scanning an ellipse window across the centroids of all census tracts ($n = 90$) in Newark noting the number of observed and expected homicides inside the window at each location. The expected number of cases in each census tract was calculated as:

$$E[h] = p \times H/P$$

where h was the observed number of homicides, p was the population in the census tract of interest, and H and P were the total numbers of homicides and population in Newark, respectively. A relative risk of homicide for each census tract-month was then calculated by dividing the observed number of homicides

3. The temporal unit used to investigate diffusion was one month. We did not put constraints on the models as to how long a clustering of homicides was allowed to last.
4. Future research should conduct a linear interpolation to reduce temporal measurement error.

by the expected number of homicides. The alternative hypothesis was that there was an elevated risk of homicide within the scanning window as compared to outside. Under the Poisson assumption, the likelihood function for a specific window was proportional to:

$$\left(\frac{h}{E[h]}\right)^{e}\left(\frac{H-h}{H-E[h]}\right)^{c-e} I()$$

where H is the total number of homicides, h is the observed number of homicides within the window, and $E[h]$ is the expected number of homicides within the window under the null hypothesis of there being no difference. Because the analysis is conditioned on the total number of cases observed, $H-E[h]$ is the expected number of cases outside the window. $I()$ is an indicator function, with $I() = 1$ when the window has more cases than expected under the null hypothesis and 0 otherwise (Kulldorff, 2011a). Hypothesis testing was conducted using 999 Monte Carlo simulations. A test statistic was calculated for each random replication as well as for the real data-set. If the latter was among the 5% highest, the test was significant at the .05 level (Kulldorff, 2011b).

A space-time analysis was also conducted. Our modeling parameters included scanning for clusters of geographic sizes that would capture between zero and 15% of the population at risk for homicide. Fifteen percent was chosen as the ceiling because it roughly represents the percentage of the population in Newark who are African-American males aged 15-44 years. We represented risk in this way because African-American males aged 15-44 years comprise the majority of homicide victims in Newark during the time period. We also scanned for temporal clusters in 50% of the population that were at least one month in length of time, and we adjusted for potential increases or decreases in temporal trends in the data.

Our space-time clusters were constrained within a 1.5-mile ellipse as research on the traveling patterns of Newark homicide victims prior to their murder suggest that, on average, homicide victims are killed 1.45 miles from their residence (Pizarro, Corsaro, & Yu, 2007). As a result, the potential at-risk locations in our study spanned 1.5 miles from the census tract centroid being scanned. The clusters detected could overlap in space; however, we did not allow pairs of clusters to be contained within each other's centers. It was important for clusters not to share their centers in order to assess the potential for homicide diffusion in space and time. The computing time for each of our models was approximately 10 h.

Results

The space-time clusters output from SaTScan were mapped at the census tract level in ArcGIS 9.3 (Environmental Systems Research Institute, 2004) with

shading and patterns differentiating the onset years of the clusters. The ward boundaries are displayed on the cluster maps. The duration of clusters in time and their Relative Risk scores (RRs) are included in a graph below each map. All of the clusters presented in the results section were statistically significant at the $p < .05$ level.

Figure 3 displays a pinpoint map of each homicide that occurred in Newark from 1982 through September 2008. This map suggests that homicides occurred in all parts of the city, and that almost the entire city appears to be a hot spot. Indeed, it appears that there are only a few "cool spots" in areas with low population density within the North and East Wards.

Figure 4 shows the onset of clusters of overall homicides in 1982 covering most of the Central Ward and contiguous West Ward. A new onset of clusters occurred in 1984 and 1985, extending farther west in the West Ward and further south in the Central Ward into the South Ward. In 1987 and 1988, other clusters appeared in the far west of the West Ward, extending south of the Central Ward and southeast into the East Ward. All of the clusters of overall homicide with onset in the 1980s extended through the mid-1990s, with the latest end date in 1997. The range in RRs of homicide in the clusters was 1.91-2.64. Between 1997 and 2000, there were no new clusters of overall homicides in Newark, which is consistent with the national and Newark trends of decrease in overall homicides.

Figure 3 Pin map of all homicides in Newark, NJ, USA, 1982-2008.

The map on the right side of Figure 4 displays the onset of clusters in the 2000s, showing a slightly different spatial pattern beginning with clusters only in the west side of the Central Ward extending to contiguous tracts in the West and South Wards. The new onset of clusters in 2001 and 2003 extended farther into western and southern Newark. These clusters generally extended in time through 2007 or 2008. The range in RRs of homicide in these clusters was 2.07-2.54. These findings suggest that there was expansion diffusion of overall homicides in Newark between 1982 and 2008 with a decline in 1997 and rise in 2000. These clusters began in the Central Ward and over time appear to diffuse into the West and South Wards. After 1997, there are no clusters in

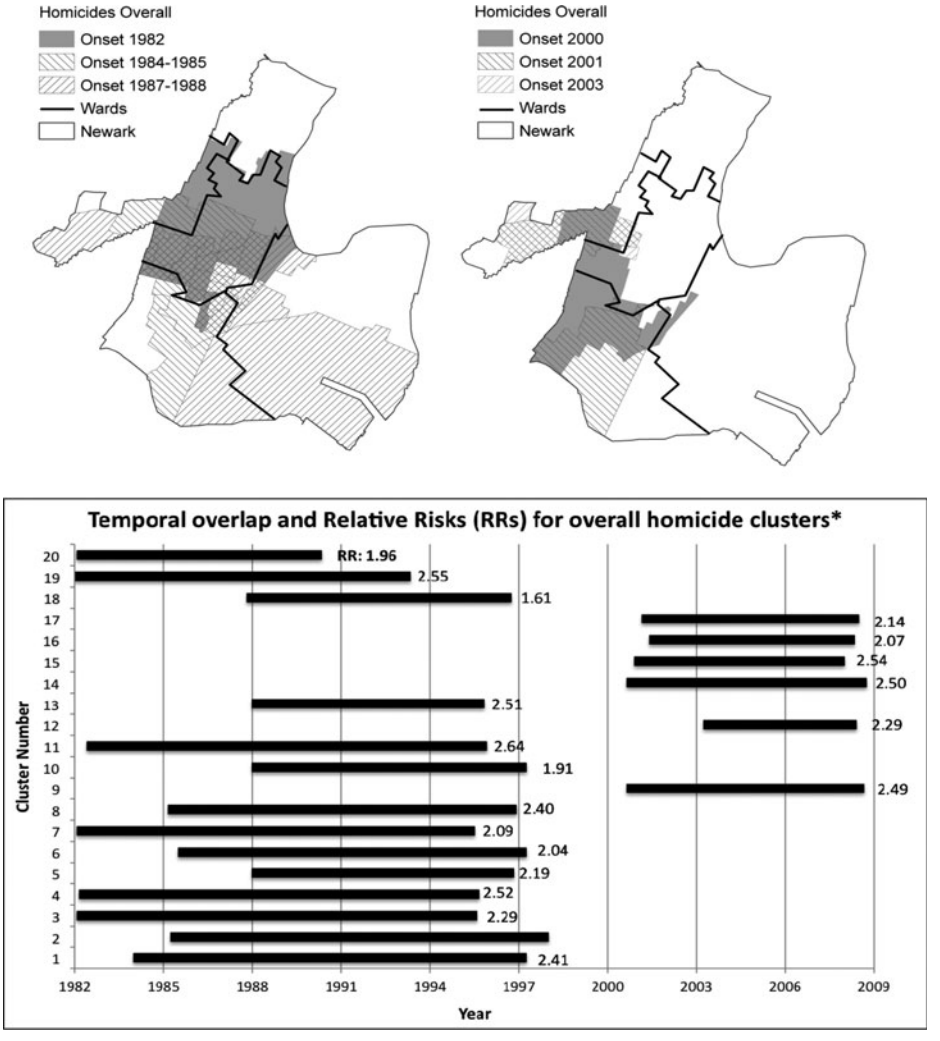


Figure 4 Space-time clusters of overall homicides in Newark, NJ, USA, 1982-2008.
*All clusters are significant at $p < .01$.

previously covered parts of the Central and West Wards, suggesting relocation diffusion.[5] While there appears to be some diffusion southeast into the East Ward on the periphery of the airport in the 1980s and 1990s, these clusters were not sustained in the 2000s.[6]

Figure 5 is a map of the onset and spatial distribution of firearm homicide clusters in Newark. Beginning in 1983 and 1984, there was a band of clusters extending from the north end of the Central Ward to the southeast end of the South Ward and immediately west in the West Ward. From 1998 through 1993, new clusters of firearm homicides emerged to cover the full extension of the West Ward and the southwest and west portion of the South Ward, suggestive of expansion diffusion during that time period. In 2001, new clusters of firearm homicides appeared in the far south of the South Ward and western portions of the East Ward. The range in RRs of firearm homicide in the clusters was 2.09-2.92.

Figure 6 is a map of the onset of clusters of gang-related homicides in Newark beginning in 1997 extending through 2007. The earliest onset of clusters, in 1997, occurred in the lower half of the Central Ward and contiguous tracts in the West and South Wards. In 1999, gang-related clusters of homicides were detected in the upper and lower tracts of the Central Ward. The onset of clusters in 2000 and 2001 extended farther west in the West Ward and south in the South Ward, suggestive of diffusion into these areas over time. The range in RRs of gang-related homicide in these clusters was 3.46-7.33.

Discussion

The present inquiry examined whether detectable patterns of movement in space and time of homicide clusters emerged for the city of Newark from 1982 through 2008. We hypothesized that the distribution of this crime was not random, but that it moved in a process similar to an infectious disease, with

5. It is possible that the absence of clusters in previously covered parts of the Central and West Wards after 1997 is the result of significant negative spatial autocorrelation (false-negative finding). However, the abrupt and persistent absence of clusters in these locations through 2008 is more suggestive of changing homicide-population processes internal to these areas or the introduction of an external intervention resulting in reduced homicide compared to the West and South Wards. More specifically, we suspect that this might be due to changes in public housing in the city, which resulted from the tearing down of high-rises in the areas during the late 1990s. Nonetheless, to fully reconcile the presence of negative spatial autocorrelation in trajectories of homicide diffusion requires testing for significant heterogeneity in homicides in these areas across the time period. In our study, we implemented the local *G*-statistic (Lee & Wong, 2001) on the homicide data from 1982 to 2008 and did not find significant negative spatial autocorrelation in these parts of Central and West Wards, supporting our hypothesis of relocation diffusion.

6. The airport appears as part of homicide clusters due to the modeling parameter of constraining the ellipse window to 1.5 miles. The airport is contained in a large census tract in the East Ward and if the centroid of that tract falls within a 1.5 buffer positioned on a contiguous tract centroid, then it is included in a cluster if that cluster is significant.

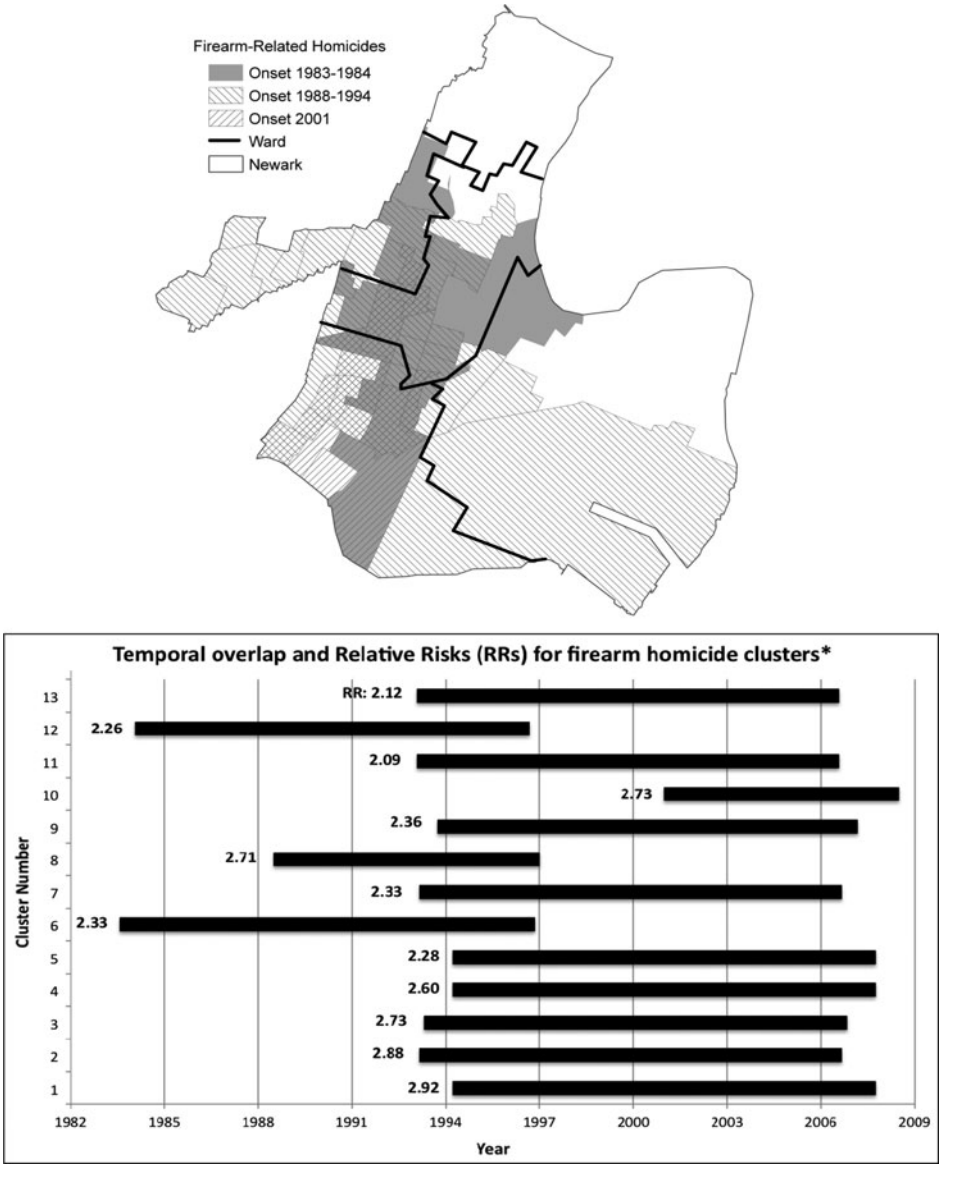


Figure 5 Space-time clusters of firearm-related homicides in Newark, NJ, USA, 1982-2008.
*All clusters significant at $p < .01$.

firearms and gangs operating as the infectious agents. While the spread of firearms and the emergence of crack markets and youth gangs of the later 1980s and early 1990s are hypothesized to make homicide more likely to diffuse (Cohen & Tita, 1999), we found evidence that homicide, in general, spread in Newark in the early 1980s, before the crack market emerged there

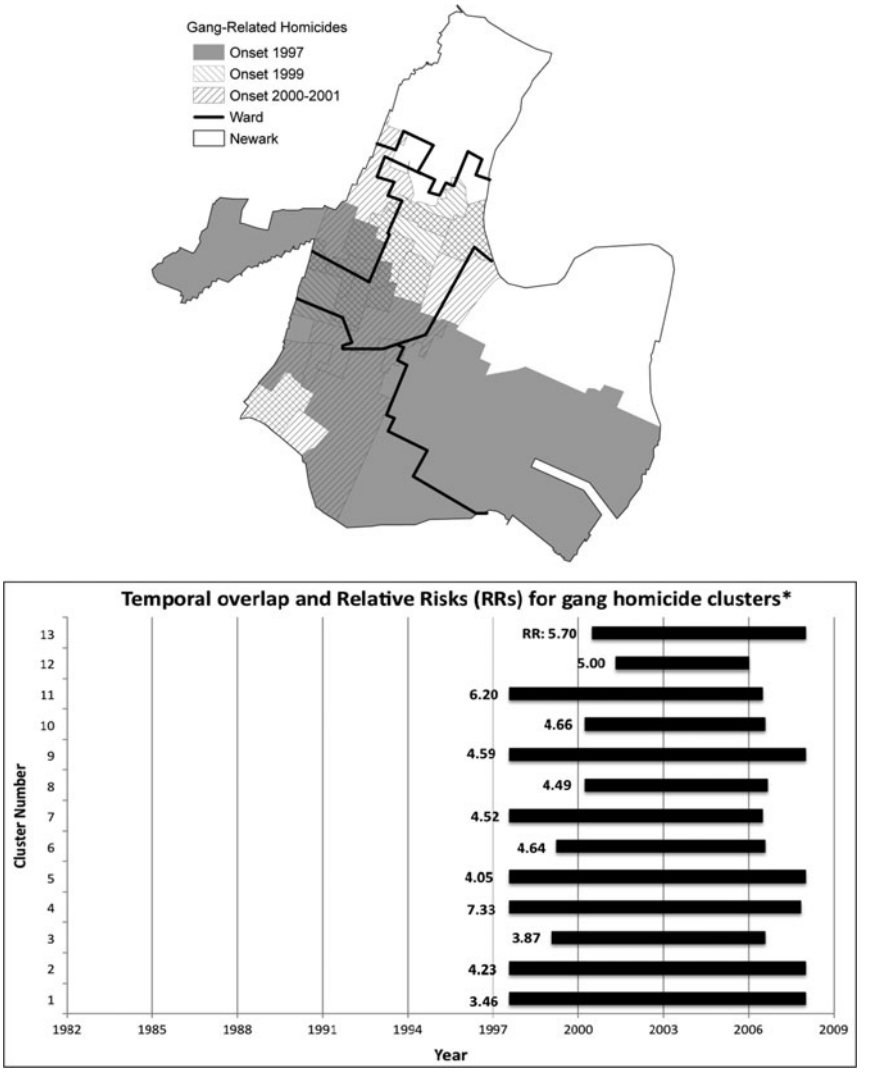


Figure 6 Space-time clusters of gang-related homicides in Newark, NJ, USA, 1982-2008. *All clusters significant at $p < .01$.

in 1986 (US Drug Enforcement Administration, n.d.).[7] Furthermore, the earliest overall homicide clusters detected in our data were in place at least one year prior to the earliest firearm homicide clusters, and the spread of overall

7. While our data suggest that the diffusion of homicide from around the Central Ward started before the advent of crack cocaine in Newark neighborhoods, conclusions related to such processes must be made with caution, as the use of 1982 as the start date of our study is arbitrary (i.e. it was the extent of our available data). If homicide indeed acts as an infectious disease, and is thus part of an ongoing process, processes set in motion prior to 1982 likely influenced the patterns witnessed in our earliest years of available data. However, given that crack markets did not emerge in the city until 1986, our data is well suited for detecting any appreciable change in the pattern of homicide that took place as a result of the introduction of this drug.

homicide included spatial areas that did not have concurrent significant firearm homicide clusters, suggesting that other infectious agents were present.

Overall, our results show that 14 of the 20 overall homicide clusters during the 27-year study period emerged in the Central and South Wards of the city. Consistent with criminological theory, the two clusters that emerged in the East Ward were centered in public housing sites. The geographic source of homicide was the Central Ward (census tract 30), the western border of the West Ward (census tract 19), and the northern border of the South Ward (census tract 40). We also detected patterns of expansion diffusion, as homicide appeared to spread from the Central to the West, East, and South Wards while remaining in the origin. Interestingly, the geographic overlay of gang-related homicides onto overall homicide clusters from 1982 through 1997 demonstrates that gang-related homicides emerged out of areas that historically had significantly high homicide rates, particularly in the South and West Ward neighborhoods bordering the Central Ward. The few clusters that emerged in the northern area of the East Ward, the southern area of the South Ward, and the western area of the West Ward appear to be conditioned by the spread of gangs.

While our data cannot be used to determine whether gang members moved into these areas or evolved out of these areas, the emergence of gangs from relatively high risk, threatening environments is consistent with most ethnographic accounts of the origins and growth of gangs over the last century (e.g. Decker & Van Winkle, 1996; Klein, 1971; Thrasher, 1927). That is, gangs are just as much a response to the (perceived or real) threat of violent altercations and the need for protection as they are a cause. The emergence of gangs as a recognized source of violence in Newark's highest risk areas in the mid-to-late 1990s is consistent with trends in the origination and continuation of gang activity more generally.

Consistent with Anderson's (1999) and Wilson's (1996) theories of urban violence, the source of the homicide epidemic in Newark appears to be primarily located in the Central and northern border of the South Wards.[8] Historically, these wards have contained the majority of Newark's public housing complexes and had the highest levels of economic disadvantage and racial segregation of all Newark's wards (see Appendix A). Indeed, of the 20 overall homicide clusters, the census tract centroids of 75% of them have a population that is over 60% African-American and, in the census tract centroids of 70% of the clusters, over 20% of the residents live below the poverty line. Overall, this finding is consistent with Rosenfeld et al. (1999) who found that homicides clustered in block groups with high socioeconomic disadvantage and a high percentage of African-Americans.

8. The American Public Health Association defines the word epidemic to mean "the occurrence in a community or region of cases of an illness (or an outbreak) with a frequency clearly in excess of normal expectancy" (Chin, 2000). Given that our clusters specifically identified areas and time periods in which the number of cases of homicide exceeded the expected level, and given our parallel between homicide and disease, the term epidemic is an appropriate term to use in describing the problem of homicide in Newark.

Furthermore, Newark's highest crime rates occur in the Central and South Wards, and it may be that the illegal drug and goods markets in these areas created an environment sufficient for the homicide epidemic to begin. Indeed, Cork's (1999) research suggests that the onset and growth of crack markets preceded the growth in youth firearm homicide in American cities. Cohen and Tita (1999) found no evidence that crack markets gave rise to growth in homicides in Pittsburgh; however, they attribute this lack of finding to the relatively late date (1989) at which crack markets emerged there. The population most susceptible to homicide—those involved in illegal markets—may reside in neighborhoods within these early homicide clusters in the Central Ward.

The present analysis provides evidence that homicide spread from the Central Ward and northern part of the South Ward into the southern part of the South Ward and the western arm of the West Ward. Specific census tracts in south Newark did not exhibit any homicide clusters until 2001. The diffusion of homicide into these areas may coincide with changes in Newark's residential landscape, as low-income high-rises were demolished and the residents redistributed into new Section 8 housing areas throughout the city (City of Newark, 2004). Interestingly, there is a small census tract in south Newark that is surrounded by gang homicide clusters, yet not included in them at any point in the study period. Future research on census tracts that appear immune to violence should explore if these properties are detectable.

A particularly important finding from the current analysis is that there are regions of Newark—the North and East Wards—that seem largely immune to the spread of homicide. These areas have a relatively low percentage of African-American inhabitants, who have traditionally had the highest risk of homicide in Newark. In this regard, our findings are consistent with the discussion by Tita and Cohen (2004) on the role of persistent racial segregation in housing patterns in isolating subpopulations from the spread of violence. More specifically, Tita and Cohen (2004, p. 175) suggested that:

> Continuing patterns of racial residential segregation, compounded by further segregation within minority communities along social and economic status dimensions, effectively isolate disadvantaged urban minority communities spatially and socially from contact with others. This physical and social isolation also may serve to limit the diffusion of homicides across space and more importantly, across population subgroups.

Importantly, for the prediction of the movement of homicide, this analysis suggests that barriers were in place to keep homicide out of the East and North Wards, and these barriers either did not exist for, or were weakened in, western and southern Newark.

The East and North Wards are the most ethnically and socioeconomically diverse in Newark, with the area on the northwestern border of the North Ward, called Forrest Hill, being the most economically advantaged residential area of the city. Additionally, the bulk of North Ward residents have changed

from primarily Italian in the 1980s and 1990s to Hispanic immigrants. Similarly, immigrants also heavily populate the Eastern Ward; however, these immigrants are primarily of European descent. The finding of no significant homicide clusters in these wards is consistent with recent research that suggests immigration levels in communities are related to low crime rates (Stowell, Messner, McGreever, & Raffalovich, 2009). According to Sampson (2006), the strong family value systems present in many, particularly Hispanic, immigrant communities may protect against crime perpetration. In addition, some immigrant groups are cohesive and socially supportive, which in turn may lead to an increase in collective efficacy (Sampson, Raudenbush, & Earls, 1997) in the communities where they reside. Thus, our findings further corroborate the robustness of previous research by showing, with an analytic approach distinct to those used by criminologists, the significant importance of neighborhood social processes related to economic disadvantage and racial isolation.

Traditional criminal justice strategies focus on secondary and tertiary prevention efforts that attempt to deter those at-risk of offending from committing acts of violence or incapacitate offenders. For example, one of the most popular strategies employs the "pulling levers approach," which involves deterring gang members from committing violent acts by threatening them with sanctions. Other strategies combine the "pulling levers approach," with service-based messages. Ceasefire Chicago, for example, identifies high risk "clients" and provides them with caseworkers who aid them in practical issues of living, such as educational attainment and finding work (Skogan et al., 2008). Similar initiatives have been implemented in Newark (i.e. The Newark Greater Safer City Initiative in 1999 and Operation Ceasefire in 2005) without much success (Boyle, Lanterman, Pascarella, & Cheng, 2010; Pizarro & Sousa, 2008). Although individuals involved in programs did not engage in violence (Boyle et al., 2010; Pizarro & Sousa, 2008), the overall violence and homicide rates in the geographic target areas did not decrease. While these interventions might have had a small impact on the mode of transmission of homicide (e.g. individual networks) they did not fully address the source of the epidemic (e.g. alter social conditions), or provide sufficient treatment to the susceptible population of these areas. As a result, only short-term decreases in homicide were obtained.

Public health offers a focus on primary prevention within populations, which can be developed from information gained through tracking trends, patterns, and epidemiologic characteristics of the problem under study. This research is among the first attempts to use spatio-temporal clustering techniques from the field of medical geography to track the movement of homicide clusters through an urban city. The pattern of movement identified suggests that social structural variables, such as economic disadvantage and racial isolation, foster the spread of homicide, and that there exist barriers to the spread of homicide to some communities.

To better inform theory and prevention efforts, researchers should use the analytic method described here to investigate whether the movement and

duration of homicide clusters can be predicted by the changing (or stagnant) structural characteristics of communities, such as economic disadvantage, collective efficacy, and social disorganization (Diem & Pizarro, 2010). For example, by including community-level characteristics in future analyses, researchers may be better able to explain the diffusion of overall homicide in Newark prior to the advent of gangs and crack markets or why some areas are resistant to homicide. By using the principles of infectious disease control (e.g. discovering the underlying risk factors and mechanisms by which some people are immune or susceptible to joining gangs or committing violence; increasing the susceptible population's resistance to committing violence; and addressing individual and environmental conditions that foster the spread of gangs and violence), we may be able to prevent homicide. Through ongoing monitoring of homicide patterns primary prevention efforts can be directed towards communities evincing an emerging homicide problem, while secondary prevention efforts can target communities with ongoing (active) homicide clusters.

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Appendix A Percent Black by census tract and other reference features in Newark, New Jersey 1982-2008.