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**Physical boundaries and City boundaries: Consequences for
Crime Patterns on Street Segments?**

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Physical boundaries and City boundaries: Consequences for Crime Patterns on Street Segments?

Abstract

Scholars have theorized how spatial boundaries (edges) can be important for understanding the location of crime, yet the empirical relationship between spatial boundaries in the environment and levels of crime is relatively less explored compared to other features of the environment. The current study extends the literature by not only studying three types of physical boundaries—rivers, parks, and interstate highways—but also one non-physical and relatively less visible boundary—city boundaries. We analyze the relationship between crime in street segments and nearness to these four types of edges in the Southern California area. We measure nearness to these boundaries in two manners: 1) whether or not the segment is adjacent to the feature; and 2) how far in physical distance the segment is to the feature. Additionally, this study examines the possible moderating effect of retail land use of a segment and nearness to these boundaries.

Keywords: Crime, Spatial boundaries, Edges, Crime pattern theory, Street segments

Word count (including all materials): 9,314

Introduction

A body of research has highlighted that different physical environments create different criminal opportunities (the mixture of motivated offenders, potential victims, and presence or absence of capable guardians), and consequently affect the amount of crime in places (Bernasco & Block, 2011; Brantingham & Brantingham, 1993, 1995; Brantingham & Brantingham, 1975; Cohen & Felson, 1979; Taylor & Gottfredson, 1986; Taylor, Koons, Kurtz, Greene, & Perkins, 1995). Research has focused on various characteristics of these physical environments, including building design, street layout, land use patterns, and physical deterioration. Although much of the existing research focuses on key characteristics of various geographic units and their relationship to the level of crime, in this study we wish to focus explicitly on the *boundaries* between these units. Furthermore, these boundaries can vary in their level of visibility.

Although scholars have theorized how boundaries can be important for understanding the location of crime (Brantingham, Brantingham, Vajihollahi, & Wuschke, 2009; Song, Spicer, & Brantingham, 2013; Song, Andresen, Brantingham, & Spicer, 2015), the empirical relationship between spatial boundaries (“edges” in Brantingham & Brantinghams’ terminology) in the environment and levels of crime has been relatively less explored compared to other features of the environment. Moreover, although the Brantinghams theorized about both physical edges and non-physical edges, empirical tests have focused more on the effect of physical boundaries and less on non-physical boundaries for crime. Therefore, along with the examination on the effects of physical boundaries on crime, a key focus of the present study is whether edges that are not inherently physical (i.e., city administrative boundaries) may be important too: City boundaries are not necessarily physically obvious to offenders, and are not necessarily characterized by land use changes in many instances. However, they may provide perceived unique opportunities to

offenders. That is, in many settings—including the southern California environment that we study here—cities typically have their own police agencies. Thus, a crime event that occurs on a city boundary can carry a certain degree of ambiguity regarding how the case should be investigated. For example, when a string of incidents occurs within a particular city, this pattern may become apparent to the police who can then implement strategies to intervene and stop future offenses (Rossmo, 2000). On the other hand, if incidents occur across city boundaries, this may make identifying such strings of offenses more difficult, which would make implementing intervention strategies less likely. If this is the case, offenses that occur just across a city border might be perceived as particularly attractive to an offender. This would imply that we would observe more crime offenses near a city border, an empirical question of which we are aware of no studies addressing.

The current study examines the effects of spatial boundaries by analyzing the relationships between crime in street segments (both sides of a street between two intersections) and distances to four types of edges in the Southern California area. Edges are operationally defined as three types of physical boundaries—rivers, parks, and interstate highways—and one non-physical boundary—city boundaries. We measure nearness to these boundaries in two manners: 1) whether or not the segment is adjacent to the feature; and 2) how far in physical distance the segment is to the feature.

The geometry of crime: Crime patterns at edges

Studies indicate that criminal opportunities (the convergence of motivated offenders, potential victims, and the presence or absence of capable guardians) play an important role in understanding crime patterns at places (Cohen & Felson, 1979). Criminal opportunities and therefore the probability of whether a motivated offender actually commits a crime differ based

on the sites and situations surrounding the targets and offenders. Studies suggest that different physical environments create different criminal opportunities. In particular, crime pattern theory (Brantingham & Brantingham, 1993, 1995; Brantingham & Brantingham, 1984) argues that certain types of built physical environment produce different patterns of opportunities for crime.

Brantingham & Brantingham (1993, 1995) specify the concept of criminal opportunities in a community as part of crime pattern theory. The theory depicts how individual behaviors interact with the physical environment to provide opportunities for crime. Specifically, they classify the physical environment into three spatial geometric notions: (1) activity nodes, (2) pathways, and (3) edges. Activity nodes are the places where people spend most of their time, thus daily routine activities are developed and shared with others. Previous studies have studied activity nodes and constantly found a positive relationship between them and levels of crime (Bernasco & Block, 2011; Block & Block, 1995; Kubrin & Hipp, 2014; Kubrin, Squires, Graves, & Ousey, 2011; McCord, Ratcliffe, Garcia, & Taylor, 2007). These studies typically measure activity nodes as certain types of facilities in locations such as bars, liquor stores, or restaurants.¹

Pathways are the transit system and road structure that connect nodes to one another. People usually take pathways to move from one place to another. Brantingham and Brantingham (1993) suggest that “the physical structure of the road network itself seems to influence how far crime spreads from major pathways” (p.17). Indeed, empirical research reveals that the spatial distribution of crime is shaped by the structure of the street network (Bevis & Nutter, 1977; Beavon, Brantingham, & Brantingham, 1994; Hillier, 1996; Johnson & Bowers, 2010; Davies & Johnson, 2015). For example, Bevis & Nutter (1977) examined the effects of isolated streets and network density on burglary levels at the census tract level, and found that less accessible street

¹ See Stucky & Ottensmann (2009) for an informative review on the literature of land use, type facilities, and crime.

layouts are associated with low residential burglary rates. Beavon et al. (1994) examined the effects of street segments' relative accessibility, traffic volume, and quantity of potential targets. They found that both road network complexity and traffic flow in each segment were associated with lower levels of property crime.

Spatial boundaries (edges) and crime

As spatial geometric ideas, activity nodes and pathways have physical boundaries where changes occur from one to another. Edges are the boundaries where these noticeable changes are observed (Brantingham & Brantingham, 1993). Edges can be physical barriers. One example of physically visible edges are locations next to rivers given that rivers can be a very pronounced boundary. Likewise, regional or local parks act as edges. Thus, a park can act as an activity node given that persons go there to spend time; but it is also the case that the boundary of the park can serve as an edge given that it represents a sharp change in the urban backcloth. In an urban setting, transit systems such as major roads, interstate highways, or railroads act as paths, but also as edges. In the case of interstate highways, they can serve as pronounced borders that are only crossable at occasional locations.

These boundaries are important in that they can increase crime because they impact the perceived likelihood of detection. That is, whereas offenders are interested in criminal opportunities (which might come from retail areas, persons walking on the street, etc) boundaries can increase opportunities if they are seen as increasing the ability to quickly exit from a crime event (i.e., a highway onramp). Boundaries can also impact crime if they reduce the sense of guardians in an area, which will also change the perceived likelihood of apprehension.

Although there has been research on the proximity to parks, highways, and crime (e.g., Groff & McCord, 2009; Kimpton, Corcoran, & Wickes, 2016; McCutcheon et al., 2015), most

studies theorize parks and highways as crime attractors, not as spatial boundaries. Thus, less attention has been paid to the effects of parks and highways as edges. In addition to physically visible boundaries, the Brantinghams recognized the importance of less physically obvious edges. For example, edges occur where strong cognitive images are created by paths and dissimilar land use on either side of a street. Locations where different land use zones adjoin act as edges.

Although the existing literature theoretically emphasizes the importance of edges in understanding crime, only a few studies have empirically tested whether street segments near edges actually have more crime (Brantingham & Brantingham, 1978; Brantingham & Brantingham, 1975; Brantingham et al., 2009; Song et al., 2013; Song et al., 2015). For example, Song et al. (2013) defined edges as locations where land use classifications changed from single-family residential land use to some other type of land use classification. They found that crime was sixty four percent higher on these edges than in the interior of the neighborhoods. In a similar study, Song et al. (2015) found that, criminal victimization rates were 2–3 times higher on an edge compared to elsewhere, yet this effect decreased very quickly moving away (about 40 meters) from the edge. Brantingham & Brantingham (1975, 1978) also hypothesized and found that street blocks in the border area of a neighborhood have higher burglary rates than street blocks located in the interior of the neighborhood. Brantingham et al. (2009) employed a “fuzzy topology algorithm” to measure the amount of land use difference and changes from one block to another. They found that the burglary levels of street blocks on the borders are about three times higher than those of street blocks in the interior of neighborhoods.

Although studies have examined the effects of physical edges on crime, herein we suggest that another type of less physically visible boundary—city boundary lines—can also act as edges. There are various possible explanations for why city boundaries may increase crime

events. We focus on three in particular: 1) the possibility of physical land use change due to a city boundary; 2) the possibility of less patrolling for geographic distance reasons; and 3) the possibility of jurisdictional ambiguity and more limited communication between police agencies. Regarding the first point, land use characteristics can differ across city boundaries given that each city government has its own jurisdiction which makes different land use of areas. Although they are geographically adjacent, in some circumstances, locations next to the city border can have very different land use types due to different land use policies across municipalities.

Previous studies have found that land uses and regulations vary across local municipalities (Gyourko, Saiz, & Summers, 2008; Quigley & Raphael, 2005). Gyourko et al. (2008) examined how regulations of local land use vary across local communities using a survey of 2,600 jurisdictions (cities) in the U.S. They developed a measure of the stringency of the local land use regulatory environment in each community comprised of information on local characteristics and legislative/executive branch behavior. They confirmed a spatial heterogeneity and variability of land use regulatory environments across local municipalities. Moreover, according to Quigley & Raphael (2005), cities in California have the most extreme autarky and autonomy in land use policies compared to cities in other states. Thus, in the Southern California area, a city boundary line as a type of edge is also an important factor in understanding change of land use and built environment, and crime.

Regarding the second point, whereas police agency stations typically are located in the center of a jurisdiction—which has the advantage of minimizing distance to locations in the jurisdiction—a consequence is that street segments on the city boundary will receive the fewest patrols. This is simply a principle of least effort effect (Zipf 1949), as patrols will be more likely to go through segments nearer the station (given that such segments must be passed through to

get to outlying locations). Unless an agency makes a specific effort to patrol segments nearer the city boundary, the pattern will be fewer patrols near the boundary. This may or may not be a pronounced pattern, but would nonetheless exist. The consequence will be that crime events will be more likely to occur closer to the city boundary, with a distance decay effect when moving further away, holding all else constant.

Regarding the third point, an interesting aspect of a city boundary line is that in many instances it can be quite nebulous. When the boundary is not visible, it is hard to detect the change of city jurisdictions when passing through. In such instances, the land use variability in the environment in general would not differ from what is observed when crossing over a city boundary. Song et al. (2015) note “because of this subtlety, such edges are defined considering social and conceptual spaces. This makes this type of edge difficult to measure, particularly over large areas, because it requires social and conceptual observation” (p.2). Nonetheless, such boundaries can have important consequences on crime, and we next describe two possible scenarios.

In the first scenario, we highlight that a general challenge for police agencies when addressing crime events is detecting repeat patterns: that is, instances in such a series of offenses are committed by one person or group of persons. This can be particularly difficult when a string of offenses occur across city boundaries. Although police agencies attempt to communicate between themselves regarding such possibilities, it is nonetheless the case that identifying a string of incidents that occur within the particular city is easier than attempting to identify a string when it requires additional communication between agencies. If this is indeed the case, it is in the offender’s interest to commit offenses across jurisdictional boundaries. Combining this preference for committing offences across city boundaries, along with the well documented

tendency in the journey to crime literature to commit crime nearby one's residence based on a distance decay function, this implies that offenders would have a tendency to commit offenses that are closest to their residence, but across a city boundary. In this case, the result would be a tendency to commit crimes nearer a city boundary.

In the second scenario, this preference for committing offenses across city boundaries may be related to the relative spatial knowledge of police agencies that are investigating crime events. Policing in the US consists of a massive patchwork of distinct police organizations that are delineated by political boundaries (Klinger, 1997). Officers will engage in police work outside their primary boundaries only in unusual situations. As Rubinstein (1973) stated "The framework of a patrolman's geographical knowledge is established by the extent of his territorial jurisdiction... [an officer] has no need to know about places beyond the district's limits. The first thing he learns... is its boundaries. His knowledge of what lies beyond them is limited and his curiosity restricted." A street segment adjacent to city boundary is nebulous in terms of jurisdiction due to the physical invisibility of the boundary. This can lead to ambiguity regarding which agency is responsible, and therefore result in less effective crime control in the area.

The two scenarios just described imply different consequences for where crime is observed. If we had information on where offenders lived and where they committed crime, this could be tested more directly (presuming we knew the location of all crime events committed by the offender regardless of which city they occurred in). We do not, so our strategy here is to draw out the implications of these two scenarios and compare them to the observed spatial distribution of crime. If the first scenario holds in which offenders commit crimes with a distance decay but in which there is an additional boost for locations in a different city, we would observe that crimes tend to occur closer to a city boundary, but there would be a distance decay from the

boundary. This is because the benefit of committing a crime across a city boundary would accrue to the offender anywhere in the city, and not just near the boundary. This preference is then combined with the well-known journey to crime distance decay to produce this pattern. In the second scenario in which officers have less information just across a city border, we should observe a distinct preference by offenders to commit crimes relatively close to a city boundary. Here, it is not simply committing a crime in a different city that matters, but committing it close to the boundary. This would imply an even sharper spike near the boundary than in the first scenario, with an accompanying relatively sharp distance decay moving further from the boundary. We test these two scenarios here.

Data and methods

The unit of analysis of this study is the street segment. The present study uses Census 2010 TIGER (Topologically Integrated Geographic Encoding and Referencing) line shape files to create street segments by splitting street lines at the points of intersections using Arc GIS 10.2. 325,239 street segments in 218 cities across Southern California area (Counties of Los Angeles, Orange, Riverside, San Bernardino, and San Diego) are included in the current study. The average length of street segments is 158.2 meters (519 feet). About 9 percent of all street segments (including alleys and highways) in the study area are not geocodable because they have no address range information for geocoding. Simply including them may introduce biased results because they necessarily have zero crime incidents. To address this, the models presented in the current study did not include those non-geocodable street segments. Thus, 295,306 street segments are included in the final models.

Dependent variables

The dependent variables of this study are the number of crime incidents of various Part 1 crimes in 2010. The crime incident data with geographic information (i.e., address) was collected from local police agencies as part of the Southern California Crime Study (SCCS) and geocoded to latitude–longitude points. Then the crime points were spatially joined and aggregated based on their proximity to street segments. Many agencies shared their data, and as a consequence the crime data covers about 83.3 percent of the 5-county region’s population (Los Angeles, Orange, Riverside, San Bernardino, and San Diego counties). Crime events were classified into five Uniform Crime Reports types: aggravated assault, robbery, burglary, motor vehicle theft, and larceny. This study excludes homicide because they are too rare on street segments in one year to show meaningful variation. The geocoding match rate was 97.2% over all cities included in the current study, with the lowest value at 91.4%.²

Some previous studies have excluded crime incidents that occurred at intersections since: (1) the events at intersections could be considered part of any one of the participating street segments, and therefore there is no clear method for assigning them to one or another; and (2) the incident reports at intersections differed dramatically from those at street segments (Weisburd et al. 2012; Weisburd et al. 2014; Groff et al. 2010). However, in our data, the characteristics of crime events at intersections (about 1% of all cases) do not exhibit systematic differences from those on street segments. Therefore, simply dropping them could bias the results. Instead of

² Geocoding was done in ArcGIS 10.2 using a specific geocoding locator for the counties of Los Angeles, Orange, Riverside, San Bernardino, and San Diego using the 2013 Census TIGER line shape file. The geocoding locator used the following parameters: spelling sensitivity = 75, minimum candidate score = 10, minimum match score = 10, side offset = 1 foot, end offset 1%, and Match if candidates tie = no. These values were chosen after exploratory tests demonstrated these to provide the optimal balance between Type 1 and Type 2 geocoding errors (misgeocoding an event to the wrong location versus inaccurately excluding an observation that was in fact accurately geocoded). We found that higher score thresholds often inaccurately excluded many incidents in which the geolocation was in fact accurate. We used MapQuest open geocoding service and Google Earth Pro to geocode unmatched incidents after the geocoding process using ArcGIS 10.2.

excluding them, we evenly assigned an event that occurred at an intersection to the contiguous street segments, weighted by the inverse of the number of segments. For example, a typical intersection where two roads cross has four street segments. If a crime incident occurred on this intersection, each of four segments is given 0.25 of a crime incident. Note that this strategy in which the crime event was equally split across all segments was also employed in the rare case of an intersection near a city boundary in which the adjacent segments were contained in two different cities.³

Independent variables

The main independent variables of this study are 1) a dichotomous variable representing whether a street segment is adjacent to the boundary of interest, and 2) a measure of the distance from the centroid of a segment to the boundary of interest (rivers, park boundaries, highways, and city borders). We calculate the Euclidean distances from the centroids of street segments to the boundary lines of the cities using the Census 2010 place boundary shapefile.⁴ We classify a street segment as being on the boundary of interest if the Euclidean distance from the segment centroid to the city border is less or equal to 10 meters. This means the segments within a 20 meter (65 feet) buffer are considered being on the edge. The freeways, rivers, and parks boundary data come from 2010 Environmental Systems Research Institute (ESRI) street map data. The freeway data includes highways and interstates. Rivers are defined by named rivers and streams. Parks are national, state, and local parks. We computed the distances in the same

³ We estimated supplemental analyses with the intersection crimes removed. The results without crime at intersections are not substantially different from the models with them. This is unsurprising given that only about 1% of crime events in our data are at intersections.

⁴ We used the line features for rivers and highways/interstates, and used the polygon features for parks. Distances were computed by calculating Euclidean distances from the centroid of each street segment to the nearest lines of rivers and highways, and to the nearest part of the park polygons.

fashion as the distances to city borders. We also created a quadratic variable for each boundary measure to capture possible non-linear relationships between the distance from the centroid of a segment to the boundary of interest (city borders, rivers, park boundaries, and highways) and crime.

To minimize the possibility of obtaining spurious results, we included a set of control variables that account for structural characteristics of the street segments in addition to the main independent variables. To do this, the present study combines two data sets from: (1) 2010 U.S. Census and 2008-12 American Community Survey 5-year estimates data, and (2) 2008 Southern California Association of Governments (SCAG) land use data. These data cover the entire region, and therefore are not impacted by city boundaries. Data collected at the street segment level is methodologically preferred but the Census data are not available at the street segment level. Instead, the present study apportioned the Census data of blocks contiguous to each street segment by calculating the average values of Census data of blocks contiguous to the street segment which takes following form:

$$SA = \frac{\sum_{j=1}^N V_j}{N}$$

where SA stands for Simple Average of the block values apportioned to a street segment, N is the total number of blocks associated with the street segment, and V_j is the value of the Census data for a given variable of block j associated with the street segment. See Kim (2016) for a description of this approach, and a validity check showing it appears to perform satisfactorily. As shown in Figure 1, a hypothetical street segment is associated with two contiguous blocks (Block A and B). The SA is the average values of these two blocks, that is apportioned to the street segment. For example, in Figure 1, if the percent Hispanic/Latino in block A is 10 and that

of block *B* is 50, the value of *SA* is calculated as $(10 + 50) / 2$ which is 30. This means that when employing the *SA* method, the apportioned value of the percent Hispanic/Latino of this street segment is 30.⁵

<<<Figure 1 about here>>>

Using these apportioned Census data at the street segment level, we, first, constructed a *concentrated disadvantage index*, a factor score of four measures: (1) percentage at or below 125% of the poverty level; (2) percentage single-parent households; (3) average household income; and (4) percentage with at least a bachelor's degree. The last two measures had reversed loadings in the factor score.⁶ Second, to account for *racial/ethnic heterogeneity*, we computed a Herfindahl index based on five racial/ethnic groups (white, African-American, Latino, Asian, and other races).

To measure *residential stability*, we utilized the *percent owner occupied units* in street segments. Also, to control for the presence of racial/ethnic minorities in street segments, we included the *percent African-American* and the *percent Latino*. The *percent occupied units* is used to measure vacancies and the *percent residents aged 16 to 29* is a measure capturing the prime ages of offenders. Given that certain types of land use and the physical characteristics of the area can affect crime, we included the percent land use of 1) *industrial*, 2) *office space*, 3)

⁵ The total number of blocks is 116,750 and that of street segments is 325,239. Of this total, we use only 102,680 blocks—which have non-zero population. So, we restricted the analyses and the *SA* imputation to blocks with non-zero population. This decision was based on the fact that blocks with zero population will have missing values on the socio-demographic variables.

⁶ Census data provide only the percent single-parent households variable at block level. For the other variables in the concentrated disadvantage measure we used an ecological inference technique. The variables used in the imputation model were: percent owners, racial composition, percent divorced households, percent households with children, percent vacant units, population density, and age structure (percent aged: 0-4, 5-14, 15-19, 20-24, 25-29, 30-44, 45-64, 65 and up). For detailed description on the imputation for small units of analysis, see the supplemental appendix of Boessen & Hipp (2015).

residential, and 4) *retail* at the street segment level. The other types of land use are the reference category.

Analytic strategy

Given that the dependent variables are counts of crime events in 2010 (aggravated assault, robbery, burglary, motor vehicle theft, and larceny), their distributions are not normally distributed. Accordingly, we estimated negative binomial regression models to effectively deal with over-dispersion (Osgood, 2000). We recognize that the structural characteristics and the distribution of crime can vary by cities in the study area. Thus, we included fixed effects for cities (dummy variables of cities).⁷

Research has emphasized the spatial dependence of neighborhoods in relation to the distribution of crime (Anselin, Cohen, Cook, Gorr, & Tita 2000; Cohen & Tita 1999). To account for potential spatial autocorrelation, this study includes spatially lagged independent variables for the following measures: *concentrated disadvantage index*, *racial/ethnic heterogeneity*, *percent owner occupied units*, *percent African-American*, *percent Latino/Hispanic*, *percent occupied units*, and *percent residents aged 16 to 29*.

These measures were created based on an inverse distance decay function with a cutoff at 0.25 mile around Census blocks that are contiguous to the segment. The resulting spatial weights matrix (W) is row standardized. This matrix is multiplied by the matrix of values in the blocks

⁷ Because a key focus of the current study is examining the effects of city jurisdiction boundaries, studying individual cities is not feasible. Furthermore, having multiple cities—rather than a single city—is necessary to attain enough statistical significance to test for city boundary effects given that they are relatively rare. We decided to have 218 cities and employed city-fixed effects modeling rather than looking at a single or few cities to gain more statistical power for testing the effects of city jurisdiction boundaries. Nevertheless, to check the robustness of the models, we performed sensitivity analyses in which we: 1) estimated the model separately on each city; 2) computed the reliability of the city estimate given the number of segments in a particular city (in which reliability is computed by dividing the variable's standard error in the full model by the standard error in the specific city model); 3) computed the empirical Bayes estimate of each coefficient using the reliability estimate; and finally 4) computed the mean and standard deviation of these adjusted coefficient estimates across all cities. The results of the main independent variables were very similar to those from the original models with all observations.

for the variables of interests. Thus, effectively, we used the *SA* method to construct the spatially lagged independent measures at the segment level. That is, the average values of the block level data of spatially lagged variables were apportioned at the street segment level using the average of the measures of blocks contiguous to the street segment. The 0.25 mile buffers of a street segment and the contiguous blocks are geographically very proximate and overlap considerably. Therefore, the spatial buffer measures of blocks and segments are very highly correlated.

We checked the Moran's *I* values of residuals from the models of the main effects to assess if there is any additional spatial autocorrelation in the residuals and found no such evidence. The Moran's *I* values of residuals in the models were very small: always less than 0.01, which is a very small correlation. This implies that the models adequately control the spatial clustering. The Moran's *I* values for the crime types ranged from 0.01 to 0.04 suggesting small spatial clustering of crime events, which effectively disappears after conditioning on the variables in the model.

Results

We begin with the coefficients for the variables capturing the effect of a physical boundary of a highway. There are strong effects for the variable capturing segments that are adjacent to a highway: such segments have higher levels of all five crime types. Thus, a street segment that is adjacent to a highway has 70% more aggravated assaults than a segment that is not adjacent to a highway ($\exp(0.5319) - 1 = 0.702$). And a segment adjacent to a highway also has 78% more motor vehicle thefts, about three times as many robberies as other segments, and 108% more burglaries and 127% more larcenies as other segments. We show the combined effect of the distance measures and the indicator variable capturing adjacency to a highway by

plotting the incidence rate ratios for these segments up to 4.5 kilometers from a highway in Figure 2: in this and the other figures the distance decay effect is plotted as the parametric form that it is, whereas the indicator variable for a segment adjacent to a boundary is added to the predicted value for the shortest distance (0-.5km), and hence explains this apparent spike in the plot (by including this boundary effect we more accurately display the spatial pattern estimated in the model). This figure shows that segments adjacent to a highway have higher levels of crime, with a consistent distance decay effect in which there are lower levels of the three property crimes as one moves further away from a highway. The two violent crimes exhibit less evidence of a distance decay effect when moving further away from a highway.

<<<Figure 2 about here>>>

There are also relatively strong effects for segments that are adjacent to a park, although this boundary does not exhibit as strong an effect as do highways. Thus, a segment adjacent to a park has 8% more burglaries (statistically significant at $p < .10$), 13% more motor vehicle thefts and larcenies, 55% more aggravated assaults, and more than twice as many robberies as other segments. Figure 3 demonstrates that there are distance decay effects in which there are lower crime rates further from a park, and this distance decay effect is particularly pronounced for robberies.

<<<Figure 3 about here>>>

The third physical boundary we studied was rivers, and we find relatively modest effects for this boundary for crimes on segments. The only statistically significant effect we detected was that segments adjacent to rivers have 43% more larcenies than other segments. In part these weak results are due to the low statistical power given the relative rarity of rivers in the study area. Rivers also exhibit a different distance decay pattern compared to the other two physical

boundaries studied here, as seen in Figure 4, as the violent crimes and burglary are more prevalent in segments that are further away from a river.

<<<Figure 4 about here>>>

Although city boundaries are not physical boundaries—and sometimes may even be difficult to observe, we find that they nonetheless are associated with elevated rates of certain types of crime. A street segment that is on a city border has 13% more aggravated assaults, 27% more robberies, and 30% more larcenies than other street segments. In looking at distance from a city boundary, the pattern differs by crime type as shown in Figure 5. Robberies and larcenies are higher for segments that are on a city boundary, and in segments that are further away from a city boundary, but are lower in segments that are relatively close to a city boundary (but not adjacent). And whereas aggravated assaults are more prevalent on a segment on a city boundary, they exhibit no distance decay effect when moving farther from city boundaries. Motor vehicle thefts exhibit a distance decay effect in which they are less prevalent on segments that are farther from a city boundary. However, burglaries are more prevalent as a segment lies farther from a city boundary.⁸

<<<Figure 5 about here>>>

⁸ To assess the extent to which land use changes across city boundaries, we adopted two approaches. First, we computed the land use mix of segments based on a Herfindahl index of five land use categories (residential, retail, industrial, office, and others), and compared the value for segments on city borders (0.56) to segments not on boundaries (0.37). This indicates that on average the segments on city borders have greater land use mix compared to interior segments. Second, we assessed if there exist significant clusters of land use in street segments on city boundaries by computing Local Indicators of Spatial Association (LISA) clusters of land use. We found that 26 percent of segments on the city borders were in statistically significant clusters of high values of residential land use (High-High cluster - HH), while 40 percent of segments not on city borders are HH. This indicates that 26 percent of segments have significant similarity in residential land use across city boundaries, whereas residential land use in the majority of segments on the city borders varies across municipality. In terms of retail land use, only 12 percent of city-border-segments are in statistically significant clusters of high values. Thus only 12% of segments on city borders have high similarity in terms of retail land use across municipalities. Thus, there do not appear to be strong patterns of change in land use across city boundaries.

Finally, we briefly describe the results of the control variables. The concentrated disadvantage index indicates significant and positive relationships, while percent owner occupied units has significant and negative relationships with all types of crime. Of the land use measures, percent retail and percent office land use are robustly positively related with all types of crime, while percent residential is negatively associated with crime.

Discussion

Although studies have theorized the importance of spatial boundaries (edges) for understanding crime, fewer studies have actually empirically assessed the relationship between edges and levels of crime. The current study attempted to test the effects of edges on various types of crime. Specifically, we operationalized edges as highways, parks, rivers, and city boundaries. A novel contribution was testing the importance of city boundaries as relatively invisible edges for crime. Our results suggest that this is an important boundary to consider, as crime rates for certain types of crime were higher for segments near a city boundary.

Our results showed that segments near highways often have more crime, and there is also a distance decay effect in which property crimes decrease moving further away from a highway. These results are consistent with the findings of previous studies that crime decreases moving away from edges (Brantingham et al., 2009; Rengert, Chakravarty, & Henderson, 2000) although our results demonstrated a much longer distance tail than some other research (Song et al. 2015). Although street segments near highways may be less desirable for residents to live in because of the physical and social environments around them, they are relatively more accessible for population inflow of nonresidents compared to areas near other types of edges (i.e., rivers) given their purpose and geographical locations in urban areas. Such characteristics help potential offenders detect more opportunities for crime – more accessibility along with fewer capable

guardians, thereby lowering surveillance levels. Highways therefore can act as crime attractors as offenders may find locations adjacent to highways more attractive for commission of a crime, as targets near highways provide easier escape as well as access. McCutcheon, Weaver, Huff-Corzine, Corzine, and Burraston (2015) tested for a relationship between interstate presence and robbery at the county-level in Georgia, and found that the number of interstate exits in a county significantly increases robbery rate.

Segments near parks demonstrated a similar pattern to those near highways, as they not only often had higher levels of crime, but there was also a distance decay effect for certain types of crime. Segments near parks may also attract increased population inflow due to use of the park, which would also increase crime opportunities and crime events, as we observed. Parks and highways can act both as edges and crime attractors, whereas rivers may not act as crime attractors. Parks (or areas near parks) can be crime attractors because parks are large public areas with less informal social control and natural surveillance. Indeed, previous studies have conceptualized parks as crime attractors, and found that parks and areas near parks are sometimes associated with increased level of crime (Groff & McCord, 2012; Kimpton et al., 2016). Another explanation is that a segment adjacent to physically visible edges such as highways and parks will have higher levels of crime because there may be fewer regular residents to serve as “eyes on the street” or capable guardians watching and keeping the neighborhood safe. These edges may serve as wedges between residents that reduce the social ties in an area and therefore reduce the level of cohesion and informal social control, which may lead to higher levels of crime. One study referred to edges as *wedges*, and found that their presence (particularly highways) reduced the level of cohesion and informal social control for the neighborhoods in which they occurred (Hipp, Corcoran, Wickes, & Li, 2014).

Our third measure of physical boundaries, rivers, operated differently from highways and parks. Segments near rivers only had modestly more larcenies, but not other crime types, which may be due to rivers' relative rarity in the study area. In fact, the violent crimes and burglary are more prevalent in segments that are *further* away from rivers. Areas close to rivers are relatively less accessible compared to those to highways and parks. This characteristic may result in less inflow of population in such locations, resulting in fewer criminal opportunities (lower probability of the convergence of potential victims and offenders). This highlights that physically visible edges have different properties, and therefore have different impacts on crime.

Our measure of less visible edges (city boundaries) also showed a significant positive relationship with crime. Although we do not know the precise mechanism that explains this relationship, it is nonetheless consistent with our earlier theorizing. We found that the three violent crime types, as well as larcenies, were more prevalent if the segment was on a city border. This result for city boundaries suggests that in spite of relative physical invisibility, city boundaries are also important features for understanding the effects of edges on crime. As theorized above, one explanation is possible limited communication between agencies regarding crime patterns. This assumes that offenders operate under some presumption that this possible lack of communication will reduce their likelihood of being detected. This is speculative, as we know of no systematic empirical evidence that offenders act in this manner. Our results therefore imply that future research studying offender behavior across more than one agency is needed, and we hypothesize that it will detect that there is an increased likelihood of offending for certain crime types when crossing a city boundary.

The results of the distance to city boundaries vary by crime type. For example, motor vehicle thefts exhibit a distance decay pattern in which segments closer to a city border are most

at risk. This is an interesting result, given that stolen vehicles are often quickly disposed of in “chop shops”; this may imply that this is a type of crime in which cross-city thefts are particularly desirable. In contrast, robberies and larcenies demonstrated an interesting pattern in which they occurred more frequently on a city boundary, but also on segments that are farther away from city boundaries. Thus, they occur least frequently on segments near, but not on, a city boundary. Whereas a distance decay effect such as that detected for motor vehicle thefts is consistent with the idea of offenders preferring to offend across a city line, this result for robberies and larcenies implies that there is something unique about a segment that is on a city boundary making these crime types more likely at those locations. These two crimes (as well as burglaries) are more likely further from a city boundary and therefore are more likely to occur near city centers, which may be because city centers have more potential victims given that they tend to have more major commercial, entertainment, and cultural spots (Hall, 1992; Jenks, Burton, & Williams, 1996; Kasarda, Appold, & Sieff, 1997; Moss, 1997). Recall that we controlled for land use characteristics, implying that there may be an additional unmeasured characteristic of such city centers that result in them acting as activity nodes (crime attractors and generators) by drawing more population inflow for robberies, larcenies, and burglaries. However, this is speculative given that we do not know the actual location of city centers, and suggests a research area needing further research.

We acknowledge some limitations to the current study. First, although we suggested possible explanations for the relationships we observed, testing how the presence of these physically visible (or less visible) edges enhances the amount of crime in adjacent street segments is beyond the scope of the current study. Future research should delve into the mechanisms of edge effects on crime. Second, we acknowledge limitations in measurement

introduced by using Euclidean distance compared to the distance based on the street network. Street network distances are more relevant to human geography because they take into account the configuration of street geography and certain physical barriers. Nonetheless, researchers frequently compute Euclidean distance rather than using street networks given that it is less computationally demanding, and also because it often yields very similar results particularly for longer distances. Third, although prior studies suggest that streets with higher usage (i.e., collectors, arteries, etc.) tend to have more crime, we were unable to account for them in the models. Although we controlled for land use characteristics, if high volume street segments have additional significant impacts on crime events, and segments on (or near) the boundaries tend to have higher usage, this could be one explanation why the segments have higher level of crime. Finally, little is known how changes in the location of edges affect crime over time. Although rivers remain relatively stable across a certain time period, highways can be newly constructed or expanded, and new interchanges can be built to merge multiple highways. Parks can be newly created or disappear by land use planning policy over time. City boundaries and jurisdictions can change because of urban planning, political, or administrative reasons. Therefore, future studies will want to employ longitudinal data to see how the changes in edges over time impact changes in crime.

The findings of the current study have some implications for public policy. Results of this study suggest that street segments on a city border are at risk of crime. As theorized, this may be partly due to the ambiguity of policing jurisdictions. Insofar as offenders can freely cross jurisdictional boundaries, they can search out suitable targets in locations where the lowest risk exists. Indeed, empirical studies have found that the spillover process and the existence of crime ‘exploring’ across contiguous communities (Hakim, Ovadia, Sagi, & Weinblatt, 1979; Mehay,

1977). These studies suggest that the effects of externalities across jurisdictional borders in metropolitan areas are important for crime control. Therefore, we suggest that law enforcement of cities which share administrative boundaries should cooperate to come up with strategic tactics for policing the areas on city boundaries. There are various strategies that might be employed, including increasing the level of formal social control by increasing the number of patrol officers and the level of surveillance specifically targeting these places in order to reduce crime, or working more closely with members of these neighborhoods in community policing initiatives. And the fact that motor vehicle theft exhibited a pattern consistent with a cross-city distance decay pattern implies that it may be particularly important for police agencies to communicate about observed spatial patterns of this type of crime.

Conclusion

In this study, we focused explicitly on spatial boundaries (edges) and crime by employing the notion of the geometry of crime. We theorized and empirically tested the various effects of physically visible boundaries (i.e., highways, parks, and rivers) as well as less visible boundaries (city administrative boundaries) on crime in street segments. We observed that street segments adjacent to an edge have higher levels of crime regardless of the type of edge. We also found consistent distance decay effects of highways and parks for crimes. Although much empirical research focuses on physical boundaries, a key focus of the current study is whether a less visible boundary may be important: city administrative boundaries. We found that city boundaries also matter for understanding crime. To the best of our knowledge, this is the first study looking at the relationship between city boundaries and crime. Therefore, a primary contribution of the current study is to expand understanding of boundaries and crime by considering city administrative boundaries. The results for city boundaries suggest that (1) although less visible,

researchers need to consider city administrative boundaries as important features for understanding crime; and (2) law enforcement agencies of cities that share administrative boundaries should cooperate to address crime in the areas adjacent to city boundaries.

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Tables

Table 1. Summary statistics

	N	Mean	Std. Dev.	Min	Max
<i>Dependent variables</i>					
Aggravated assault	339,395	0.09	0.50	0	53
Robbery	339,395	0.05	0.32	0	32
Burglary	339,395	0.17	0.68	0	71
Motor vehicle theft	339,395	0.13	0.57	0	59
Larceny	339,395	0.32	1.93	0	254
<i>Independent variables</i>					
Population (logged)	340,579	4.94	1.10	0.05	8.71
Distance from city border (Km)	340,579	1.42	1.59	0	10.06
Distance from HWY (Km)	340,579	1.46	1.62	0	44.38
Distance from Park (Km)	340,579	0.80	1.10	0	42.54
Distance from River (Km)	340,579	5.05	4.00	0	49.46
City border (1/0)	340,579	0.02	0.15	0	1
Hwy border (1/0)	340,579	0.01	0.07	0	1
Park border (1/0)	340,579	0.02	0.15	0	1
River border (1/0)	340,579	0.00	0.03	0	1
<i>Structural Characteristics</i>					
Concentrated disadvantage	337,045	-1.89	8.81	-15	15
Racial/Ethnic heterogeneity	340,579	0.43	0.18	0	0.79
Percent owners	338,529	68.84	26.79	0	100
Percent Black	340,579	5.63	11.77	0	100
Percent Latino	340,579	34.34	28.03	0	100
Percent Occupied units	338,578	93.86	8.93	0	100
Percent residents aged 16 to 29	340,579	19.96	9.01	0	100
Percent residential land use	340,533	71.27	29.88	0	100
Percent retail land use	340,533	4.37	11.76	0	100
Percent Office land use	340,533	2.20	8.87	0	100
Percent Industrial land use	340,533	2.54	9.87	0	100
<i>Spatial lags (0.25 mile)</i>					
Concentrated disadvantage	329,727	-1.21	8.03	-15	15
Racial/Ethnic heterogeneity	329,727	0.47	0.16	0	0.77
Percent owners	329,412	64.97	25.04	0	100
Percent Black	329,727	5.58	10.24	0	100
Percent Latino	329,727	36.17	27.15	0	100
Percent Occupied units	329,499	93.88	7.40	0	100
Percent residents aged 16 to 29	329,727	20.74	7.42	0	100

Table 2. Negative binomial regression models predicting crime

	Agg assault		Robbery		Burglary		MV theft		Larceny	
Distance from city border (Km)	0.0062		0.0791	**	-0.0095		-0.0439	**	0.0221	*
	0.4282		4.8958		-0.9059		-3.9628		2.4357	
Distance from city border (Km), squared	-0.0015		-0.0068	**	0.0055	**	0.0042	**	0.0004	
	-0.8034		-3.2551		4.0168		2.9135		0.3078	
Distance from highway (Km)	0.0124		0.1312	**	-0.0285	*	-0.0704	**	-0.1053	**
	0.8675		5.8394		-2.3475		-5.2466		-10.2824	
Distance from highway (Km), squared	-0.0016		-0.0269	**	-0.0053	*	0.0022		0.0049	**
	-0.7008		-5.2623		-2.3627		0.8311		2.6770	
Distance from park (Km)	-0.0183		0.3110	**	0.0875	**	0.1558	**	0.0805	**
	-0.7686		5.2949		3.9500		6.5229		4.2329	
Distance from park (Km), squared	-0.0102		-0.1897	**	-0.0371	**	-0.0541	**	-0.0410	**
	-1.5563		-5.9892		-4.8577		-5.9878		-6.2729	
Distance from river (Km)	0.0255	**	0.0584	**	0.0187	**	-0.0071		-0.0027	
	3.0781		6.1507		3.4065		-1.1926		-0.5917	
Distance from river (Km), squared	-0.0020	**	-0.0036	**	-0.0008	*	0.0001		-0.0002	
	-3.5057		-5.6059		-2.3328		0.2539		-0.7987	
City border (1/0)	0.1209	*	0.2372	**	-0.0490		0.0330		0.2647	**
	2.2358		3.6836		-1.0106		0.6631		6.8586	
Highway (1/0)	0.5319	**	1.1115	**	0.7336	**	0.5760	**	0.8221	**
	6.9512		16.2498		11.2983		8.9423		14.6951	
Park (1/0)	0.4401	**	0.7169	**	0.0788	†	0.1251	*	0.1251	**
	8.0140		11.9580		1.6616		2.4471		10.5820	
River (1/0)	0.0067		0.2646		0.1007		-0.2713		0.3587	*
	0.0195		0.7317		0.4509		-0.9681		2.0855	
Structural Characteristics										
Population (logged)	0.1914	**	0.1916	**	0.1142	**	0.2215	**	0.1318	**
	22.5610		19.2919		17.3866		31.7590		24.1428	
Concentrated disadvantage	0.0092	**	0.0118	**	0.0065	**	0.0048	**	0.0065	**
	4.7171		5.1383		4.3259		2.9719		5.1576	
Racial/Ethnic heterogeneity	-0.0794		-0.0664		0.0959		0.1225	†	0.1998	**
	-1.0066		-0.7503		1.5516		1.8430		3.8668	
Percent owners	-0.0114	**	-0.0078	**	-0.0070	**	-0.0114	**	-0.0093	**
	-22.2843		-13.2933		-17.5067		-27.1102		-27.7480	
Percent Black	0.0055	**	0.0050	**	0.0005		0.0036	**	-0.0006	
	4.5420		3.8124		0.4041		3.1080		-0.6283	
Percent Latino	0.0072	**	0.0037	**	0.0005		0.0048	**	-0.0021	**
	8.7064		3.9790		0.7424		7.0890		-4.0160	
Percent Occupied units	-0.0065	**	-0.0047	**	-0.0053	**	-0.0027	*	-0.0015	†
	-5.0991		-3.5493		-4.9867		-2.3911		-1.6913	
Percent residents aged 16 to 29	0.0034	**	0.0022		0.0045	**	0.0087	**	0.0077	**
	2.7390		1.6359		4.5393		8.5658		9.3972	
Percent Industrial land use	-0.0042	**	-0.0061	**	-0.0001		0.0053	**	0.0008	
	-5.3469		-7.1440		-0.0972		8.4231		1.4783	
Percent Office land use	0.0033	**	0.0035	**	0.0039	**	0.0088	**	0.0060	**
	3.5704		3.5922		5.3877		11.7007		9.7331	
Percent residential land use	-0.0019	**	-0.0071	**	0.0001		0.0020	**	-0.0034	**
	-5.5357		-16.8420		0.0302		6.7103		-15.0807	
Percent retail land use	0.0132	**	0.0223	**	0.0117	**	0.0124	**	0.0196	**
	22.9004		38.2293		22.7938		24.1226		45.1512	
Spatial lags(0.25 mile)										
Concentrated disadvantage	0.0401	**	0.0278	**	0.0142	**	0.0207	**	0.0028	
	13.0633		7.4003		6.4147		8.4586		1.5379	
Racial/Ethnic heterogeneity	0.0466		0.1668		0.1905	**	0.1139		0.0017	
	0.5148		1.5934		2.7634		1.5301		0.0303	
Percent owners	-0.0018	**	-0.0061	**	-0.0009	†	-0.0029	**	-0.0043	**
	-2.7539		-7.9838		-1.8430		-5.3883		-10.2147	
Percent Black	0.0160	**	0.0171	**	0.0106	**	0.0038	**	0.0024	*
	11.1076		10.6876		8.0977		2.8119		2.0343	
Percent Latino	0.0036	**	0.0063	**	-0.0019	*	0.0018	*	-0.0049	**
	3.4995		5.1820		-2.4997		2.1539		-7.6744	
Percent Occupied units	-0.0172	**	-0.0163	**	-0.0024		-0.0064	**	-0.0060	**

	-8.5925		-7.0224		-1.6097		-3.5963		-4.7975
Percent residents aged 16 to 29	0.0088	**	0.0078	**	0.0082	**	0.0108	**	0.0090
	5.0175		3.9834		6.1138		7.6467		7.9698
Intercept	-1.3386	**	-19.8901		-3.4481	**	-3.7252	**	-1.5309
	-3.5642		-0.0052		-7.8291		-6.9974		-5.6165
N	299014		299014		299014		299014		299014
Pseudo R ²	0.1781		0.2350		0.0611		0.1333		0.0748

** $p < .01$ (two-tail test), * $p < .05$ (two-tail test), † $p < .05$ (one-tail test). *T-values in parentheses.*

Dummy variables of cities are included

Figures

Figure 1. Associations between street segment, residential parcels, and blocks

Figure 2. Distances from highways predicting various types of crime

Figure 3. Distances from park boundaries predicting various types of crime

Figure 4. Distances from rivers predicting various types of crime

Figure 5. Distances from city boundaries predicting various types of crime