Barriers to Integration:
Institutionalized Boundaries and the Spatial Structure of Residential Segregation

Elizabeth Roberto
Princeton University

Jackelyn Hwang
Princeton University

December 7, 2016

Abstract

Despite modest declines in residential segregation levels since the Civil Rights Era, segregation continues to be a defining feature of the US landscape. This paper argues that physical barriers in urban space and municipal boundaries that separate central cities from their surrounding suburbs are powerful forces that exacerbate residential segregation for urban residents and contribute to its persistence. We draw on population data and corresponding shapefiles from the 2010 decennial census and a novel approach to measuring and analyzing segregation that allows us to incorporate physical barriers and municipal boundaries. We show how these boundaries impose stark separations between spatial areas and contribute to higher levels of residential segregation across 14 US cities. The findings demonstrate an important mechanism that facilitates and maintains residential segregation.

Keywords: segregation, boundaries, race and ethnicity, cities, methods

* This research was supported by the James S. McDonnell Foundation Postdoctoral Fellowship Award in Studying Complex Systems, the facilities and staff of the Yale University Faculty of Arts and Sciences High Performance Computing Center, and the National Institutes of Health. Special thanks to Julia Adams, Richard Breen, Jacob Faber, Scott Page, and Andrew Papachristos for their valuable feedback on this research.
Barriers to Integration: 
Institutionalized Boundaries and the Spatial Structure of Residential Segregation

A long line of research shows that residential segregation by race—the extent to which racial groups reside in distinct places—plays an important role in perpetuating racial stratification in the US (Massey 2016). In the US, different race groups live, on average, in distinct social environments (Logan 2011), which can lead to unequal outcomes for families and individual life chances (Jargowsky 1997; Sampson 2012). Despite the decline of residential segregation levels since the Civil Rights Era, when legislation made explicit discrimination in real estate and lending illegal, segregation levels remain high, and segregation continues to be a defining feature of the US landscape (Rugh and Massey 2014).

Research focuses on three primary causes for explaining the persistence of segregation: 1) socioeconomic differences, 2) residential preferences, and 3) housing market discrimination (Charles 2003). Although these factors contribute to explaining why residents of different groups tend to live in separate areas from each other, we know less about the processes that lead people to end up living where they live (Crowder and Krysan 2016). We argue that spatial boundaries are one key mechanism that contributes to these processes that facilitate the persistence of residential segregation. Residents may move to different places due to differences in socioeconomic status, residential preferences, and housing market practices, but spatial boundaries structure urban space by separating areas to which residents move. Using a novel approach to measuring and analyzing segregation, we systematically demonstrate in our analysis that spatial boundaries divide urban space in ways that increase residential segregation.

Although few studies focus on the mechanisms by which residential space comes to be separated to begin with vis-à-vis spatial boundaries, a number of studies implicate the importance of spatial boundaries as key features of residential segregation. Jane Jacobs (1961), for example, laments how physical barriers, such as dead-end streets and cul-de-sacs, restrict social integration and physical access, and others document efforts to reinforce segregation in the emergence of gated communities (e.g., Blakely and Snyder 1997). These physical barriers keep residents isolated, fostering segregation. Others show how municipal boundaries facilitate segregation as residents seek to protect land values and their access to resources and services through establishing municipal boundaries (e.g., Miller 1981; Bischoff 2008). Such boundaries further structure how residents make decisions about where to live (Krysan and Bader 2009). Moreover, studies of segregation using instrumental variable approaches—a statistical method to identify the causal effect of segregation on another outcome variable by identifying a variable (the “instrument”) that is correlated with the segregation measure but is unrelated to the outcome variable—implicate such spatial boundaries. These studies frequently use municipal boundaries, as well as natural boundaries (e.g., rivers) or built boundaries (e.g., railroad tracks), as instruments for their analyses (e.g., Cutler and Glaeser 1995; Hoxby 2000; Ananat 2011; Hyra et al. 2013).

Altogether, these studies suggest that physical barriers and municipal boundaries reinforce residential segregation. A key feature of these particular types of spatial boundaries is that they are difficult to negotiate. These boundaries are distinct from spatial boundaries like streets or landmarks that can carry symbolic meaning that structure discrimination and residential
preferences and prohibit social interaction but are still negotiable (e.g., white gentrifiers moving into previously minority areas separated by a symbolic racial divide) (Anderson 1990; Lamont and Molnar 2002). Physical barriers and municipal boundaries, on the other hand, are difficult to negotiate and are maintained by—and sometimes created by—institutions. Dismantling these boundaries would require institutional actions. Removing physical barriers requires city-sanctioned urban planning and design that connects streets, urban spaces, and both natural and built boundaries by adding connective paths where cul-de-sacs and dead end streets exist and building bridges or highway underpasses to connect areas across bodies of water or highways, for example. Negotiating municipal boundaries, or at least removing differences between governances and access to services and resources that these boundaries often separate, entails major bureaucratic processes and political will. Thus, these spatial boundaries are more than symbolic boundaries and serve as distinct mechanisms that facilitate the perpetuation of segregation. It is these types of boundaries on which we focus our study.

In this paper, we argue that spatial boundaries maintained by institutions are a powerful force that exacerbates residential segregation and contributes to its persistence. Although research implicates these boundaries in maintaining residential segregation, only a handful of studies examine how spatial boundaries themselves contribute to the persistence of residential segregation. Our study is the first to our knowledge to systematically examine how these spatial boundaries affect residential segregation levels across several cities. We do this by employing a novel method developed by Roberto (2015) that builds on recent developments for measuring segregation and can incorporate physical barriers and municipal boundaries. By allowing us to integrate physical barriers and municipal boundaries in measuring segregation levels, the method permits us to systematically examine how physical barriers and municipal boundaries influence residential segregation levels. This study contributes to understandings of the persistence of segregation by demonstrating an important mechanism that facilitates and maintains residential segregation.

Spatial Boundaries and the Persistence of Residential Segregation

Although segregation between blacks and whites has declined over the last forty years, segregation levels still remain high, particularly in areas that historically have had the highest levels of segregation for these groups in the country (Rugh and Massey 2014). The level of segregation for Hispanics has also increased moderately, especially in areas where their population has grown rapidly; Asians, on the other hand, have maintained moderate levels of segregation that have changed little over this time (Rugh and Massey 2014). How boundaries separate the areas in which residents live, shaping residential selection processes and thereby maintaining residential segregation, are important yet missing pieces from existing explanations of the persistence of segregation.

Throughout the literature in urban sociology, spatial boundaries have played a prominent role in distinguishing spatial areas in which residents live. After all, the notion of neighborhoods as an organizing unit of residence implies a separation of residents along spatial boundaries that separate one place from another. Early Chicago school scholars Park, Burgess, and McKenize (1925) described neighborhoods as “natural areas,” demarcated by land uses, distinctive streets and landmarks, rivers, railroad tracks, and streetcar lines, that separated racial and ethnic groups,
as well as residents with distinct socioeconomic statuses and family compositions. These “natural” boundaries of the physical environment, they argued, organized the physical separation of groups of residents.

While there are many examples of the fluidity of neighborhood boundaries that residents negotiate and navigate, such as distinctive streets that may carry symbolic meaning as a boundary between residents of different race groups (Suttles 1968; Suttles 1972; Hunter 1974; Anderson 1990; Coulton et al. 2001; Sastry, Pebley, and Zonta 2002; Hwang 2016), there are also distinct types of boundaries that are far less fluid and negotiable. We argue that these types of spatial boundaries play a particularly important role in the persistence of residential segregation. Although symbolic spatial boundaries also contribute to the persistence of residential segregation and the integration resulting from crossing such boundaries may be temporary, such integration would not be possible with the distinct types of spatial boundaries on which we are focusing. The literature points to two examples of spatial boundaries that fall into this category: physical barriers and municipal boundaries. Physical barriers and municipal boundaries demarcate strong and persistent forms of spatial boundaries and therefore serve as the focus of our study.1

Physical Barriers

Physical barriers block the connectivity of urban spaces that roads and/or walking paths typically connect. Jane Jacobs (1961) called attention to the negative consequences of disconnected areas—spatial areas separated by physical barriers or distinct land uses, such as railroads, cul-de-sacs, and dead end streets. Jacobs (1961) argues that physical separation created and maintained distinct social and economic conditions and prohibited social contact, thereby resulting in a self-perpetuating process that maintained divisions between these two spaces. Drawing parallels with gated communities, Blakely and Snyder (1997) show that blocked streets and cul-de-sacs are motivated by efforts to socially exclude people and reinforce segregation. Grannis’ (1998) work on defining neighborhoods with tertiary streets—smaller streets conducive to pedestrian traffic—demonstrates how the connectivity of streets and roads provide a better way of capturing residential segregation compared to administratively-defined boundaries, like census tracts.

Several studies also document how gated communities—a more extreme version of cul-de-sacs and dead end streets limiting the connectivity of streets—emerged as attempts to reinforce segregation as a social exclusion effort, though often guised as efforts to curb crime and maintain home values (Blakely and Snyder 1997; Helsley and Strange 1999; Caldeira 2000; Low 2001; Webster, Galsze, and Frantz 2002; Atkinson and Flint 2004). Efforts to construct fences or other types of barriers reflect similar processes. For example, in Baltimore, an "eight-foot-tall spiked fence" was constructed around a public housing project in the Hollander Ridge neighborhood in 1998 to block access to the mostly white neighborhood of Rosedale, whose residents wanted the fence to "keep out crime and keep their property values up" (Schindler 2015:1957). Thus, whether by street design that disconnects areas or the presence of gates, walls, or fences, such physical barriers can lead racially or economically distinct groups to reside separately from each other, even if they are spatially proximate to each other (Neal 2012).

1 There are also other examples of political and legal boundaries that are beyond the focus of this particular study, such as school district boundaries (Bischoff 2008; Schwartz, Voicu, and Horn 2014).
While the existence of these physical barriers may limit social interaction between residents on one side of the barrier and those on the other side, they also maintain residential segregation by structuring residential sorting. Physical barriers can increase the value of areas on one side while decreasing the value on the other side (Noonan 2005). Housing developers have even purposely marketed such barriers as protection from those on the other sides of them (Aktinson and Flint 2004). While many neighborhood boundaries are often flexible and fluid, cognitive mapping studies tend to find that residents often agree on these distinct physical features (Chaskin 1997; Campbell et al. 2009). As a result, the differentiation between spatial areas separated by such barriers can have greater permanence in maintaining residential segregation compared with streets or landmarks carrying symbolic meaning of separation.

Few studies have systematically examined the relationship between physical barriers and residential segregation. In an analysis of Chicago, Noonan (2005) finds that differences between the share of blacks in adjacent areas is greater along physical barriers like parks, landmarks, railroads, state highways, major roads, and industrial corridors, rather than along census divisions that are not separated by such barriers. In a study of Glasgow, Mitchell and Lee (2014) find a weak association on average between socioeconomic differences and the presence of physical features, like rivers, parks, railroad tracks, and highways as neighborhood boundaries, rather than other divisions, such as streets. They also find significant heterogeneity: whereas rivers and open spaces matter sharply in some instances, they did not in others. These studies, however, do not consider the connectivity of these physical features, through bridges or pedestrian crossings into their analysis. Our analysis extends this research by examining multiple types of physical barriers that restrict connectivity in urban space. In a study focusing exclusively on gated communities, which our analysis also considers, Le Goix (2005) does not find an effect of gated communities on racial segregation in Los Angeles but, instead, finds an effect on segregation by age and income. Le Goix (2005) explains that racial groups in the region generally separate along municipal boundaries instead and that many of the gated communities were built in unincorporated areas that eventually became their own municipalities or part of new ones.

**Municipal Boundaries**

Municipal boundaries represent another type of spatial boundary that reinforces segregation. Historically, anti-fiscal actions to avoid paying property taxes and to control land development to “protect” home values often motivated municipal incorporation (Miller 1981). While demands to incorporate have generally surrounded stated intentions of protecting home values, often they come with underlying intentions to segregate from populations with which they were once combined—similar to the processes that often motivated the construction of physical barriers (Danielson 1976; Miller 1981). The result of municipal fragmentation is that each municipality can maintain control over municipal resources and services and often schools that can reinforce differences between a city and an adjacent municipality, particularly when adjacent municipalities have unequal resources and services (Miller 1981). For example, some municipalities restrict multifamily housing by controlling land use, which can restrict the entry of lower-income and minority families (Bischoff 2008). These actions may align with goals to
minimize the need and cost of public services and to keep land values high, but they effectively can increase segregation (Bischoff 2008).

While municipal boundaries do not legally restrict access to areas based on race, they can produce and maintain racial segregation by structuring residential sorting (Bischoff 2008). Residents select their neighborhoods based on public good expenditures, with municipalities providing a market choice for public goods (Tiebout 1956). Recent studies on the housing search process further suggest that, because housing searches are time consuming and expensive, movers rely on broad categorizations about places to constrain their searches (Bader and Krysan 2015). Thus, individuals may choose to avoid certain municipalities, as well-defined municipal identities and boundaries make this residential sorting process easier, and they may be attracted to certain municipalities that have public goods matching their preferences or municipalities in which their own racial or ethnic group is overrepresented (Krysan and Bader 2009). Like physical barriers, municipal boundaries demarcate clear divisions between spatial areas, and, because municipalities offer distinct provisions of goods and controls over land values, such divisions can lead to residential sorting processes that facilitate residential segregation.

While our study directly examines the effect of municipal boundaries on residential segregation levels for places within several cities, several studies have considered the relationship between municipal fragmentation and residential segregation levels across metropolitan areas. In particular, studies that use instrumental variables to examine the effect of segregation find a positive association between segregation levels for a metropolitan area and municipal fragmentation (Cutler and Glaeser 1995; Hyra et al. 2013). Further, a recent study by Lichter and colleagues (2015) examining the components of metropolitan-level segregation finds that racial segregation between municipalities has increased since 1990 while racial segregation within municipalities has decreased. These findings suggest that municipal boundaries increasingly serve as a dividing dimension between racial groups.

**Institutionalized Boundaries**

We argue that these spatial boundaries—physical barriers and municipal boundaries—are key mechanisms in maintaining residential segregation today in the US. In contrast to streets or landmarks that hold symbolic meaning but do not physically block the connectivity of areas, these strong boundaries are maintained by the lack of institutional actions to dismantle them. Some of these boundaries, such as municipal boundaries or gated communities, emerged through institutional actions supporting the discriminatory demands of actors advocating for the social exclusion of proximate outgroups; other boundaries, such as the lack of bridges connecting areas separated by rivers, exist from the absence of institutional actions to connect areas. While the sources of how these spatial boundaries have come to exist vary and are beyond the scope of this study, their continued existence makes them institutionalized and contributes to the perpetuation of segregation. In the post-Civil Rights Era, it is these institutionalized boundaries that play important roles in limiting integration.

These boundaries powerfully structure residential sorting processes by providing clear demarcations to distinguish land values between one geographic space from another, to ease the categorization of areas in the housing search process, and to market as “protection” from
residents on the other sides of the boundaries. Thus, they have important implications for inequality by distinguishing actual differences in access to resources and opportunities. For example, each municipality has its own tax base and political representation that can result in unequal services, like policing or additional school expenditures, and spaces separated by physical barriers within a municipality can result in unequal quality of services or resources distributed within a municipality. Physical barriers can also produce socially isolated environments with distinct social and economic conditions, which can lead to unequal outcomes for individuals and households.

While research implicates physical barriers and municipal boundaries in affecting residential segregation, our study is the first to our knowledge to consider these barriers and boundaries in measuring segregation to directly examine whether these features increase residential segregation levels. An analytic approach that compares residential segregation levels between measures that consider or do not consider such boundaries can shed light on this question. Existing residential segregation measures, however, face limitations in incorporating these features to assess this question.

Residential Segregation Measures

Despite the long interest in sociology in measuring segregation, Duncan and Duncan’s (1955) critique that most existing measures are inconsistent with the theoretical concept of segregation and its processes holds true today. Most studies of residential segregation mainly focus on two of the five dimensions that Massey and Denton (1988) identify in their review of measures: evenness and exposure. The dissimilarity index—which measures the extent to which two groups are evenly distributed across smaller spatial units (e.g., neighborhoods) within a larger spatial unit (e.g., a city)—remains the most widely used measure of evenness, and exposure measures the degree to which one group lives in similar spatial units as another group (Massey and Denton 1988).

Although these widely used measures are convenient to calculate with public data, they have notable shortcomings that limit our understanding of the mechanisms of segregation. First, traditional measures of segregation are limited to comparisons between two groups at a time, but, as the US becomes increasingly multiethnic, segregation measures that incorporate multiple groups are increasingly important to understand segregation patterns and trends (Reardon and Firebaugh 2002). Second, these measures are “aspatial”—they do not integrate spatial concepts like proximity and geographic scale into the measurement of segregation. Where areas are located relative to each other, the relative size of segregated clusters, or the geographic extent of segregation patterns are important characteristics of segregation that these measures do not capture (White 1983; Morrill 1991; Reardon and O’Sullivan 2004; Brown and Chung 2006).

Third, these measures do not consider variation in the geographic scale of spatial units and instead impose assumptions about which scales are relevant (Lee et al. 2008; Reardon et al. 2008; Fowler 2016). For example, a census tract with equal representation of each racial group as a city’s overall population composition would reflect evenness, or low dissimilarity, but could be comprised of distinct racial and ethnic enclaves within the tract, with residents living in

2 The other three dimensions are centralization, concentration, and clustering.
racially homogeneous blocks. Consequently, if blocks were the spatial unit of analysis, the area would appear highly segregated. In other words, the degree of segregation measured with traditional measures is sensitive to the size of geographic units, and these units are often defined by arbitrary administrative borders, like census-defined tracts or blocks (Grengs 2007; Spielman and Logan 2013).

For decades, scholars have noted these shortcomings (Duncan and Duncan 1955; Duncan, Cuzzort, and Duncan 1961; Openshaw 1977; Openshaw and Taylor 1979; Massey and Denton 1988), but only in recent years have researchers developed solutions for addressing them. Some approaches incorporate multiple ethnic groups into traditional measures and increasingly use entropy (i.e., information theory) indexes, which generally reflect the diversity within a smaller spatial unit relative to the diversity of a larger aggregate spatial unit (for a review of these and other approaches, see Reardon and Firebaugh 2002). Other recent developments, such as Reardon and O’Sullivan’s (2004) multi-group spatial exposure index and spatial information theory index, incorporate spatial proximity and scale using the location of small spatial units and their proximities to one another (for reviews of other measures, see Wong [1993] and Reardon and O’Sullivan [2004]). Incorporating multiple scales of segregation allows researchers to examine how segregation changes depending on the spatial extent used to define a “local environment,” i.e. the area surrounding individual residential spaces. With this approach, a segregation measure is calculated for multiple distances from each residential space yielding a “segregation profile” (Lee et al. 2008; Reardon et al. 2008; Spielman and Logan 2013; Fowler 2015). By incorporating multiple ethnic groups, space, and scale into segregation measures, researchers are able to compare patterns of segregation across groups and metropolitan areas (Lee et al. 2008; Reardon et al. 2008), identify neighborhoods (Spielman and Logan 2013), and examine which patterns are present at different geographic scales (Fowler 2016).

The developments in measuring segregation along these three fronts have undoubtedly advanced our understanding of segregation, but these approaches do not integrate physical barriers and municipal boundaries, which we argue are additional facets of residential space that are important for understanding the mechanisms of residential segregation. Measures that incorporate distance and spatial scale rely on straight line distance: the distance from Point A to Point B without considering the fact that spatial areas are not connected in this way. Two areas may be spatially proximate to each other, but if they are not connected easily through the road network, they may be segregated from each other (Neal 2012). Grannis (1998) argues that measures of segregation should move away from census tracts as spatial units and focus on “t-communities”—streets connected by a tertiary intersection (i.e., streets connected by single lanes in each direction with no dividers)—where social interaction is more likely. While Grannis’ (1998) emphasis is on social interaction, his insight on the importance of road connectivity informs our approach. Physical barriers limit road connectivity, and they can inform our understanding of segregation. We therefore extend upon this insight on road connectivity to examine the effect of physical barriers on segregation levels.

Further, while several recent studies examine the geographic scale of residential sorting by comparing segregation within and between places, such as municipalities in a metropolitan area, comparing central cities and the suburbs, or school districts (Bischoff 2008; Farrell 2008; Fischer 2008; Fischer et al. 2004; Lichter et al. 2012; Parisi et al. 2011; Reardon and Bischoff 2011),
they do not directly examine the effect of municipal boundaries on segregation levels for a particular place. These studies find that over the course of the twentieth century, the geographic basis of segregation patterns has shifted from regions to neighborhoods to the city-suburb line and between municipalities in metropolitan areas (Fischer et al. 2004; Lichter et al. 2015). In this study, we also directly examine the impact of municipal boundaries on segregation levels in cities to contribute to our understanding of segregation.

Strategy

To better understand how physical barriers and municipal boundaries facilitate the persistence of segregation, we examine how the presence of these boundaries influences segregation levels in cities. We do this by measuring segregation in a way that overcomes the shortcomings described in the previous section and further extends upon recent developments by incorporating physical barriers and municipal boundaries. The goal of our paper is not to draw causal conclusions but rather to use improved measures of segregation to describe the impact of physical barriers and municipal boundaries on segregation levels.

We first describe the method we use for measuring segregation, which was recently developed by Roberto (2015) and better captures distinct features of interest associated with residential segregation compared to previous measures. The method considers multiple groups and spatial proximity and does not impose geographic units of analysis on the structure of segregation in a city. Next, we test our hypothesis that physical barriers facilitate segregation by comparing measures that incorporate the road connectivity between locations and those that do not. Then, we test our hypothesis that municipal boundaries facilitate segregation by comparing measures that do and do not take these boundaries into account. Our unit of interest is the central city of metropolitan areas for this analysis. Therefore, in our analysis of municipal boundaries, we focus on the boundary separating the central city from its adjacent municipalities. We view this as a starting point for future research in this area, but the analytic approach is applicable to any area of interest (e.g., school districts, metropolitan areas, states, etc.).

Data and Methods

We draw from publicly available population data from the 2010 decennial census (US Census Bureau 2011) and the corresponding shapefiles for blocks, roads, and municipalities (US Census Bureau 2012). The US census subdivides the entire US into several nested geographic units. We rely on information for census blocks—the smallest unit of census geography for which data are publicly available. Blocks are polygons that are typically bounded by street or road segments on each side and often correspond to the size of a city block in urban areas. It is not uncommon for blocks in a city to contain no population, as many blocks can represent spatial areas without residential land use, such as industrial areas, parks, or areas between railroad tracks. The Census groups blocks into block groups, which contain an average of 39 blocks and an average population of 1,500 people; block groups are grouped within census tracts—the most commonly used unit of analysis for constructing segregation measures and contain an average population of 4,000 individuals.
For our analysis, we must first select which cities to explore more closely. Because the method we use is computationally intensive and we are interested in closely examining patterns of residential segregation, we strategically select cities that have well-documented histories of residential segregation and then examine the patterns within them. Residential segregation reached particularly high levels in cities with strong manufacturing industries in the Northeast and Midwest during the mid-twentieth century when these cities peaked in urban growth, and segregation has been the most persistent in these cities (Logan 2000). With these legacies of segregation, physical barriers and municipal boundaries were often institutionalized in response to racial tensions (e.g., Sugrue 1996). By selecting these cities, we can explore whether these spatial boundaries contribute to maintaining segregation today.

We focus our analysis on a subset of 14 cities in the US: Baltimore, MD; Boston, MA; Cincinnati, OH; Cleveland, OH; Detroit, MI; Hartford, CT; Milwaukee, WI; New Haven, CT; New York, NY; Newark, NJ; Philadelphia, PA; Providence, RI; Saint Louis, MO; and, Washington, DC. Because segregation patterns are very different in other areas of the country, such as the West, we believe that there may be alternative, though perhaps related, spatial processes associated with the persistence of residential segregation that merit future analysis. While the findings that we present may not be generalizable to other cities, this selection of cities offers a starting point for future research.

**Measuring Segregation**

The next step in our analysis is to implement a method for measuring segregation across these cities that incorporates multiple racial and ethnic groups, considers spatial proximity, and measures segregation at multiple geographic scales. To do this, we rely on a novel approach for measuring and analyzing segregation called STARC (Spatial Topography and Residential Context) developed by Roberto (2015) that we describe below. The main advantage of this method is its flexibility to incorporate additional features of the spatial environment, which then allows us to compare across different measures that do or do not incorporate the spatial boundaries that we wish to study.

The first feature of our method for measuring segregation incorporates multiple racial and ethnic groups, overcoming the shortcoming of many traditional measures of segregation that only allow for two-group comparisons. Scholars have suggested various measures, and the most popular ones are the entropy (i.e., information theory) indexes described earlier (for a review, see Reardon and Firebaugh 2002). For our method of measuring segregation, we rely on an index developed by Roberto (2015) called the Divergence Index.

The Divergence Index is based on relative entropy—an information theoretic measure also known as Kullback-Leibler (KL) divergence (Kullback 1987). The Divergence Index measures the difference between the composition of groups within a smaller spatial unit relative to the composition in a larger aggregate spatial unit. The Divergence Index differs from Reardon and O’Sullivan’s (2004) Information Theory Index because it compares the population compositions of smaller spatial units to a larger aggregate spatial unit rather than measuring the diversity of smaller spatial units relative to the overall diversity of the larger aggregate unit (Roberto 2015). For our purposes, measuring the difference between compositions, rather than diversity per se, is
favorable because it allows us to directly assess which groups are over- or under-represented relative to their overall proportions, whereas diversity measures lose information about the proportions of specific groups and instead focus on variety or relative quantity of groups. In the results that we present below, we focus on segregation between whites, blacks, and Hispanics because, in the cities that we examine in this study, the Asian population is relatively new and small compared to the remaining groups. The results including all major ethnoracial groups, however, are similar and are available upon request.

The Divergence Index can be interpreted as a measure of surprise—how surprising is the composition of smaller geographic areas, which we refer to as “local environments,” given the overall composition of a larger aggregate area of interest, which we refer to as a “region.” If all the local environments within the region have the same composition as that of the region, the Divergence Index would equal 0 and would indicate no segregation, while higher values indicate more segregation.

The second feature of our method for measuring segregation incorporates spatial proximity. We use proximity-weights for population sizes within the local environments to weight the relative influence of nearby and more distant locations. This approach follows developments in the literature that incorporate geographic proximity (Reardon and O’Sullivan 2004; Fowler 2015). We use a uniform proximity function in the results that we present, but the method can accommodate other proximity weight functions.3 Reardon and O’Sullivan (2004) do not recommend a specific proximity weight function and conclude that results within cities would not be entirely sensitive to this choice. Like the Spatial Information Theory Index, the Overall Divergence Index for a larger aggregate unit, such as a city, is the population-weighted average of all the spatially-weighted Divergence Indexes for each local environment.

A third feature of our method of measuring segregation incorporates various geographic scales. We measure segregation based on geographic points and varying distances from them to define their local environments (Lee et al. 2008; Reardon et al. 2008; Speilman and Logan 2013). Instead of using census tracts or other administratively-defined spatial units as the local environments for calculating segregation, we use the intersections of roads and the distance from these intersections to define their local environments. We then calculate the Divergence Index for each intersection by comparing the composition of each intersection’s local environment to the composition of the region. The overall composition of the region used in this calculation is based on the aggregate population of all local environments for all of the intersections in a city.

For each intersection in a city, we assign a portion of the populations of their contiguous census blocks based on the length of the adjoining side of the census block. This procedure has the advantage of using the distribution of the population of all surrounding census blocks rather than imposing arbitrary administrative boundaries for individual census blocks, and it smooths the distribution of the population by avoiding sharp discontinuities along administrative boundaries. More details on this procedure and the construction of the Divergence Index are available in the Appendix. In the results that we present below, we use varying distances ranging from .1 to 4 kilometers (2.4 miles) as the “reach” for each intersection’s local environments (RLE), and we

---

3 Others have used a two-dimensional biweight kernel proximity function (e.g., White 1983; Reardon and O’Sullivan 2004; Lee et al. 2008).
measure the Divergence Index for each distance. The Overall Divergence Index value presented for each city and each RLE distance is the population-weighted average of each intersection's Divergence Index value for that RLE distance.

In addition to measuring overall segregation for the city, we also calculate group-specific results, which represent the average degree of segregation experienced by each ethnoracial group for a given RLE. The weighted average of the group-specific results is equal to the city’s overall segregation (equations are provided in the Appendix).

Assessing Physical Barriers

To assess the impact of physical barriers on residential segregation, we construct each intersection’s local environment using two different measures of distance—straight line distance and distance along the road network. The straight line distance measures the shortest distance between each pair of locations in a city. To measure road distance, we construct a network using geographic information from the US Census for all roads and paths, including walking paths through parks for example. We then calculate the shortest pairwise distance between all intersections along the road network. The road network distance captures the connectivity of roads and thereby incorporates the excess distance created by physical barriers. If roads connect all intersections, then there would be no difference between the two measures of distance. The difference is greater if there is less connectivity, i.e., a higher prevalence of physical barriers. We measure segregation using local environments constructed with each type of distance such that the measure of segregation is a function of these distance measures. We refer to these distinct segregation measures as the straight line distance divergence index and the road distance divergence index. Existing spatial measures of segregation use the straight line distance approach, so these measures of segregation do not incorporate physical barriers.

In our analysis, we calculate the divergence index for each intersection’s local environment at each specified “reach”—the distance from the intersection—for each type of distance measure and then compare the two sets of segregation results. For example, for a RLE of 1 kilometer, at each intersection in a city, we calculate the divergence index for the composition of the spatial area within a 1 kilometer radius of the intersection and compare this composition to the composition of the region; this is the straight line distance divergence index. We also calculate the divergence index for the composition of the spatial area within 1 kilometer via the road network from the intersection and compare this composition to the composition of the region; this is the road distance divergence index.

When physical barriers are present but there is no difference between the road distance and straight line distance divergence indexes for a local environment, this indicates that physical barriers do not structure the spatial pattern of segregation in this location. This occurs where there are no differences in the racial compositions of the local environments measured by each type of distance measure. If the divergence index for a local environment using the road distance is higher than the straight line distance divergence index, this would indicate that physical barriers play a role in increasing segregation for residents of that intersection. The road distance

---

4 We use the Dijkstra algorithm in the igraph R package (Csardi and Nepusz 2006) to calculate the shortest paths.
divergence index is lower than the straight line distance divergence index for a local environment when a physical barrier separates a spatial area that has a composition similar to the region (i.e., low segregation) from an area with a composition that differs from the region (i.e., higher segregation).

We take the population-weighted average of each type of divergence index for each intersection for each RLE to calculate the Overall Divergence Index. We then compare the two divergence indexes for each RLE to evaluate the extent to which physical barriers structure the overall segregation of the city. Given that the Overall Divergence Index reflects an average difference between the segregation measures for all intersections within the city, any differences in the Overall Divergence Indexes using the road network distance or straight line distance divergence index—even if small in value—is meaningful. We expect that, in many areas within cities, the local environments using road network and straight line distance will have similar compositions to each other and will thus yield zero differences in divergence indexes. Therefore, even small positive differences between the road network and straight line distance segregation measures indicate that physical barriers structure segregation for a city.

Assessing Municipal Boundaries

To examine the impact of municipal boundaries on residential segregation, we compare two separate segregation measures that each incorporate different types of local environments—those that are truncated at the municipal boundary and those that extend into surrounding areas beyond the municipal boundary. We refer to these segregation measures as truncated and extended, respectively. We truncate local environments by constraining them to the municipal boundary for intersections within the specified distance (either by road network or straight line distance) of the municipal boundary. For example, if the RLE is 1 kilometer, the local environment of an intersection within 1 kilometer of the municipal boundary does not include residents across the municipal boundary even though they are within 1 kilometer of the intersection. An extended local environment, on the other hand, includes the population spanning the municipal boundary if they are within the specified reach of the intersection. While most measures of segregation do not take into account the location of municipal boundaries, a handful of studies have used truncated local environments to measure residential segregation in US metropolitan areas (Lee et al. 2008; Reardon and Bischoff 2011; Reardon et al. 2008). These studies, however, do not compare results for truncated and extended local environments to explicitly examine the role of municipal boundaries in structuring residential segregation in central cities.

When we use truncated local environments to construct the segregation measure, we simply compare the racial and ethnic composition of each intersection’s local environment to the overall composition of the city; when we use extended local environments, we compare the racial and ethnic composition of each intersection’s local environment to the overall composition that includes the population of areas outside the city within the specified RLE of all intersections of the city. In other words, when we use extended local environments, the overall population includes a buffer beyond the municipal boundaries of the city defined by the distance (either by road network or straight line distance) of the specified RLE. We refer to this overall population as the extended area aggregate population. Local environments can span bodies of water, such as a rivers and lakes, and will include the population on the other side of the water if it is within
the RLE (via the road network or straight line distance). Where the city is bordered by another country (e.g., where Detroit borders Canada), the truncated and extended local environments for all intersections do not cross the U.S. border.

If the divergence of the racial and ethnic composition of an intersection’s truncated local environment and its city's overall composition is similar to the divergence of the composition of the intersection’s extended local environment and the extended area aggregate population composition of the city (within a given RLE), then we will not observe a difference between the extended and truncated divergence indexes. We will, however, observe a difference if either (or both) the city racial and ethnic composition differs from the extended overall population composition within the RLE or the racial and ethnic compositions of an intersection’s truncated and extended local environments differ.

The city population and extended area aggregate population compositions will differ most when there is a stark difference between the population composition of the city and its surrounding areas. The population compositions of extended and truncated local environments are most likely to differ for intersections near a municipal boundary, where local environments may have a different composition when they extend into areas beyond the municipal boundary rather than being truncated. The local environments of intersections that are not within the reach of a municipal boundary at a particular RLE will have identical compositions using either truncated or extended local environments. The level of segregation for an intersection reflects the extent to which the composition of its local environment differs from the overall (city or extended area aggregate) population composition. Thus, even for an intersection with the same truncated and extended local environment composition, segregation will differ for extended and truncated local environments for the intersection if the city’s population composition differs from the extended area aggregate population composition.

Segregation levels for extended local environments will be greater than for truncated local environments if the divergence index is higher, on average, for extended local environments than truncated local environments. A positive difference would indicate that the municipal boundary increases segregation, on average, for those living within the city; a negative difference would indicate that the city's pattern of segregation is not structured by the municipal boundary. Instead, incorporating areas outside the city boundaries into local environments reduces segregation for city residents, on average. This can occur if the compositions of truncated local environments diverge from the city's composition (i.e. higher segregation) to a greater extent than the compositions of extended local environments relative to the extended area aggregate population composition (i.e. lower segregation).

Using each of these two different approaches for measuring the composition of local environments, we take the population-weighted average of the divergence indexes for all intersections to calculate the Overall Divergence Index for each RLE. We compare the two sets of results to examine the extent to which municipal boundaries structure the overall segregation levels of cities. While any difference indicates that city boundaries are an important consideration in understanding the spatial structure of residential segregation patterns, a larger Overall Divergence Index using extended local environments compared to an Overall Divergence Index using truncated local environments indicates that municipal boundaries
increase segregation, on average, for those living within the city. Since the results represent an average across all intersections in the city, even small differences between the truncated and extended local environment results are important. Like our analysis of physical barriers, any positive differences, even if small in value, indicate that municipal boundaries structure a city’s spatial pattern of segregation. In the results that we present below, we only compare truncated and extended local environments for measures using road network distance, but comparisons using straight line distance divergence indexes are available upon request.

**Results**

We first describe the cities that we use in our study. Table 1 displays the population size and share of non-Hispanic whites, non-Hispanic blacks, Hispanics, and Asians for the 15 cities based on the 2010 decennial census. Figure 1 displays four multi-group measures of segregation: the Index of Dissimilarity (Reardon and O'Sullivan 2004), the Normalized Exposure Index (Reardon and Firebaugh 2002), and the spatial and aspatial versions of the Divergence Index (Roberto 2015). The figure displays the multi-group segregation of white, black, and Hispanic residents for the traditionally-used aspatial Dissimilarity and the Normalized Exposure Indexes and the aspatial Divergence Index for each city and using census tracts as the units of analysis. The spatial Divergence Index displayed in Figure 1 is the population-weighted average of the Divergence Indexes for each intersection in a city. The index presented incorporates blacks, Hispanics, and whites and is based on a .5 km RLE, which is close to the average size of a census tract in our sample. We use the road network distance and truncated boundaries to calculate the scores for the spatial Divergence Index presented in this figure.

[Table 1 about here.]

[Figure 1 about here.]

The table illustrates how most of the cities that we include in our analysis are not majority white and have varying levels of multi-group segregation. Only Boston and two boroughs of New York City—Manhattan and Staten Island—have much larger shares of non-Hispanic whites compared to other race groups. In contrast, Baltimore, Cleveland, Detroit, Newark, and Washington DC have much larger shares of blacks compared to other race groups in their respective cities. In Hartford and the Bronx, Hispanics comprise the largest share of the populations.

The Dissimilarity and Normalized Exposure Indexes both indicate that Baltimore, Cleveland, Detroit, Milwaukee, Philadelphia, St. Louis, and Washington are among the most segregated cities of the group, while New York and its boroughs, Harford, New Haven, Newark, and Providence have relatively low levels of segregation on both of these measures. By contrast, the spatial Divergence index reveals very high levels of segregation in Milwaukee, Philadelphia, and New York—particularly Brooklyn and Queens—and low levels of segregation in the Bronx, Staten Island, Cincinnati, Detroit, Hartford, New Haven, and Providence.

These differences stem from the aspatial ways in which the Dissimilarity and Normalized Exposure Indexes are measured and the distinct features that these measures capture. For example, Detroit has relatively high Dissimilarity and Exposure Indexes because, although most
locations within the city are similar to its overall composition: most areas are primarily black in a city with a population that is 82% black. Hispanics tend to reside in separate tracts in and around “Mexicantown” in Southwest Detroit while whites tend to reside in tracts downtown. Thus, a large share of these groups would need to move to a different tract to generate an even distribution of these groups, which the Dissimilarity Index captures, and these groups have little exposure to each other in the tracts where they currently live, which the Normalized Exposure Index captures. Detroit has a lower Divergence Index, however, because most areas are similar to the overall city composition, and the areas with large white or Hispanic populations are surrounded by areas with a different population composition, making their local environments more representative of the city’s overall composition and thereby lowering the segregation levels for residents within these areas.

**Physical Barriers**

Next, we compare segregation measures incorporating road distance to those that only use straight line distance for each of the cities to examine the impact of physical barriers on segregation levels. We assess overall segregation levels for five RLEs: .5 km, 1 km, 2 km, 3 km, and 4 km, which each approximate the area of a single census tract, three to four census tracts, larger aggregate units often used as neighborhood statistical areas, and even larger aggregate units that conform to large regions of the city, respectively. For each city using each RLE with extended local environments—those that are not truncated at the municipal boundaries, we present the Overall Divergence Indexes, which are the population-weighted averages of the divergence indexes for every city intersection’s local environment. Figure 2 presents the percent differences between the road distance divergence index and the straight line distance divergence index for each city. The segregation levels are presented in Appendix Table A1.

The results indicate that the differences between the two measures of segregation vary depending on the RLE, as well as across cities. The meaning of each RLE, of course, varies across cities depending on the geographic size and population density of the city itself. At an RLE of .5 km, which roughly approximate the area of a census tract, the differences across all cities are very small—with an average difference of about 4 percent. Cincinnati, Hartford, and New Haven show the largest percent difference between the road distance divergence index and the straight line distance divergence index—all greater than a 5 percent increase. These differences may seem like small values, but it is important to remember that they reflect the population-weighted average segregation levels for all of the intersections within each city, including locations where no physical barriers are present. It is not surprising that differences between these divergence indexes is relatively small at this scale: for most local environments at this scale within a city, the racial compositions are similar between the local environments measured using either the road network distance or straight line distance. To observe an overall difference, even if seemingly small in number, indicates greater separation between groups in the city resulting from physical barriers.

5 Others have found that the Dissimilarity Index is upwardly biased when the population includes small groups (e.g. Carrington and Troske 1997, Winship 1997), and Detroit is a predominantly black city with small white and Hispanic populations.
Greater differences emerge on average in all cities at greater distances. Using an RLE of 2 km, the differences between the segregation measures increase across all cities with Baltimore, New Haven, and Cincinnati having the highest percent increases in segregation levels of 30, 25, and 21 percent, respectively, using the road network divergence index relative to the straight line distance divergence indexes. Baltimore, New Haven, and Cincinnati are cities where the geographic scale of segregation tends to be more at the micro-scale, i.e. there is a patchwork of racial or ethnic enclaves throughout the city, rather than at the macro scale, i.e. clustering that encompasses large sections of the city, such as a prominent north-south racial divide. In cities with micro-scale segregation there are a greater number of segregated residential clusters but they are smaller in size, compared to cities with macro-scale segregation. The large differences between the road network and straight line distance divergence indexes in Baltimore, New Haven, and Cincinnati suggests that physical barriers tend to mark the borders of segregated clusters in these cities.

In Cleveland, Detroit, Milwaukee, St. Louis, and Washington, on the other hand, the difference between the road distance and straight line distance divergence indexes remains relatively small. These cities tend to have more macro-scale segregation — racial groups are separated within the cities in large residential clusters. Thus, for most intersections, the local environments measured by the road network and straight line distances have similar racial and ethnic compositions. Where these clusters of racial and ethnic groups converge is where differences are more likely. Physical barriers may indeed mark the clusters' borders, but the relatively fewer instances of where these groups meet seems to explain why physical barriers have a relatively lower impact on average within this set of cities.

Figures 3 and 4 illustrate how physical barriers can structure patterns of residential segregation in a city. Figure 3 displays a map of the black-Hispanic-white racial compositions in Baltimore. The overall composition of Baltimore is 28% white, 63% black, 4% Hispanic, and 2% Asian. The color labeled “City Composition” would indicate an intersection that matches the white, black, and Hispanic composition of Baltimore. As the map shows, however, there are few intersections that match the city's composition. There is a distinct pattern of racial clustering throughout the city, which Brown (2016) describes as the “White L” and the “Black Butterfly.” The White L stretches from north to south along the Charles Street corridor and turns to the east along the Inner Harbor, and the Black Butterfly extends out from the White L to the east and west in the shape of butterfly wings.

[Figure 3 about here.]

In a separate map in Figure 4, we highlight an area of Baltimore—the neighborhoods of Waverly and Guilford, which are divided by Greenmount Avenue. Waverly is a poor, predominantly black neighborhood on the east side of Greenmount Avenue, and Guilford is a wealthy, predominantly white neighborhood on the west side of Greenmount Avenue (Schindler 2015). The map illustrates the lack of road access between Guilford and Waverly crossing Greenmount Avenue. Whereas Waverly contains a dense network of roads within it, the roads connecting it with Guilford are far less dense. As a result, we find differences between the road distance and straight line distance divergence indexes.
The darker intersections indicate relatively larger differences between the road distance and straight line divergence indexes for each intersection’s local environment using an RLE of .5 km. Only the lightest shaded dots indicate negative differences. The prevalence of darker points in the map indicate that the lack of road connectivity between Guilford and Waverly exacerbates segregation for individuals living within both of these neighborhoods. When we examine the divergence indexes for each neighborhood on average, we find that, at a RLE of .5 km, the road distance divergence index is 37% greater than the straight line distance divergence index in Guilford and 44% greater in Waverly.

Armborst et al. (2015) describe Greenmount Avenue between 33rd Street and Cold Spring Lane as a wall used to disconnect one side from the other. For example, among the streets that intersect Greenmount Avenue between 33rd Street and Cold Spring Lane, very few streets cross Greenmount to provide connectivity between the neighborhoods. Our estimate of the extent to which the lack of connectivity across Greenmount Avenue exacerbates segregation may in fact be a conservative estimate. Our method incorporates the connectivity provided by walking paths across Greenmount Avenue between Waverly and Guilford, despite the presence of bollards and one-way streets that inhibit vehicle traffic from Waverly to Guilford (Mikin 2012).

Altogether, these results provide evidence that physical barriers indeed increase the degree of segregation across cities on average. Nonetheless, the degree to which they matter varies by the size of local environments for which we measure segregation. The difference generally increases when we consider larger spatial areas; however, in some cities, the maximal difference occurs in local environments that are not necessarily the largest. For example, in Cincinnati and New Haven, the difference is higher using a 2 km RLE rather than a 4 km RLE. This suggests that physical barriers have a greater average effect on structuring segregation within 2 km of intersections in these cities.

Municipal Boundaries

We next compare segregation measures that truncate the local environments to municipal boundaries with measures that allow local environments to extend outside the municipal boundaries. Figure 6 presents results assessing municipal boundaries. These results use road distance and use the same geographic scales as presented above. The figure displays the percent difference between the Overall Divergence Indexes for cities that use extended local environments versus those that are truncated at the city boundary. The actual segregation levels are reported in the Appendix in Table A2.

The results in Figure 6 indicate that there are generally no differences between these segregation measures when we use RLEs less than about 2 km, with the exception of Detroit and Hartford. It is not surprising that these differences are small given that the vast majority of local environments for intersections within the city at these scales do not intersect the city boundaries,
and the aggregate composition of local environments is quite similar to the city's composition. Given that these differences represent the population-weighted average for intersections across the entire city, any observed differences, even if small, indicate that municipal boundaries impact segregation levels in a particular city.

We observe greater differences using a 2 km RLE in some cities, such as Detroit and Hartford, while other cities exhibit smaller differences between the truncated and extended measures or no difference at all. Notably, Detroit and Hartford have the largest percent differences, both greater than 30 percent. In other words, in Detroit and Hartford, segregation levels are much larger when using local environments that extend outside the municipal-level boundaries rather than being truncated, indicating that municipal boundaries structure segregation patterns in these cities. At a 4 km RLE, the average difference between extended and truncated divergence indexes increases, and these differences are particularly large in Baltimore, Detroit, Hartford, and New Haven. In some cities there is are larger regional patterns of segregation that do not conform to the municipal boundary, especially in St. Louis and Washington, DC. The lack of differences in some cities may reflect the increasing suburbanization of minorities and associated decline of inner-ring suburbs in recent decades (Kneebone and Garr 2010). It is possible that in some regions the municipal boundaries between inner- and outer-ring suburbs may play a greater role in structuring segregation patterns, such as in Cleveland and Newark.

Several cities also have negative differences, including Newark, Philadelphia, and Washington. In addition, the New York boroughs of Brooklyn, the Bronx, and Queens also exhibit small negative differences. These negative differences suggest that, on average, including the population of adjacent municipalities makes the local environments more similar than different to the overall population composition of the city (or borough) and its surrounding area that falls within the specified RLE.

The differences discussed thus far are the average for all residents in each city. When we examine the differences separately for white, black, and Hispanic residents in each city, there is striking variation in the race-specific differences. Figure 6 shows the differences separately for white, black, and Hispanic residents in each city. The results demonstrate that even in cities that have small differences, the differences are often much larger for particular ethnoracial groups, especially blacks. For example, Cincinnati, Milwaukee, and Cleveland all have very small or slightly negative percent differences overall, but much larger differences for black residents (22%, 49%, and 79%, respectively, at a 4 km RLE).

[Figure 6 about here.]

Figure 7 illustrates how municipal boundaries can structure patterns of residential segregation in a city. Figure 7 presents the city of Detroit, with the municipal boundary highlighted. As the map shows, there are sharp racial differences surrounding most of the municipal boundary of the city. Detroit—a city that is 82% black—is primarily surrounded by whites along its municipal boundary.

---

6 We also calculated race-specific differences for our analysis of the impact of physical barriers on segregation levels, but we did not find major differences between white, black, and Hispanic residents. This suggests that groups are separated from each other by physical barriers in a more or less equal way. However, municipal boundaries have a more disparate impact on residents of different races.
boundary. This pattern generally occurs along the entire boundary except the western half of the northern boundary, which marks the infamous 8 Mile Road. Accordingly, the large difference between the extended and truncated divergence indexes in this city reveal that the municipal boundary facilitates segregation.

[Figure 7 about here.]

Overall, the results reveal that, on average, municipal boundaries affect segregation levels in RLEs of at least 1 km. The average difference across cities increases as the reach increases, but, in some cities, the difference is very small or negative, indicating that municipal boundaries do not structure the spatial patterns of segregation in these cities.

**Discussion and Conclusions**

While earlier work has implicated the roles of physical barriers and municipal boundaries in facilitating residential segregation, our study draws on recent advances in the measurement of segregation to offer a direct examination of the effects of these spatial boundaries on residential segregation levels. With this research, we seek to bridge the theoretical concept of segregation with its operationalization—following what Duncan and Duncan (1955) advocated for decades ago. We build on recent developments in segregation measures that incorporate multiple racial and ethnic groups, spatial proximity, and geographic scale and utilize novel measures that incorporate physical barriers and municipal boundaries to examine their role in influencing residential segregation levels across several US cities. By comparing segregation levels that incorporate these features with measures of segregation that imply the absence of these physical barriers, using straight line distance measures, or the absence of these municipal boundaries, using segregation measures with extended local environments, we find that, in general, both physical barriers and municipal boundaries increase levels of segregation across these cities. The results imply that without these boundaries in place, segregation would be lower and residential integration more likely.

Although legislation passed nearly 50 years ago ended explicit racial discrimination in real estate and lending practices and race relations have certainly improved since then, residential segregation levels remain persistently high across the US. Our study contributes to our understanding of segregation by demonstrating how physical barriers and municipal boundaries serve as mechanisms that separate residential space to facilitate the persistence of residential segregation. We show that these boundaries, which institutions maintain by their lack of action to remove them, impose separations between spaces that result in higher levels of residential segregation. These boundaries often provide clear divisions between spaces that yield agreement among residents, real estate agents, and other administrative units and influence residential sorting patterns (Ananat 2011; Bader and Krysan 2015). As a result, the presence of these boundaries can result in distinct social conditions and experiences for individuals on different sides of them. While weaker boundaries that are negotiable offer the possibility for change whereby residents or real estate agents can reconstruct boundaries, identities, and reputations, these institutionalized boundaries limit such possibility.
Altogether, our results provide direct evidence that these spatial boundaries increase residential segregation levels. Existing explanations of segregation largely focus on three main factors or the persistence of residential segregation today—socioeconomic differences, residential preferences, and housing market discrimination, but these factors focus less on how space itself can contribute to the perpetuation of residential segregation. Considering the spatial dimensions of segregation, including features of the built environment, as well as legal boundaries that demarcate differential access to services and resources, advances theoretical accounts of segregation. These features shape different patterns of residential sorting on which socioeconomic differences, residential preferences, and housing market discrimination operate.

While we believe that our results provide convincing evidence that these types of spatial boundaries reinforce or exacerbate segregation and limit racial integration, our ability to draw causal conclusions is limited. We do not examine changes in segregation levels over time with the introduction or removal of these spatial boundaries. Instead, our analysis provides an exercise where we measure segregation in ways that consider or do not consider the presence of such boundaries. While our results suggest that these boundaries increase segregation levels compared to if they were absent, it is possible and likely that the racial composition or changes in the composition of an area incited the creation of the spatial boundaries that we examine and that the removal of such boundaries may lead to alternative patterns of residential sorting that may maintain residential segregation. An analysis over time with historical data that examines both the creation and removal of such boundaries would shed more light on the causal direction and causal process between these boundaries and racial segregation. We argue, however, that the continued existence of these boundaries continues to reinforce segregation today.

Our analysis examines a limited set of cities with relatively similar histories of urbanization, long histories of residential segregation, and relatively large black populations, but our findings and approach raise new questions that can enhance our understanding of mechanisms contributing to residential segregation. How do spatial boundaries structure residential segregation in cities with distinct histories of urban growth and residential segregation? In cities with historically small minority populations and experiencing a rapid growth of immigrants in recent decades, municipal boundaries may play even greater roles in facilitating segregation as municipalities may institute laws and restrictions that limit where immigrants move, such as prohibiting multifamily housing. We also find variation across the cities that we examine; thus, despite the cities having similarities, the results suggest that the need for future research on the causes of variation across cities.

While we find that there are differences in the average divergence indexes across cities, there is also important variation within cities as indicated by the standard deviations of the differences in segregation measures. In some cities, physical barriers can matter in one section of a city in structuring racial segregation, but it may not matter in another section of the city where there are relatively more white residents, for example. Moreover, municipal boundaries may matter on one side of the city, where more black reside separately from surrounding white suburban areas, but they may not matter on another side of a city, where more whites reside and are surrounded by similarly white suburban areas. Such variation has important implications for understanding the consequences of segregation and their uneven distribution.
We also assumed that municipal boundaries draw divisions between access to services and resources, but such differences in services and resources should be explored in future research. Further, how do school boundaries and other types of boundaries that distinguish access to services and resources affect segregation patterns, or are such boundaries less relevant over time with the increase of school choice? Do such boundaries affect segregation patterns more today beyond central cities and into the suburbs? Recent studies suggest that these factors are important in residential segregation processes (e.g., Bischoff 2008; Lichter, Pais, and Taquino 2015; Schwartz, Voicu, and Horn 2014), and our approach provides a way in which future research can explore these questions.

Methodologically, we use an innovative measure that advances the study of segregation by incorporating a variety of dimensions that previous measures do not consider (Roberto 2015). These dimensions are all important to capture, however, because they shed new light on how we understand segregation and how it varies across space. The unique contribution of this approach is the consideration of the road network, which allows us to assess physical barriers. While this significantly improves upon even the most advanced measures of segregation, which use straight line distance to examine separation between spaces in a city, there are even more avenues for incorporating space into measures of segregation. First, the measure we use considers bridges and underpasses as connected roads, but these types of areas can also separate space if they are desolate or poorly lit, for example. In this case, they can perpetuate residential segregation rather than bridge spaces together. The measure incorporates the connectivity of roads and walking paths, but residents can connect through backyards, for example. Thus, developing systematic measures of the quality of these connective roads or the quality of these barriers could further enhance our understanding of how physical barriers structure residential segregation. Second, the measures focus only on where residents live, but the literature on physical barriers often discuss the limitations that they pose on social interaction and access to spaces. Further analysis could examine how such spatial boundaries affect segregation in individuals’ activity space with data on how individuals get around places and the places in which they interact with others.

Despite the further questions that this study poses, the findings have implications for reducing segregation. Importantly, the boundaries that we examine are institutionalized, but they likewise can be changed or removed by institutions. Urban design and planning that connects racially segregated areas can promote racial integration. For example, a recent initiative called Reimagining the Civic Commons is funding a demonstration projects to revitalize and connect public spaces, including converting an abandoned elevated railroad into a park with walking paths (http://www.civiccommons.us/). Such an effort would connect the areas on both sides of the railroad tracks, having the potential to promote integration. Likewise, reducing the stark inequalities in the quality and availability of services and resources between municipalities could reduce residential segregation. While the political will to support such changes is yet to be seen, recent efforts in the St. Louis area to merge St. Louis City with St. Louis county or to disincorporate its municipalities are in discussion that would pool regional resources and services and has the potential to lead to less extreme racial divisions that plague the area (http://www.betertogetherstl.com/). Removing such boundaries or the inequalities on either side of them will not guarantee residential integration, but it can weaken the boundaries, make them negotiable, and therefore create the possibility for integration, which otherwise would not exist.
Appendix

Procedure for Assigning Block Populations to Road Locations

For each block, we identify all roads that lie on the boundary of the block or within the block, and we identify all of the intersections of these roads. We use these intersections as the locations for constructing local environments and measuring segregation. We disaggregate the population of each block by assigning each individual to a specific intersection. We do this in two steps. First, we assign individuals to one of the roads in their block, with the probability of assignment equal to the length of the road segment. Second, we randomly assign individuals to one of the endpoints of their assigned road segment, i.e. one of the intersections.

The random assignment procedure affects the composition of each intersection, but this would only be a concern if we were measuring segregation aspatially and treating each blocks intersections as the unit of analysis. However, our spatial approach involves constructing local environments around each location and incorporating nearby populations into its composition. Even at a reach of 0 kilometers, much of the variability of random assignment is mitigated, because adjacent blocks share intersections and each block contributes to the intersection's population. But to err on the side of caution, we only report results for local environments with a reach of at least 0.1 kilometers, which is an area at least as large as a typical residential block in the cities we study.

Measuring Segregation with the Divergence Index

The divergence index for location $i$'s local environment with a reach of $r$ kilometers is:

$$
\bar{D}_{ri} = \sum_{m=1}^{M} \bar{\pi}_{rim} \log \frac{\bar{\pi}_{rim}}{\pi_{rm}}
$$

where $\pi_{rm}$ is group $m$’s proportion in the overall population, and $\bar{\pi}_{rim}$ is group $m$’s proportion of the proximity weighted population in location $i$’s local environment.

For the truncated local environment measures, the overall population is simply the city population. For the extended local environment measures, the overall population is the aggregate population of all local environments, which includes the city population as well as any individuals outside the city who are included in the local environment of a city resident. The aggregate population can grow and change in composition as the reach of extended local environments increases.

The proximity weighted population composition for each location is calculated as:

$$
\bar{\pi}_{rim} = \frac{\int_{j \in R} \tau_{jm} \phi(i,j) dj}{\int_{j \in R} \tau_j \phi(i,j) dj}
$$
where \( \tau_j \) and \( \tau_{jm} \) are the total and group-specific population counts for each location \( j \) in region \( R \), and \( \phi(i,j) \) is the proximity function for locations \( i \) and \( j \). We use a uniform proximity function to weight the influence of nearby and more distant locations:

\[
\phi(i,j) = \begin{cases} 
1 & \text{if } d(i,j) < r \\
0 & \text{otherwise}
\end{cases}
\]

where \( d(i,j) \) is the pairwise distance between locations \( i \) and \( j \), and \( r \) is the reach of local environments.

The city’s overall segregation for a given reach of local environments is the population weighted average of the divergence indexes for all locations, calculated as:

\[
\bar{D}_r = \frac{1}{T} \sum_{i=1}^{N} \frac{\tau_i}{T} \bar{D}_{ri}
\]

where \( T \) is the city population, and \( \tau_i \) is the population of location \( i \).

In our analysis of the impact of municipal boundaries on segregation, we calculate group-specific segregation results for each reach of local environments. For each location, we calculate \( \bar{D}_{ri} \) as above, and then calculate the average degree of segregation experienced by each ethnoracial group as:

\[
\bar{D}_{rm} = \frac{1}{\tau_m} \sum_{i=1}^{N} \frac{\tau_{im}}{\tau_m} \bar{D}_{ri}
\]

where \( \tau_m \) is the population of group \( m \) in the city, and \( \tau_{im} \) is the population of group \( m \) in location \( i \). The weighted average of the group-specific segregation results is equal to the city’s overall segregation:

\[
\bar{D}_r = \frac{1}{T} \sum_{m=1}^{M} \frac{\tau_m}{T} \bar{D}_{rm}
\]

[Table A1 about here.]

[Table A2 about here.]
References

Armborst, T., D. D'Oca, and G. Theodore, eds. 2015. The Arsenal of Exclusion/Inclusion. Actar.

Ananat, Elizabeth Oltmans. 2011. "The Wrong Side(s) of the Tracks: The Causal Effects of Racial Segregation on Urban Poverty and Inequality." American Economic Journal: Applied Economics 3 (2): 34-66.

Anderson, Elijah. 1990. Streetwise: Race, Class, and Change in an Urban Community. Chicago: University of Chicago Press.

Anderson, Elijah. 1999. Code of the Street: Decency, Violence, and the Moral Life of the Inner City. New York: W.W. Norton.

Atkinson, Rowland, and John Flint. 2004. “Fortress UK? Gated Communities, the Spatial Revolt of the Elites and Time–Space Trajectories of Segregation." Housing Studies 19 (6): 875-892.

Bader, M. D. M. and J. A. Ailshire. 2014. “Creating Measures of Theoretically Relevant Neighborhood Attributes at Multiple Spatial Scales.” Sociological Methodology 44(1):322–68.

Bader, Michael DM, and Maria Krysan. 2015. “Community Attraction and Avoidance in Chicago What’s Race Got to Do with It?.” The ANNALS of the American Academy of Political and Social Science 660 (1): 261-281.

Bischoff, Kendra. 2008. “School District Fragmentation and Racial Residential Segregation How Do Boundaries Matter?” Urban Affairs Review 44(2):182–217.

Bivand, Roger and Colin Rundel. 2014. rgeos: Interface to Geometry Engine - Open Source (GEOS).

Bivand, Roger and Nicholas Lewin-Koh. 2014. maptools: Tools for reading and handling spatial objects.

Bivand, Roger, Tim Keitt, and Barry Rowlingson. 2014. rgdal: Bindings for the Geospatial Data Abstraction Library.

Blakely, Edward J. and Mary Gail Snyder. 1997. Fortress America: Gated Communities in the United States. Washington, DC: Brookings Institution Press.

Brown, Lawrence A., and Su-Yeul Chung. 2006. "Spatial Segregation, Segregation Indices and the Geographical Perspective." Population, Space and Place 12 (2): 125-143.

Caldeira, Teresa PR. 1992. City of Walls: Crime, Segregation, and Citizenship in Sao Paulo. Berkeley, CA: University of California Press.

Campbell, Elizabeth, Julia R. Henly, Delbert S. Elliott, and Katherine Irwin. 2009. “Subjective Constructions of Neighborhood Boundaries: Lessons from a Qualitative Study of Four Neighborhoods.” Journal of Urban Affairs 31 (4): 461-90.

Carrington, W. J. and K. R. Troske. 1997. “On Measuring Segregation in Samples with Small Units." Journal of Business & Economic Statistics 15(4):402–9.

Charles, Camille Zubrinsky. 2003. “The Dynamics of Racial Residential Segregation.” Annual Review of Sociology 29:167–207.

Chaskin, Robert J. 1997. "Perspectives on Neighborhood and Community: A Review of the Literature." Social Service Review 71 (4): 521-47.
Coulton, Claudia J., Jill Korbin, Tsui Chan, and Marilyn Su. 2001. "Mapping Residents' Perceptions of Neighborhood Boundaries: A Methodological Note." *American Journal of Community Psychology* 29 (2): 371-83.

Cover, T. M. and Joy A. Thomas. 2006. *Elements of Information Theory*. Hoboken, N.J.: Wiley-Interscience.

Crowder, Kyle, and Maria Krysan. 2016. “Moving Beyond the Big Three: A Call for New Approaches to Studying Racial Residential Segregation.” *City & Community* 15(1):18-22.

Crowder, Kyle, Jeremy Pais, and Scott J. South. 2012. “Neighborhood Diversity, Metropolitan Constraints, and Household Migration.” *American Sociological Review* 77(3):325–53.

Csardi, G. and T. Nepusz. 2006. “The igraph Software Package for Complex Network Research.” *InterJournal."

Cutler, David M., and Edward L. Glaeser. 1995. “Are Ghettos Good or Bad?” *National Bureau of Economic Research Working Paper No. w5163.*

Danielson, Michael N. 1976. *The Politics of Exclusion*. New York: Columbia University Press.

Deener, A. 2010. “The 'Black Section' of the Neighborhood: Collective Visibility and Collective Invisibility as Sources of Place Identity.” *Ethnography* 11(1):45–67.

Duncan, Otis Dudley, Ray P. Cuzzort, and Beverly Duncan. 1961. *Statistical Geography: Problems in Analyzing Areal Data*. Free Press.

Duncan, Otis Dudley, and Beverly Duncan. 1955. "A Methodological Analysis of Segregation Indexes." *American Sociological Review* 20 (2): 210-217.

Emerson, John W. and Michael J. Kane. 2013. *biganalytics: A library of utilities for big.matrix objects of package bigmemory.*

Farrell, Chad R. 2008. “Bifurcation, Fragmentation or Integration? The Racial and Geographical Structure of US Metropolitan Segregation, 1990–2000.” *Urban Studies* 45(3):467–99.

Fischer, Claude S., Gretchen Stockmayer, Jon Stiles, and Michael Hout. 2004. “Distinguishing the Geographic Levels and Social Dimensions of U.S. Metropolitan Segregation, 1960-2000.” *Demography* 41(1):37–59.

Fischer, Mary J. 2008. “Shifting Geographies: Examining the Role of Suburbanization in Blacks’ Declining Segregation.” *Urban Affairs Review* 43(4):475–96.

Fotheringham, A. Stewart and David W. S. Wong. 1991. “The Modifiable Areal Unit Problem in Multivariate Statistical-Analysis.” *Environment and Planning A* 23(7):1025–44.

Fowler, Christopher S. 2016. "Segregation as a Multiscalar Phenomenon and Its Implications for Neighborhood-Scale Research: The Case of South Seattle 1990–2010." *Urban Geography* 37 (1): 1-25.

Grannis, Rick. 1998. “The Importance of Trivial Streets: Residential Streets and Residential Segregation.” *American Journal of Sociology* 103(6):1530–64.

Grannis, Rick. 2002. “Discussion: Segregation Indices and Their Functional Inputs.” *Sociological Methodology* 32(1):69–84.

Grengs, Joe. 2007. "Reevaluating Poverty Concentration with Spatial Analysis: Detroit in the 1990s." *Urban Geography* 28 (4): 340-360.

Helsley, Robert W., and William C. Strange. 1999. "Gated Communities and the Economic Geography of Crime." *Journal of Urban Economics* 46 (1): 80-105.
Hipp, John R. 2007. “Block, Tract, and Levels of Aggregation: Neighborhood Structure and Crime and Disorder as a Case in Point.” *American Sociological Review* 72(5):659–80.

Hoxby, Caroline. 2000. “Peer Effects in the Classroom: Learning from Gender and Race Variation.” *National Bureau of Economic Research Working Paper No. w7867*.

Hunter, Albert. 1974. *Symbolic Communities: The Persistence and Change of Chicago's Local Communities*. Chicago, IL: University of Chicago Press.

Hwang, Jackelyn. 2016. “The Social Construction of a Gentrifying Neighborhood: Reifying and Redefining Identity and Boundaries in Inequality”. *Urban Affairs Review* 52 (1): 98-128.

Hyra, Derek S., Gregory D. Squires, Robert N. Renner, and David S. Kirk. 2013. "Metropolitan Segregation and the Subprime Lending Crisis." *Housing Policy Debate* 23 (1): 177-198.

Jacobs, Jane. 1961. *The Death and Life of Great American Cities*. New York: Random House.

Jargowsky, Paul A. 1997. *Poverty and Place: Ghettos, Barrios, and the American City*. New York: Russell Sage Foundation.

Jargowsky, Paul A. and J. Kim. 2005. “A Measure of Spatial Segregation: the Generalized Neighborhood Sorting Index.” *University of Texas, Dallas*.

Kane, Michael J. 2014. *bigmemory.sri: A shared resource interface for Bigmemory Project packages*.

Kane, Michael J., John W. Emerson, and Peter Haverty. 2013. *bigmemory: Manage massive matrices with shared memory and memory-mapped files*.

Krysan, Maria, and Michael DM Bader. 2009. “Racial Blind Spots: Black-White-Latino Differences in Community Knowledge." *Social Problems* 56 (4): 677-701.

Kullback, Solomon. 1987. “Letters to the Editor.” *The American Statistician* 41:338–41.

Lamont, Michèle, and Virág Molnár. 2002. “The Study of Boundaries in the Social Sciences." *Annual Review of Sociology* 28: 167-195.

Le Goix, Renaud. 2005. "Gated Communities: Sprawl and Social Segregation in Southern California." *Housing Studies* 20 (2): 323-343.

Lee, Barrett A., Sean F. Reardon, Glenn Firebaugh, Chad R. Farrell, Stephen A. Matthews, and David O'Sullivan. 2008. “Beyond the Census Tract: Patterns and Determinants of Racial Segregation at Multiple Geographic Scales.” *American Sociological Review* 73(5):766–91.

Lichter, Daniel T., Domenico Parisi, and Michael C. Taquino. 2015. “Toward a New Macro-Segregation? Decomposing Segregation Within and Between Metropolitan Cities and Suburbs.” *American Sociological Review* 80 (4): 843-873.

Lichter, Daniel T., Domenico Parisi, and Michael C. Taquino. 2012. “The Geography of Exclusion: Race, Segregation, and Concentrated Poverty.” *Social Problems* 59(3):364–88.

Logan, John R. 2012. “Making a Place for Space: Spatial Thinking in Social Science.” *Annual Review of Sociology* 38(1):507–24.

Logan, John R. 2000. "Ethnic diversity grows, neighborhood integration lags." p. 235-251 in Katz, B. and R. Lang, eds. *Redefining Urban and Suburban America: Evidence from Census 2000*. Washington, DC: Brookings Institution Press.

Logan, John R. and Wenquan Zhang. 2004. “Identifying Ethnic Neighborhoods with Census Data: Group Concentration and Spatial Clustering.” Pp. 113–26 in *Spatially integrated social science*. New York: Oxford University Press.
Logan, John R., Seth Spielman, Hongwei Xu, and Philip N. Klein. 2011. “Identifying and Bounding Ethnic Neighborhoods.” Urban Geography 32(3):334–59.

Low, Setha M. 2001. "The Edge and the Center: Gated Communities and the Discourse of Urban Fear." American Anthropologist 103 (1): 45-58.

Massey, Douglas S. 2016. “Residential Segregation is the Linchpin of Racial Stratification.” City & Community 15(1):4-7.

Massey, Douglas S., and Nancy A. Denton. 1988. "The Dimensions of Residential Segregation." Social Forces 67 (2): 281-315.

Mikin, Mark. 2012. “The United States of 2012.” Esquire, February 9.

Miller, Gary J. 1981. Cities by Contract: The Politics of Municipal Incorporation. Cambridge, MA: MIT Press.

Mitchell, Richard, and Duncan Lee. 2014. "Is There Really a ‘Wrong Side of the Tracks’ in Urban Areas and Does It Matter for Spatial Analysis?" Annals of the Association of American Geographers 104 (3): 432-443.

Morrill, Richard L. 1991. “On the Measure of Geographical Segregation.” Geography Research Forum 11: 25–36.

Neal, Zachary P. 2012. The Connected City: How Networks are Shaping the Modern Metropolis. New York: Routledge.

Neuwirth, Erich. 2014. RColorBrewer: ColorBrewer Palettes.

Noonan, Douglas S. 2005. “Neighbours, Barriers and Urban Environments: Are Things' Different on the Other Side of the Tracks’?” Urban Studies 42 (10): 1817-1835.

O'Sullivan, David and David W. S. Wong. 2007. “A Surface-Based Approach to Measuring Spatial Segregation.” Geographical Analysis 39(2):147–68.

Openshaw, S. 1984. “Ecological Fallacies and the Analysis of Areal Census-Data.” Environment and Planning A 16(1):17–31.

Openshaw, Stan. 1977. "A Geographical Solution to Scale and Aggregation Problems in Region-Building, Partitioning and Spatial Modelling." Transactions of The Institute Of British Geographers 2 (4): 459-472.

Openshaw, Stanley and Peter Taylor. 1979. “A Million or So Correlation Coefficients: Three Experiments on the Modifiable Area Unit Problem.” Pp. 127–44 in Statistical applications in the spatial sciences. London : Pion.

Papachristos, A. V., D. M. Hureau, and A. A. Braga. 2013. “The Corner and the Crew: The Influence of Geography and Social Networks on Gang Violence.” American Sociological Review 78(3):417–47.

Papachristos, Andrew V. 2009. “Murder by Structure: Dominance Relations and the Social Structure of Gang Homicide.” American Journal of Sociology 115(1):74–128.

Park, Robert E., Ernest W. Burgess, and Roderick D. McKenzie. 1925. The City. Chicago, IL: The University of Chicago Press.

Parisi, Domenico, Daniel T. Lichter, and Michael C. Taquino. 2011. “Multi-Scale Residential Segregation: Black Exceptionalism and America’s Changing Color Line.” Social Forces 89(3):829–52.

Pattillo, Mary E. 2007. Black on the Block: The Politics of Race and Class in the City. Chicago: University of Chicago Press.
Pattillo, Mary. 2003. “Extending the Boundaries and Definition of the Ghetto.” *Ethnic and Racial Studies* 26(6):1046–57.

Pebesma, Edzer and Roger Bivand. 2015. *sp: Classes and Methods for Spatial Data.*

R Core Team. 2014. *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing.

Rae, Douglas W. 2003. *City: Urbanism and Its End.* New Haven: Yale University Press.

Rankin, William. 2010. “Cartography and the Reality of Boundaries.” *Perspecta* 42:42–45.

Raudenbush, Stephen W. and Robert J. Sampson. 1999. “Ecometrics: Toward a Science of Assessing Ecological Settings, with Application to the Systematic Social Observation of Neighborhoods.” *Sociological Methodology* 29:1–41.

Reardon, Sean F. and David O’Sullivan. 2004. “Measures of Spatial Segregation.” *Sociological Methodology* 34(1):121–62.

Reardon, Sean F. and Glenn Firebaugh. 2002. “Measures of Multigroup Segregation.” *Sociological Methodology* 32:33–67.

Reardon, Sean F. and Kendra Bischoff. 2011. “Income Inequality and Income Segregation.” *American Journal of Sociology* 116(4):1092–1153.

Reardon, Sean F., Chad R. Farrell, Stephen A. Matthews, David O’Sullivan, Kendra Bischoff, and Glenn Firebaugh. 2009. “Race and Space in the 1990s: Changes in the Geographic Scale of Racial Residential Segregation, 1990–2000.” *Social Science Research* 38(1):55–70.

Reardon, Sean F., Stephen A. Matthews, David O’Sullivan, Barrett A. Lee, Glenn Firebaugh, Chad R. Farrell, and Kendra Bischoff. 2008. “The Geographic Scale of Metropolitan Racial Segregation.” *Demography* 45(3):489–514.

Revolution Analytics and Steve Weston. 2014. *foreach: Foreach looping construct for R.*

Roberto, Elizabeth. 2015. *iterators: Iterator construct for R.*

Sampson, Robert J. 2012. *Great American City: Chicago and the Enduring Neighborhood Effect.* Chicago and London: University of Chicago Press.

Sampson, Robert J. 2012. “Moving and the Neighborhood Glass Ceiling.” *Science* 337(6101):1464–65.

Sampson, Robert J. and Stephen W. Raudenbush. 1999. “Systematic Social Observation of Public Spaces: A New Look at Disorder in Urban Neighborhoods.” *American Journal of Sociology* 105(3):603–51.

Sastry, Narayan, Ann R. Pebley, and Michela Zonta. 2002. "Neighborhood Definitions and the Spatial Dimension of Daily Life in Los Angeles." in *Labor and Population Working Paper: RAND Corporation.*

Savitz, Natalya Verbitsky and Stephen W. Raudenbush. 2009. “Exploiting Spatial Dependence to Improve Measurement of Neighborhood Social Processes.” *Sociological Methodology* 39:151–83.

Schindler, S.B., 2015. Architectural Exclusion: Discrimination and Segregation Through Physical Design of the Built Environment. *Yale LJ,* 124:6.
Schwartz, Amy Ellen, Ioan Voicu, and Keren Mertens Horn. 2014. "Do Choice Schools Break the Link between Public Schools and Property Values? Evidence from House Prices in New York City." Regional Science and Urban Economics 49: 1-10.

Sharkey, Patrick and Jacob W. Faber. 2013. “Where, When, Why, and For Whom Do Residential Contexts Matter? Moving Away from the Dichotomous Understanding of Neighborhood Effects.” Annual Review of Sociology 40(1):140512172738005.

South, Scott J., Kyle Crowder, and Jeremy Pais. 2011. “Metropolitan Structure and Neighborhood Attainment: Exploring Intermetropolitan Variation in Racial Residential Segregation.” Demography 48(4):1263–92.

Spielman, Seth E. and John R. Logan. 2013. “Using High-Resolution Population Data to Identify Neighborhoods and Establish Their Boundaries.” Annals of the Association of American Geographers 103(1):67–84.

Sugrue, Thomas J. 1996. The Origins of the Urban Crisis: Race and Inequality in Postwar Detroit. Princeton, NJ: Princeton University Press.

Suttles, Gerald D. 1972. The Social Construction of Communities. Chicago, IL: University of Chicago Press.

Suttles, Gerald D. 1968. “The Social Order of the Slum: Ethnicity and Territory in the Inner City.”

Theil, Henri and Anthony J. Finizza. 1971. “A Note on the Measurement of Racial Integration of Schools by Means of Informational Concepts.” The Journal of Mathematical Sociology 1(2):187–93.

Tiebout, Charles M. 1956. "A Pure Theory of Local Expenditures." The Journal of Political Economy 64 (5): 416-424.

Timberlake, J. M. and John Iceland. 2007. “Change in Racial and Ethnic Residential Inequality in American Cities, 1970–2000.” City & Community 6(4):335–65.

U.S. Census Bureau. 2011. “2010 Census Summary File 1—United States.”

U.S. Census Bureau. 2012. “2010 TIGER/Line Shapefiles.”

Webster, Chris, Georg Glasze, and Klaus Frantz. 2002. "The global spread of gated communities." Environment and Planning B: Planning and Design 29 (3): 315-320.

White, Michael J. 1983. “The Measurement of Spatial Segregation.” American Journal of Sociology 88(5):1008–18.

White, Michael J. 1986. “Segregation and Diversity Measures in Population-Distribution.” Population Index 52(2):198–221.

Winship, C. 1977. “A Revaluation of Indexes of Residential Segregation.” Social Forces 55(4):1058–66.

Wong, David WS. 1993. "Spatial Indices of Segregation." Urban Studies 30 (3): 559-572.

Wu, X. B. and D. Z. Sui. 2001. “An Initial Exploration of a Lacunarity-Based Segregation Measure.” Environment and Planning B: Planning and Design 28(3):433–46.

Zorbaugh, Harvey Warren. 1929. The Gold Coast and the Slum: A Sociological Study of Chicago’s Near North Side. Chicago: University of Chicago Press.
## Tables

### Table 1. Population Compositions for Cities

| City            | Population Count | Non-Hispanic White | Non-Hispanic Black | Hispanic | Asian |
|-----------------|------------------|--------------------|--------------------|----------|-------|
| Baltimore       | 620,961          | 0.28               | 0.63               | 0.04     | 0.02  |
| Boston          | 617,594          | 0.47               | 0.22               | 0.17     | 0.09  |
| Cincinnati      | 296,943          | 0.48               | 0.45               | 0.03     | 0.02  |
| Cleveland       | 396,815          | 0.33               | 0.52               | 0.10     | 0.02  |
| Detroit         | 713,777          | 0.08               | 0.82               | 0.07     | 0.01  |
| Hartford        | 124,775          | 0.16               | 0.35               | 0.43     | 0.03  |
| Milwaukee       | 594,833          | 0.37               | 0.39               | 0.17     | 0.03  |
| New Haven       | 129,779          | 0.32               | 0.33               | 0.27     | 0.05  |
| New York        | 8,175,133        | 0.33               | 0.23               | 0.29     | 0.13  |
| Brooklyn        | 2,504,700        | 0.36               | 0.32               | 0.20     | 0.10  |
| Bronx           | 1,385,108        | 0.11               | 0.30               | 0.54     | 0.03  |
| Manhattan       | 1,585,873        | 0.48               | 0.13               | 0.25     | 0.11  |
| Queens          | 2,230,722        | 0.28               | 0.18               | 0.28     | 0.23  |
| Staten Island   | 468,730          | 0.64               | 0.09               | 0.17     | 0.07  |
| Newark          | 277,140          | 0.12               | 0.50               | 0.34     | 0.02  |
| Philadelphia    | 1,526,006        | 0.37               | 0.42               | 0.12     | 0.06  |
| Providence      | 178,042          | 0.38               | 0.13               | 0.38     | 0.06  |
| St. Louis       | 319,294          | 0.42               | 0.49               | 0.03     | 0.03  |
| Washington      | 601,723          | 0.35               | 0.50               | 0.09     | 0.03  |
Table A1. Divergence Index for each city for .5km, 1km, 2km, 3km, and 4km for straight line and road distance.

| City           | Straight Line Distance | Road Distance |
|----------------|------------------------|---------------|
|                | 0.5 km  | 1 km  | 2 km  | 3 km  | 4 km  | 0.5 km  | 1 km  | 2 km  | 3 km  | 4 km  |
|                | Mean    | SD     | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    | Mean  | SD    |
| Baltimore      | .44     | .34    | .37   | .30   | .23   | .21   | .15   | .17   | .11   | .12   | .46   | .35   | .40   | .32   | .30   | .25   | .21   | .20   | .15   | .17   |
| Boston         | .45     | .38    | .40   | .40   | .31   | .33   | .23   | .24   | .17   | .18   | .48   | .38   | .43   | .40   | .35   | .37   | .28   | .29   | .21   | .23   |
| Cincinnati     | .34     | .30    | .28   | .27   | .19   | .17   | .14   | .11   | .11   | .10   | .36   | .30   | .31   | .28   | .23   | .22   | .16   | .16   | .12   | .11   |
| Cleveland      | .53     | .29    | .50   | .28   | .46   | .27   | .42   | .21   | .37   | .14   | .55   | .29   | .52   | .29   | .48   | .28   | .45   | .26   | .41   | .20   |
| Detroit        | .36     | .58    | .37   | .53   | .39   | .43   | .37   | .38   | .35   | .31   | .36   | .60   | .37   | .56   | .39   | .48   | .39   | .42   | .38   | .37   |
| Hartford       | .33     | .30    | .28   | .24   | .25   | .17   | .21   | .13   | .14   | .08   | .36   | .33   | .32   | .30   | .28   | .25   | .26   | .20   | .21   | .15   |
| Milwaukee      | .68     | .35    | .66   | .38   | .59   | .39   | .51   | .33   | .42   | .24   | .69   | .35   | .67   | .37   | .63   | .40   | .56   | .37   | .49   | .30   |
| New Haven      | .35     | .24    | .26   | .19   | .13   | .09   | .10   | .06   | .08   | .04   | .37   | .26   | .30   | .22   | .16   | .13   | .11   | .07   | .09   | .05   |
| New York       | .62     | .33    | .56   | .31   | .45   | .29   | .37   | .26   | .30   | .22   | .63   | .33   | .58   | .32   | .49   | .30   | .41   | .27   | .35   | .25   |
| Brooklyn       | .64     | .29    | .57   | .27   | .43   | .26   | .35   | .26   | .28   | .23   | .66   | .29   | .59   | .28   | .48   | .26   | .38   | .26   | .31   | .25   |
| Bronx          | .28     | .37    | .23   | .29   | .16   | .16   | .13   | .11   | .12   | .07   | .30   | .40   | .26   | .34   | .19   | .20   | .14   | .14   | .12   | .10   |
| Manhattan      | .45     | .31    | .40   | .23   | .33   | .15   | .28   | .13   | .22   | .12   | .47   | .34   | .42   | .26   | .36   | .17   | .32   | .14   | .28   | .14   |
| Queens         | .60     | .42    | .55   | .42   | .45   | .39   | .35   | .32   | .28   | .25   | .62   | .43   | .57   | .42   | .49   | .38   | .40   | .33   | .33   | .28   |
| Staten Island  | .29     | .33    | .25   | .23   | .20   | .12   | .17   | .13   | .14   | .12   | .30   | .36   | .27   | .30   | .21   | .19   | .17   | .12   | .15   | .10   |
| Newark         | .48     | .32    | .42   | .26   | .32   | .17   | .23   | .15   | .15   | .12   | .49   | .34   | .45   | .30   | .36   | .21   | .26   | .16   | .18   | .13   |
| Philadelphia   | .61     | .36    | .54   | .33   | .41   | .26   | .33   | .21   | .27   | .17   | .63   | .37   | .57   | .34   | .45   | .28   | .37   | .23   | .31   | .19   |
| Providence     | .30     | .23    | .25   | .21   | .19   | .15   | .12   | .10   | .07   | .05   | .31   | .24   | .27   | .22   | .21   | .17   | .15   | .12   | .09   | .07   |
| St. Louis      | .47     | .33    | .42   | .33   | .36   | .32   | .31   | .28   | .26   | .24   | .49   | .33   | .44   | .33   | .37   | .33   | .33   | .30   | .29   | .26   |
| Washington DC  | .53     | .30    | .48   | .31   | .40   | .31   | .33   | .30   | .27   | .26   | .54   | .30   | .50   | .31   | .43   | .31   | .37   | .31   | .31   | .30   |
Table A2. Divergence Index for each city for .5km, 1km, 2km, 3km, and 4km for truncated and extended environments.

| Road Distance | Truncated Local Environments | | | Extended Local Environments | | |
|---------------|-------------------------------|---|---|-------------------------------|---|---|---|---|---|
|               | 0.5 km | 1 km | 2 km | 3 km | 4 km | 0.5 km | 1 km | 2 km | 3 km | 4 km |
|               | Mean   | SD    | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Baltimore     | .46    | .38   | .40  | .36 | .28  | .29 | .17  | .21 | .10  | .16 | .46  | .35 |
|               | .40    | .32   | .30  | .25 | .25  | .20 | .19  | .16 | .48  | .38 | .43  | .40 |
| Boston        | .37    | .29   | .32  | .27 | .23  | .24 | .16  | .21 | .11  | .18 | .36  | .30 |
|               | .48    | .36   | .43  | .35 | .25  | .20 | .19  | .16 | .48  | .38 | .43  | .40 |
| Cincinnati    | .55    | .29   | .52  | .28 | .47  | .25 | .43  | .22 | .40  | .19 | .55  | .29 |
|               | .52    | .29   | .52  | .28 | .47  | .25 | .43  | .22 | .40  | .19 | .55  | .29 |
| Cleveland     | .34    | .64   | .32  | .62 | .29  | .57 | .25  | .52 | .22  | .46 | .36  | .60 |
|               | .30    | .30   | .22  | .22 | .15  | .15 | .10  | .11 | .36  | .33 | .32  | .30 |
| Milwaukee     | .69    | .33   | .65  | .33 | .59  | .32 | .52  | .29 | .44  | .24 | .69  | .35 |
|               | .65    | .33   | .65  | .33 | .59  | .32 | .52  | .29 | .44  | .24 | .69  | .35 |
| New Haven     | .38    | .26   | .30  | .23 | .15  | .14 | .09  | .10 | .06  | .08 | .37  | .26 |
|               | .30    | .23   | .15  | .14 | .09  | .10 | .06  | .08 | .37  | .26 | .30  | .22 |
| New York      | .63    | .33   | .58  | .32 | .50  | .30 | .43  | .28 | .37  | .26 | .63  | .33 |
|               | .58    | .32   | .58  | .32 | .50  | .30 | .43  | .28 | .37  | .26 | .63  | .33 |
| Brooklyn      | .66    | .30   | .60  | .28 | .48  | .25 | .38  | .24 | .31  | .23 | .66  | .29 |
|               | .60    | .28   | .60  | .28 | .48  | .25 | .38  | .24 | .31  | .23 | .66  | .29 |
| Bronx         | .30    | .40   | .26  | .36 | .20  | .25 | .15  | .20 | .10  | .15 | .30  | .40 |
|               | .30    | .40   | .26  | .36 | .20  | .25 | .15  | .20 | .10  | .15 | .30  | .40 |
| Manhattan     | .47    | .35   | .42  | .31 | .34  | .24 | .27  | .20 | .22  | .17 | .47  | .34 |
|               | .42    | .31   | .42  | .31 | .34  | .24 | .27  | .20 | .22  | .17 | .47  | .34 |
| Queens        | .62    | .43   | .57  | .43 | .50  | .41 | .42  | .39 | .35  | .36 | .62  | .43 |
|               | .62    | .43   | .57  | .43 | .50  | .41 | .42  | .39 | .35  | .36 | .62  | .43 |
| Staten Island | .30    | .36   | .27  | .30 | .21  | .19 | .17  | .12 | .14  | .09 | .30  | .36 |
|               | .30    | .36   | .27  | .30 | .21  | .19 | .17  | .12 | .14  | .09 | .30  | .36 |
| Newark        | .50    | .33   | .46  | .30 | .37  | .24 | .27  | .18 | .18  | .15 | .49  | .34 |
|               | .50    | .33   | .46  | .30 | .37  | .24 | .27  | .18 | .18  | .15 | .49  | .34 |
| Philadelphia  | .63    | .37   | .57  | .34 | .46  | .28 | .38  | .23 | .33  | .20 | .63  | .37 |
|               | .63    | .37   | .57  | .34 | .46  | .28 | .38  | .23 | .33  | .20 | .63  | .37 |
| Providence    | .31    | .26   | .27  | .24 | .20  | .20 | .13  | .14 | .07  | .09 | .31  | .24 |
|               | .31    | .26   | .27  | .24 | .20  | .20 | .13  | .14 | .07  | .09 | .31  | .24 |
| St. Louis     | .49    | .33   | .44  | .33 | .38  | .33 | .33  | .30 | .28  | .26 | .49  | .33 |
|               | .49    | .33   | .44  | .33 | .38  | .33 | .33  | .30 | .28  | .26 | .49  | .33 |
| Washington DC | .54    | .30   | .50  | .30 | .43  | .31 | .38  | .30 | .31  | .28 | .54  | .30 |
|               | .54    | .30   | .50  | .30 | .43  | .31 | .38  | .30 | .31  | .28 | .54  | .30 |
## Figures

### Figure 1. Segregation Indexes for Cities

| Dissimilarity Index (Census Tracts) | Normalized Exposure Index (Census Tracts) | Divergence Index (Census Tracts) | Divergence Index (0.5 km RLE) |
|------------------------------------|-----------------------------------------|----------------------------------|-------------------------------|
| Philadelphia                       | Philadelphia                            | Milwaukee                        | Milwaukee                     |
| Detroit                            | Baltimore                               | Philadelphia                     | Philadelphia                  |
| Milwaukee                          | Washington                              | Cleveland                        | New York                      |
| Baltimore                          | Milwaukee                               | Boston                           | Cleveland                     |
| Cleveland                          | St. Louis                               | St. Louis                        | Newark                        |
| Washington                         | Detroit                                 | Baltimore                        | St. Louis                     |
| St. Louis                          | Cleveland                               | Cincinnati                       | Boston                        |
| Cincinnati                         | Boston                                  | New Haven                        | Baltimore                     |
| Hartford                           | Hartford                                 | Hartford                         | New Haven                     |
| New Haven                          | Providence                              | Detroit                          | Cincinnati                    |
| Providence                         | New Haven                                | New York                         | Hartford                      |
| New York                           | New York                                 | Providence                       | Detroit                       |
| Newark                             | Newark                                   |                                 | Providence                    |
| Brooklyn                           | Brooklyn                                 |                                 |                               |
| Queens                             | Queens                                   |                                 |                               |
| Staten Island                      | Staten Island                           |                                 |                               |
| Bronx                              | Bronx                                    |                                 |                               |
| Manhattan                          | Manhattan                                |                                 |                               |

**Notes:** All segregation indices consider whites, blacks, and Hispanics using 2010 U.S. Census Data. The Overall Divergence Index is calculated using the road distance and local environments truncated to municipal boundaries.
Figure 2. Percent Difference between Road Distance and Straight Line Distance Divergence Indexes by City Using Extended Local Environments
Figure 3. White, Black, and Hispanic Population in Baltimore in 2010
Figure 4. Quartiles of the Difference between Road Distance and Straight Line Distance Divergence Indexes in the Guilford and Waverly Neighborhoods of Baltimore using Extended Local Environments with a Reach of .5 km
Figure 5. Percent Difference between Extended and Truncated Road Distance Divergence Indexes by City

| City       | .5 | 1  | 2  | 3  | 4 km |
|------------|----|----|----|----|------|
| Baltimore  |    |    |    |    |      |
| Boston     |    |    |    |    |      |
| Cincinnati |    |    |    |    |      |
| Cleveland  |    |    |    |    |      |
| Detroit    |    |    |    |    |      |
| Hartford   |    |    |    |    |      |
| Milwaukee  |    |    |    |    |      |
| New Haven  |    |    |    |    |      |
| New York   |    |    |    |    |      |
| Newark     |    |    |    |    |      |
| Philadelphia | |    |    |    |      |
| Providence |    |    |    |    |      |
| St. Louis  |    |    |    |    |      |
| Washington DC |    |    |    |    |      |

Reach of Local Environments
Figure 6. Percent Difference between Extended and Truncated Road Distance Divergence Indexes by Ethnoracial Group and City
Figure 7. White, Black, and Hispanic Population in Detroit in 2010