An Alternative Approach to the Measurement of Urban Sprawl

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Abstract

The term "urban sprawl" is generally used to refer to patterns of development in suburban areas. Low-density is the most often cited characteristic of sprawl. This paper examines sprawl in 2010 in 59 large urban areas in the United States by looking at multiple measures of density within the suburban areas, the areas added to the urban areas after 1950. Areas with the highest levels of sprawl are mostly in the Northeast and the South, including the Boston-Providence area, while most of the urban areas with the lowest sprawl are in the West, including Los Angeles. Urban areas with larger suburban areas, that have grown more rapidly since 1950, have somewhat lower levels of sprawl. Sprawl is much lower in those areas where urban expansion has been limited by the presence of barriers including mountains and wetlands.

Measuring Suburban Sprawl in Suburban Areas

Urban sprawl has received a great deal of attention. Urban areas vary in the degree to which they sprawl. Understanding this phenomenon requires the measurement of the extent of sprawl. Considerable effort has been devoted to such measurement.

It is clear that when most people are talking about (and criticizing) urban sprawl, they are referring to patterns of development in the suburbs, especially those areas developed since World War II. This could not be more obvious than in the title of the critique of sprawl by Duany, Plater-Zyberk, and Speck (2001), *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. The reference to "greenfields" in the title of the book by Benfield, Raimi, and Chen (1999) indicates the suburban focus of their concern. Gillam (2002) says that "one thing that almost all of the definitions shown have in common is that they portray sprawl as essentially a suburban phenomenon." Squires (2002) refers to sprawl as "new development on the fringe of settled areas" that has occurred during the last 5 decades of the twentieth century. Burchell, *et al.* (1998) in their landmark study on the costs of sprawl describe it as "a particular type of suburban peripheral growth." And the *Beyond Sprawl* report (1995) explicitly refers to post-World War II development.

The suburban locus is apparent not only in descriptions of urban sprawl but in the very terminology used to refer to this phenomenon. In a paper on sprawl and urban decline, Downs (1999) used the term "suburban sprawl." The same description appeared in the titles of 2 reports by the Sierra Club (2000, 2003) critical of sprawl, *Sprawl Costs Us All: How Your Taxes Fuel Suburban Sprawl* and *Population Growth and Suburban Sprawl*. Likewise, 2 papers by Batty, Bessusi, and Chin (2003) and Bessusi and Chin (2003) include "suburban sprawl" in their titles. The article by Jaret, *et al.* (2009) discusses the measurement of suburban sprawl.

If urban sprawl refers to development in the suburbs, then the measurement the extent of urban sprawl should focus on the patterns of development in suburban areas. This is in contrast to virtually all efforts attempting to measure the sprawl of urban areas by considering the character of the entire extent of those areas, suburban and otherwise. To include variations in the patterns of development of non-suburban areas in the measurement of sprawl is to confound that measurement with irrelevant information.

Several examples show that meaningful measures of sprawl should only include consideration of the patterns of the suburban portions of urban areas. For the purpose of these examples, some measure of the extent of sprawl is required. Low-density development is generally accepted as at least one characteristic or sprawl so density will be taken as a measure of the extent of sprawl in presenting these examples.

For the first example, consider 2 urban areas with identical suburban areas having equal amounts of sprawl and the same densities. Both urban areas have older areas at the center developed at the same higher density, but the first older area was larger than the second. Because of the difference in the extent of the older higher-density areas, the overall density of the first urban area will be higher than the second. So a measure of urban sprawl based on the pattern of the entire urban area will show the second area to be more sprawling, despite the fact that the suburban areas and their degrees of sprawl are the same.

The second example has the same identical suburban areas but this time older central areas with the same populations. The first older area was developed at very high densities (think New York) while the second was developed at somewhat lower but still high densities (think Chicago). So the overall density of the first urban area is again greater than the second, which would be seen as being more sprawling based on that measure, despite identical suburban areas with identical sprawl. Note that this would effectively be saying that the older dense areas of Chicago are more sprawling than Manhattan.

The third example concludes with a paradox. The two suburban areas have the same populations but the first is sprawling with very low-density development while the second was developed at significantly higher densities and is less sprawling. The older center of the first area is large and has a very high density. The second center is much smaller and was developed with much lower densities. Given the larger and denser center, the overall density of the first urban area could well be higher than the second despite the very low density, sprawling suburban development. So a measure of sprawl based on the pattern of the entire urban area would be showing the second area with the less sprawling, higher-density suburban area to have a higher level of urban sprawl. This might seemed to be an extreme, contrived example that would not actually occur. This paper will show this not to be the case.

This paper develops a measure of urban (suburban) sprawl based on the patterns of development in the suburban portions of urban areas. This measure is used to examine sprawl in 59 of the largest urban areas in the United States in 2010. Since the big departure in this paper is the focus on the suburbs, the first section reviews areas that have been used in other works measuring urban sprawl. Obviously sprawl measurement requires the definition of what is meant by urban sprawl, and some of the approaches taken are discussed in the next section. The paper then describes the data being used in this study and the definition of the suburban areas. Low-density is being taken as the primary characteristic of sprawl, with the next section addressing the multiple measures of density used in this study. Finally levels of urban (suburban) sprawl in the large urban areas are examined, including variation by region and the effect of barriers to urban development on the extent of sprawl.

Areas Used for the Measurement of Urban Sprawl

The major innovation of this paper involves the selection of the area in which the pattern of urban development is considered for the measurement of sprawl. As background, the areas used for other sprawl measures are reviewed. A sampling of studies using different areas are addressed. No attempt is being made to include every study of urban sprawl. Mainly studies within the United States are being considered, as the selection of potential study areas is highly dependent upon available data, which in turn depends on the definitions of areas used for the reporting of those data. This review starts with works considering levels of sprawl in entire urban areas and is followed by studies examining sprawl in other areas.

Sprawl in Entire Urban Areas

The Census Urbanized Areas delineate the extent of developed urban areas in fine geographic detail, making them one reasonable option for the measurement of urban sprawl. Galster, *et al.* (2001) is one of the most widely cited studies measuring urban sprawl, providing multiple measures of the patterns of settlement within Urbanized Areas. However they subsequently argue that these areas neglect lower-density sprawl beyond the Urbanized Area boundaries and define and use larger areas which they term "extended urbanized areas" (Wolman, *et al.* 2005).

An article on the extent of sprawl in *USA Today* (El Nasser and Overberg 2001) received considerable favorable attention. It used Urbanized Area data. In a study looking at the relationship of urban sprawl to reliance on automobiles, Wassmer (2008) likewise used Urbanized Areas. In order to look at urban patterns and sprawl over time, Paulsen (2014) used census block group data which he aggregated into areas approximating census Urbanized Areas.

While Urbanized Areas have the advantage of closely corresponding to the extent of developed urban areas, they have major limitations in the availability of data because their irregular boundaries do not correspond to smaller areas for which data are reported (other than blocks) and change from census to census, limiting comparisons over time. For this reason, many more studies of urban sprawl in the United States have focused on Metropolitan Statistical Areas (MSAs) and their related areas. A few examples are the works by Malpezzi and Guo (2001), Glaeser and Kahn (2004), and Tsai (2005).

Density is often considered to be a key measure of the extent of urban sprawl. MSAs are composed of entire counties and can include arbitrary and potentially very large areas that are clearly not urban or metropolitan. Therefore the basic measure of density—total population divided by total area—is not especially meaningful for MSAs. This has resulted in the measurement of density for MSA sprawl in other ways. Pendall (1999) used population divided by the amount of developed land as reported by the National Resource Inventory. Ewing, Pendall, and Chen (2002) used data for census tracts with population densities greater than 100 persons per square mile. And numbers of studies (Lopez 2004; Zhao and Kaestner 2010; Laidley 2016) have looked at the percentages of the population living in tracts or other small areas with densities below various thresholds, quantities not significantly affected by the small populations in the nonurban areas.

The new definition of MSAs first used in 2003 resulted in the splitting up of numbers of larger MSAs into multiple areas that some might see as not reflecting the full extent of those metropolitan areas (Ottensmann 2017b). Larger areas called Combined Statistical Areas (CSAs) were also defined when the new MSA definition was created. Burchfield, *et al.* (2006) used CSAs in their study of urban sprawl.

A number of efforts to measure urban sprawl employed the Metropolitan Divisions or Primary Metropolitan Statistical Areas (PMSAs) for those larger MSAs that were subdivided (Ewing, Pendall, and Chen 2002; Ewing and Hamidi 2014; Lopez and Hynes 2003; Lopez 2004). Paulsen (2014) defined areas similar to Urbanized Areas using census block groups but created those areas within the boundaries of PMSAs. And Fulton, *et al.* (2001) rather confusingly used the larger, unsubdivided areas in their descriptive measurement of sprawl but employed data at the PMSA level for their regression analysis of factors associated with sprawl.

Both the new and old MSA definitions provided for the subdivision of some of the largest MSAs into multiple, smaller areas. The current definition calls these Metropolitan Divisions. The definition used in 2000 and earlier (subdividing more MSAs) referred to the subareas as Primary Metropolitan Statistical Areas (PMSAs). Those MSAs that had these smaller subdivisions were then confusingly renamed Consolidated Metropolitan Statistical Areas (CMSAs). This was despite the fact that these larger areas were defined in exactly the same way as all of the other MSAs and in no way resulted from the consolidation of the PMSAs. Likewise, the PMSAs did not come first and were in no sense "primary."

The Metropolitan Divisions and PMSAs are an unusual, heterogeneous collection of areas. In some MSAs that resulted from the merging of several large urban centers, the smaller units were the areas surrounding those centers. For example, the Dallas-Fort Worth MSA (CMSA) included subareas for Dallas and Fort Worth. But in other MSAs, especially some of the largest, the Metropolitan Divisions and PMSAs were a strange mix. Some were areas surrounding smaller subcenters, such as the Newark Metropolitan Division/PMSA in the New York area, thus making some areas effectively suburbs of both Newark and New York. Other subdivisions were primarily suburban and lacked significant subcenters and were therefore designated by the names of the counties constituting these areas, such as the Nassau-Suffolk Metropolitan Division/PMSA. Then the New York Metropolitan Division/PMSA consisted of the city of New York and whatever suburban areas were left after designation of the other subareas.

If sprawl is being measured for MSAs, the intent is obviously to provide measures characterizing the level of sprawl across entire metropolitan areas. In such instances, substituting the Metropolitan Divisions or PMSAs for the MSAs/CMSAs for those larger metropolitan areas seems dubious at best. It may not be unreasonable for an area such as Dallas-Fort Worth for which it may still be appropriate to talk about the levels of sprawl for the Dallas area and the Fort Worth area separately. But for a metropolitan area with subdivisions such as the New York MSA/CMSA it makes little sense. While some confusion is created by the measurement of sprawl for an area like the Newark Metropolitan Division/PMSA, the more egregious problem arises with Nassau-Suffolk. This area is entirely suburban and does not contain a major city. Obviously a suburban area will nearly always be more sprawling than the combination of a suburban area with a large central city. To compare the sprawl of Nassau-Suffolk with that of entire metropolitan areas does not make sense. But the problem for sprawl measurement extends beyond Nassau-Suffolk. By excluding the large, more sprawling, suburban area of Nassau and Suffolk counties from the larger New York metropolitan area, levels of sprawl measured for remaining areas, especially the New York Metropolitan Division/PMSA will be increased. It is rather obvious that in measuring sprawl for a metropolitan area, if one removes a sprawling suburban portion from that area, a measure of sprawl for the remainder will show a decreased level of sprawl.

Sprawl in Other Areas

Other efforts creating and using measures of urban sprawl have focused on different spatial units and do not claim to be providing measures characterizing sprawl in entire urban or metropolitan areas. For example, Ewing, Schieber, and Zegeer (2003) and Ewing, Schmid, Killingsworth, Zlot, and Raudenbusch (2003) used measures of sprawl at the county level in assessing different health effects of the urban pattern. Explicitly acknowledging the distinction between sprawl measurement for metropolitan areas and the smaller county units, Ewing and Hamidi (2014) describe different measures used for the two applications. Both are multidimensional measures of sprawl but the county-level uses a subset of the metropolitan measures, excluding some measures only applicable to entire metropolitan areas.

Frenkel and Ashkenazi (2008) report on the measurement of sprawl for "towns" in Israel, units again smaller than entire urban areas. A number of studies have focused on sprawl in exurban areas beyond the more completely developed portions of metropolitan areas such as Lamb (1983), Nelson and Sanchez (2005), Irwin and Bockstael (2007), and Clark, *et al*. (2009). And at least one study reported on sprawl at the state level (Anthony 2004).

Defining Urban Sprawl

The measurement of sprawl necessarily requires its definition. This has been a very fraught topic over which there has been little agreement. This section begins by addressing this confusion, identifying numbers of definitions and approaches that are less useful in the present context. Following is a review of the more conventional definitions of sprawl as some aspects of the urban pattern. Of these, low densities and scattered development have proven to be the primary variables used to measure sprawl in practice. Finally, since considerable effort has been devoted to conceptualizing and measuring sprawl as a multidimensional phenomenon, these approaches are briefly considered.

Confusion as to the Nature of Urban Sprawl

Bruegmann (2005) argues that sprawl has been more of a negative statement characterizing what the user sees as undesirable urban development, with the meaning varying across persons and over time. Indeed, some have simply adopted Justice Potter Stewart's famous definition of pornography for urban sprawl—"I know it when I see it"

(Pelham 1992). Of course, this can hardly serve as the basis for the measurement of sprawl and its comparison across urban areas.

More seriously, sprawl has been defined as unplanned urban growth (e.g., Batty, Bessusi, and Chin 2003; Bhatta, Saraswati, Badnyopadhyay 2010). Such a definition has 2 major problems. For the measurement of levels of sprawl in urban areas, the measurement of the extent to which growth had been planned would be difficult or impossible. More problematic is the definition of planning implied in such a definition. Most jurisdictions in the United States have planning and zoning. But certainly no one would conclude that there is no urban sprawl. So is the problem not the lack of planning but the lack of "good" or "successful" planning? How would one go about defining "bad" planning? It better not be any planning that leads to the development of urban sprawl. Bruegmann (1985) deals with the latter problem by defining sprawl as "low-density, scattered, urban development without systematic large-scale or regional public land-use planning," but that still leaves the difficulty of measurement.

Galster and his colleagues (2001) have tackled the ambiguities surrounding the definition of sprawl, identifying 6 different approaches that have been taken. These include definition by example, an aesthetic judgment, the cause of an unwanted externality, a consequence of something else, selected patterns of development, and a process of development. Defining sprawl by example (e.g., Los Angeles = sprawl) or as an aesthetic judgment can be quickly dismissed has having no utility for the measurement of sprawl.

For an example of defining sprawl as the cause of an unwanted externality, Eidlin (2010) proposes that automobile orientation, measured by vehicle miles of travel, be the definition of sprawl. But if this is what is meant by sprawl, how is sprawl associated with other negative consequences that have been attributed to it, such as the loss of agricultural land or negative health consequences? If the argument would be that automobile orientation is caused by certain urban patterns and that these patterns result in those additional negative consequences, then the pattern would seem to be primary. Also, defining sprawl by an effect such as automobile orientation can lead to the oxymoronic outcome of "high-density sprawl," which Eidlin at least acknowledges. Galster, *et al.* (2001) conclude that "conceptually, a thing cannot simultaneously be what it is and what causes it or what it causes." It is ultimately necessary to untangle the causes and effects of sprawl from the phenomenon of sprawl itself (Jaeger and Schwick 2014).

The idea that sprawl should be considered to be a process of development as opposed to a pattern involves what Galster, *et al*. (2001) aptly describe as considering sprawl as a verb as opposed to a noun. However the measurement of the process of sprawl seems to frequently involve the determination of changes in the urban pattern. For example, Fulton, *et al.* (2001) described sprawl as the consumption of land at a rate faster than population growth. They looked at increases in urbanized land in metropolitan areas (process) but then proceeded to examine densities (pattern). Other studies have also considered sprawl as a process by looking at changes in density but it is always a question as to whether they mean that change to be the actual measure of sprawl or whether that change is considered to be change in the level of sprawl (e.g., Pendall 1999; El Nasser and Overberg 2001; Jaret, *et al.* 2009; Angel, *et al.* 2010). While it is certainly possible to compare urban areas with respect to the rate at which they are sprawling, this is distinct from the levels of sprawl in those areas. An area having a pattern with a very high level of sprawl could hypothetically have zero increase in sprawl over some given interval of time.

An alternative process view considers sprawl to be the deconcentration of urban areas over time. This is most often measured by looking at the change over time in the density gradient associated with the decline of density from the center of urban areas (e.g., Brueckner and Fansler 1983; Glaeser and Kahn 2004; Angel, *et al*. 2010; Paulsen 2012). It is certainly the case that the development of sprawl in some urban areas in the second half of the twentieth century has been associated with such changes, with the higher densities near the centers declining and very low-density development occurring at the edge. But deconcentration has problems even as a measure of the process of sprawl, for movement from high-density areas near the center to high-density areas farther out would constitute deconcentration yet would hardly be thought to involve a process of sprawl. And, again, an urban area experiencing no deconcentration at some point in time could have a very sprawling pattern.

This leaves sprawl as some aspect(s) of the urban pattern. At least for the measurement of the degree of sprawl in urban areas and their comparison, focusing on the pattern of urban development is most appropriate.

Conventional Definitions of Sprawl as Aspects of the Urban Pattern

In defining sprawl as one or a few aspects of the pattern of urban settlement, a small number of characteristics are most often mentioned. Harvey and Clark (1965) early identified three major types of sprawl as low-density development, ribbon development extending out from the city, and discontinuous or leapfrog development. Subsequent efforts to define sprawl have generally included one or more of these. Ewing (1997; see also Ewing 1994, 2008) tabulated the ways in which sprawl had been described in previous studies and described 4 forms of development which he said "characterized" urban sprawl: low-density development, strip development, scattered development, and leapfrog development. Any distinctions between the last 2 are rather subtle and Ewing actually refers to them together as "leapfrog or scattered development," and a later paper refers back to this paper as describing 3 forms of sprawl (Ewing, Bartholomew, and Nelson 2011).

In addition to these "characterizations" of sprawl (which he elsewhere refers to as definitions), Ewing (1997) proposes 2 "indicators" of sprawl, poor accessibility and lack of functional open space. He cites as advantages of accessibility that it can be readily measured and that it recognizes sprawl as a matter of degree, as opposed to "simple archetypes" such as leapfrog development. This is something of a straw-man argument, as the degree to which development is scattered or is low-density can be readily measured, as has been demonstrated in many studies of sprawl.

While accessibility can be operationalized, it can mean accessibility to so many different things in so many different ways that it becomes difficult to see what would be the appropriate measures of sprawl. In addition, it is questionable as to whether at least some measures of accessibility are that clearly related to sprawl as this concept is generally understood. Ewing mentions average travel time as one simple measure of accessibility that is readily available. Consider these data on the mean journey-to-work times for the New York and Los Angeles MSAs from the 2012 American Community Survey (U.S. Bureau of the Census 2016): First, one has to either distinguish by mode or lump all modes together. The mean times for the journey-to-work by public transit were 50.5 minutes for New York and 50.2 minutes for Los Angeles. For car, truck, and van trips, alone or carpooling, the corresponding means were 29.4 minutes and 27.9 minutes. Of course, combining all modes will make the mean for New York much longer than Los Angeles because far more of the trips used public transit. It is not clear how this serves to characterize the levels of sprawl in the 2 regions.

It is understandable why the lack of functional open space would be added as an indicator of sprawl. Scattered or leapfrog development (considered negatively as sprawl) implies the presence of vacant land separating developed areas. On the other hand, cluster development with residential units developed more densely and surrounded by open space is viewed positively. As both involve developed areas separated by land that is not developed, a concept of "functional" open space is necessary to distinguish the two. Yet the extent to which any undeveloped land serves useful functions is itself a matter of degree. Virtually any such land would provide for groundwater recharge, one of the positive contributions attributed to functional open space. And while the extent to which undeveloped lands serve useful purposes might be ascertained when looking at specific areas, making such distinctions from generally available data for the nation as a whole would certainly be problematic.

Of the original characteristics of sprawl, ribbon or strip development is perhaps the least specific and useful. Among the articles cited by Ewing (1997) it is listed as an aspect of sprawl the fewest number of times. What is meant is ambiguous—some use the term to refer to a strip commercial development (Ewing 1997) while others take ribbon development to refer to a pattern in which all types of urban development including both residential and commercial extend outward along transportation arteries (Harvey and Clark 1965). Such development patterns characterize not only contemporary development but the development that occurred along streetcar and other rail lines in the late nineteenth and early twentieth centuries. And many would not describe that development as urban sprawl. A final problem arises in that the measurement of the extent to which the pattern of development in an area can be characterized in this manner would be difficult.

This leaves low-density development and scattered or leapfrog development as the two primary characteristics for the definition of urban sprawl. A large body of research on sprawl suggests that these are in fact the aspects of urban development most associated with sprawl, for studies using a single measure for urban sprawl inevitably use measures of either density or the extent to which development is fragmented. Only examples from the large literature will be cited here.

Many studies have used straight measures of density—population or housing units per area—as measures of urban sprawl (e.g., Pendall 1999; Fulton, *et al.* 2001; Anthony 2004; Angel, *et al.* 2010). Lopez (2004), Zhao and Kaestner (2010), and Laidley (2016) are examples of works that have identified low-density sprawl as the percentage of the population living in smaller areas with densities less than some threshold. Measures of the scatter of development have been used as the indicators of sprawl by Burchfield, *et al.* (2006) and Irwin and Bockstael (2007).

Multidimensional Measures of Sprawl

An alternative approach to its measurement is to view sprawl as a multidimensional phenomenon and use multiple indicators. Given the confusion and multiple, varying descriptions of sprawl, the decision to do this is not surprising. This involves assuming numerous measures of the urban pattern as being indicative of degrees of sprawl, designating increases or decreases as representing greater levels of sprawl.

Galster *et al*. (2001) presented one of the first and most widely cited examples of the multidimensional measurement of sprawl. They initially identified 8 dimensions of sprawl—density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. They later extended this to more more dimensions for a greater number of urban areas defined more broadly (Cutsinger *et al*. 2005).

Ewing, Pendall, and Chen (2002) took a slightly different approach, starting by specifying 4 general sprawl factors related to density, land use mix, centrality, and the street network. Multiple variables were used as measures of each factor, with the value produced using principal components analysis. This work has been updated to include data from the 2010 census (Ewing and Hamidi 2014).

Many additional studies have examined multiple dimensions of sprawl. Only a few examples are cited here. Malpezzi and Guo (2001) developed many measures using population distributions across census tracts. Frenkel and Ashkenazi (2008) used measures derived from landscape ecology in their study of sprawl in smaller Israeli towns. Schwarz (2010) included over 50 landscape, population, and socioeconomic indicators of sprawl for several hundred European cities. Ewing and Hamidi (2015) cite many of the studies measuring sprawl as a multidimensional phenomenon.

It is questionable as to whether some of the measures of urban patterns included in these multidimensional sprawl studies can reasonably be considered to be related to urban sprawl as it is generally understood. Consider 2 of the measures included in many of these studies, the variation in density and the centralization of population or housing units. Imagine 2 identical urban areas with high densities near the center and low-density, sprawling development at the periphery. A new development is added to each at the fringe. In the first area, it is a continuation of the very low-density development, while the second adds a transit-oriented development at a much higher density (though much lower than at the center). The higher-density development in the second area will reduce the variation in density for the entire urban area and, by bringing more development to the edge, will decrease the level of concentration at the center, an increase in sprawl on both measures. But virtually everyone would agree that the second area now has a somewhat lower level of sprawl. As Ewing (1997) has observed, "monocentric development is an anachronism, as downtowns have become just one of many centers in large metropolitan areas," making centralization a dubious indicator of sprawl.[1]

Data for the Analysis of Urban Patterns

This research uses a dataset for the analysis of urban patterns over time that was developed with data on numbers of housing units in census tracts for large urban areas in the United States from 1950 to 2010. The tracts for urban portions of metropolitan areas were identified within the Combined Statistical Areas (CSAs) as delineated by the Office of Management and Budget for 2013 (U.S. Bureau of the Census 2013). CSAs were used rather than the more commonly employed Metropolitan Statistical Areas (MSAs) as it was felt they more properly represented the full extent of the metropolitan areas, including those instances in which 2 or 3 MSAs should more properly be considered to be parts of a single area (Ottensmann 2017b). For those MSAs which were not incorporated into a CSA, the MSA was used.

The 59 CSAs and MSAs with 2010 populations over one million were selected for the creation of the dataset. A number of these areas had multiple large centers associated with separate urban areas that had grown together. This posed the issue of identifying those cases in which a second or third urban area could be considered

[1] I was involved in research related to the multidimensional measurement of sprawl around the turn of the century. To the extent that this discussion might be seen as a criticism of aspects of such work, it applies to me as well.

sufficiently large in relation to the largest area to be considered as an additional center. The decision was made by comparing the populations of census Urbanized Areas (either from the current census or the last census in which the areas were separate) with the largest area. A center was considered to be an additional center if its population were greater than 28 percent of the population of the largest area. The three areas included with the lowest percentages were Akron (with Cleveland), Tacoma (with Seattle), and Providence (with Boston).

The primary data source for this research was the Neighborhood Change Database developed by the Urban Institute and Geolytics (2003). This unique dataset provides census tract data from the 1970 through 2000 censuses, with the data for 1970 through 1990 normalized to the 2000 census tract boundaries. Population and housing unit data from the 2010 census were added by aggregating the counts from the 2010 census block data (U.S. Bureau of the Census 2012).

Housing unit densities—the numbers of housing units divided by the land areas of the tracts in square miles—are used in this research rather than the more commonly employed population density measure for two reasons. Housing units better represent the physical pattern of urban development as they are relatively fixed, while the population of an area can change without any changes in the stock of housing. Other studies of urban patterns have made similar arguments for choosing housing units over population, for example Galster, *et al.* (2001), Theobald (2001), Radeloff, Hammer, and Stewart (2005), and Paulsen (2014).

Using housing units also allows the extension of the analysis to census years prior to 1970. The census included data on housing units classified by the year in which the structure was built, and these data are included in the Neighborhood Change Database. The 1970 year-built data can be used to estimate the numbers of housing units present in the census tracts for 1940, 1950, and 1960. Several prior studies have used the housing units by year-built data to make estimates for prior years in this manner, though they have used more recent census data to make the estimates, not the earlier 1970 census data (Radeloff, *et al.* 2001; Theobald 2001; Hammer, *et al.* 2004; Radeloff, Hammer, and Stewart 2005).

Sources of error in these housing unit estimates for earlier years from the year-built data arise from imperfect knowledge of the year in which the structure was built and from changes to the housing stock due to demolitions, subdivisions, and conversions to or from nonresidential uses. These errors increase for estimates farther back in time. Numbers of housing units for 1970 to 1990 were estimated from the 2000 year-built data and compared with the census counts in the Neighborhood Change Database. The judgment was made that estimates 2 decades back involved acceptable levels of error, but this was not the case for 3 decades back. As a result, the decision was made to use the housing unit estimates for 1950 and 1960 but not for 1940.

Suburban Areas for the Measurement of Sprawl

Urban sprawl is used to refer to the pattern of development in the suburban portions of urban areas. These are taken to be the areas that have developed more recently and fit the common notion of "suburban." Note that the definition here is intended as a definition of the suburbs only for the purposes of the measurement of sprawl in the current context. It does not address the meaning of "suburb" in a broader historical context in the way the term has been used, for example, by Warner in *Streetcar Suburbs* (1978) or Jackson in *Crabgrass Frontier* (1985).

Little agreement exists as to the definition of suburbs (Forsyth 2012). Cox (2018) includes density and transit use in the definition. Kolko (2018) cites the predominance of single-family housing. For Canadian urban areas, suburbs have been defined as being those areas outside the core areas that use "active transportation"—walking and bicycling (Gordon 2018). Forsyth (2012) refers to definitions based on negative consequences of sprawl such as high levels of automobile use and the loss of land to urbanization.

Discussions of sprawl have most commonly considered suburbs to be the more recently developed portions of urban areas. Squires (2002) refers to sprawl as "new development on the fringe of settled area" that has occurred in the last 5 decades of the twentieth century. Burchell, *et al.* (1998) says sprawl refers to "a particular type of suburban peripheral growth." Newness and location outside the core are repeatedly cited by Forsyth (2012) as characteristics of suburbs. Benfield, Raimi, and Chen (1999) talk of sprawl as involving development that has taken place in the second half of the twentieth century, especially after 1960. And the *Beyond Sprawl* report (1995) explicitly refers to development that occurred after World War II.

For the measurement of sprawl in this paper, the suburban areas are defined as those portions of urban areas that have become parts of their urban areas since the middle of the twentieth century. This necessarily begins with the delineation of the urban areas. Then the more recently developed, suburban portions can be identified.

Urban areas have been defined for the broader urban patterns research for each census year from 1950 to 2010 consisting of those tracts contiguous to each urban center meeting a minimum housing unit density threshold. (This is comparable to the way in which Paulsen (2012) defined urban areas using block groups as the basic units.) For the definition of Urbanized Areas for the 2000 and 2010 censuses, a minimum population density of 500 persons per square mile was required for a block or larger area to be added to an Urbanized Area (U.S. Bureau of the Census 2002, 2011). Using the ratio of population to housing units for the nation as a whole in 2000 of 2.34 persons per unit, a density of 500 persons per square mile is almost exactly equivalent to 1 housing unit per 3 acres or 213.33 units per square mile. This was used as the minimum urban density threshold. Note that this is a measure of gross density, not lot size, as the areas of roads, nonresidential uses, and vacant land are included.[2]

Given historical patterns of urban and suburban development in the United States, treating development that has occurred after 1945, the end of World War II, as suburban would be quite reasonable. If one is relying on census data, choices are limited to the decennial census years. Because the urban patterns data only goes back to 1950 due to the unreliability of the earlier estimates, suburban development is considered to be those areas added to the urban area after that year. For each census year from 1960 to 2010, the suburban area is that portion of the urban area outside the 1950 urban area. So these are cumulative additions to the suburban area with the growth of the urban area at each census.

These suburban portions of the 59 urban areas included in this research had a population in 2010 of 98 million persons. This is 64 percent of the total population of the urban areas in 2010. Nearly a third of the population of the United States lives within these suburban areas.

By defining the suburban areas as portions of urban areas, exurban development beyond the more built-up areas is not being considered. The highly dispersed development in these exurban areas could also be considered a component of urban sprawl. As part of the urban patterns research, exurban areas were also defined as contiguous tracts beyond the urban areas meeting a much lower density threshold. These exurban areas showed extremely wide variation in size across the urban areas (Ottensmann 2017a). Including the exurban areas with the suburban areas in the measurement of sprawl would result in the variation in the exurban areas completely dominating any differences in the suburban sprawl. For this reason, the exurban areas are not included here. Exurban sprawl needs to be addressed separately from suburban sprawl.

Density Measures for Urban Sprawl

The review of the definitions of urban sprawl identified low densities and scattered or leapfrog development as the most commonly accepted characteristics of sprawl. These are taken as the starting point for the development of measures of sprawl. However, this can be quickly simplified further. Because of the undeveloped land, scattered/leapfrog development produces low population and housing-unit densities when densities are measured for areas larger than the individual dwellings or developments. Harvey and Clark (1965) noted that low densities are associated with all 3 forms of development they identified as sprawl. And Burchell, *et al.* (1998) observed

[2] More detail on the construction of the dataset and the delineation of the urban areas is provided in Ottensmann (2014).

that “density, or more specifically, low density, is one of the cardinal defining characteristics of sprawl.”

Density itself is a complex concept that can be measured in a variety of ways. Various studies have therefore used multiple measures of density. Angel, *et al.* (2010) considered density for different areas and measured in different ways. Among a very large number of measures of urban structure used in their analysis (50), Nasri and Zhang (2018) included multiple measures of residential density including variation in density and percentages in various density categories.

This study follows the approach of using multiple density variables as the measures of urban sprawl. These are grouped into two categories—measures of the overall density of the suburban area and measures of the prevalence of very low-density development. Numerous potential variables are considered with the best 2 selected in each category as discussed in the following sections. These are then evaluated and combined into sprawl indices. The final part looks at sprawl over time and the problems associated with that.

Measures of Overall Density

The most obvious first measure of density for the suburban areas is, well… density. That is, the total number of housing units in the suburban area divided by the total land area. (Housing units are being used in the current research rather than population.) This is the measure of density totally unrelated to the distribution of the housing units within the suburban area.

A different measure of density has been suggested as an alternative, particularly in the context of the measurement of urban sprawl. This is population-weighted density, the mean of the densities of small areas within the larger area weighted by the population of each of the small areas. (The measure here will, of course, be housing-unit-weighted density, which is the mean of housing-unit densities of the census tracts weighted by the number of units in each tract.) This views density more from the perspective of the residents of the area, being the average of the densities experienced by residents within the small areas within which they live. Population- or housing-unit-weighted densities will be greater in areas with more uneven distributions of population and housing units, as more people and housing units will be within the denser subareas. Many have written favorably about the use of population-weighted density as an alternative to the standard density measure. I have discussed population-weighted density in great detail in another paper and will not repeat that here (Ottensmann 2018).

Density and housing-unit-weighted density were the two variables initially selected as measures of overall density. However, additional measures can be developed and have been examined that were also calculated using the densities of the census tracts. One point needs to be made before proceeding with the description of these alternatives. The standard, conventional density measure—total housing units divided by total area—is equivalent to area-weighted density. That is, take the densities of the census tracts and calculate the mean weighted by the areas of the tracts and one gets the standard density measure. This means that parallel versions of the additional measures can be developed that are both area-weighted and housing-unit-weighted.

In discussions of population-weighted density, Craig (1984, 1985) notes that the usual population-weighted density measure involves taking the weighted *arithmetic* mean of the small-area densities. He suggests that a weighted density calculated by taking the weighted *geometric* mean would be superior because comparisons of densities are most appropriately made using percentage differences rather than absolute differences. (Note that taking the weighted arithmetic mean of the logarithm of densities and converting the result back to the non-logged form is equivalent to the geometric mean.) So the area-weighted and housing-unit-weighted geometric means of density are considered as additional measures of overall density.

The mean is the most commonly used measure of the central tendency of a distribution. However the median—the middle value—is an alternative that is often considered to be preferable for skewed distributions or distributions with outliers. Area-weighted and housing-unit-weighted median densities for the census tracts are two more measures. (Because census tracts arbitrarily vary in terms of both areas and numbers of housing units, some type of weighting is necessary. The unweighted medians would not make much sense.)

The objective sought in considering multiple measures of density was to capture significant variations of the patterns of density across the urban areas. It was not to include larger numbers of density variables for their own sake. Following the principle that simpler is better, additional density measures would be included only to the extent that they would appear to add significant variation to the analysis.

With this standard in mind, values of the various overall density measures were computed using the 2010 data for each of the 59 urban areas. The correlations among the measures were examined. The correlations of the area-weighted and housing-unit-weighted geometric means of density and median densities with the standard housing-unit density measure ranged from 0.96 to 0.99. In other words, they varied little and added very little to the measurement of density. As a result, the first two variables, standard density and housing-unit-weighted density, are taken as the 2 measures of overall density.

Measures of Low Density

The overall density variables reflect averages of the densities of the census tracts. This section looks at measures of the distribution of densities across the census tracts.

The goal is to identify the extent of very low-density development. This section begins with percentages of housing units in tracts with densities below selected values. Alternatives are considered including other density thresholds and other measures of the density distribution.

Some studies have used as measures of sprawl the percentages of the population or housing units in small areas having densities less than some value, as discussed earlier. In those cases, the density thresholds were been selected based on the judgment of the researchers. While the selection of such levels are to some extent necessarily arbitrary, the attempt is made here to at least base the choice on the data.

Density thresholds were selected as the quartiles for the distribution of densities in 2010 across all of the census tracts in the 59 suburban areas included in this research. (Because tracts vary in area, these are necessarily area-weighted quartiles.) So the tracts with densities less than the first quartile, for example, are those encompassing the quarter of the total of the land area of the suburban area with the lowest densities. The tentative measures were then the percentages of housing units in a suburban area in tracts with densities less than these quartiles—the first density quartile, the median density, and the third density quartile.

All three of these variables for 2010 were, of course, strongly correlated with the overall density measures, as would be expected. The magnitudes of the correlations were all greater than 0.8. However the correlation of the percentages less than the third density quartile with density was 0.92, so very highly related to overall density. It is perhaps not surprising that the percentages less than the lower density thresholds—the first quartile and the median—would be better measures of the presence of low densities while the percentage less than the third quartile would be more closely related to the overall density levels. Based on this, the percentages of housing units in census tracts with densities less than the first density quartile and the median density were taken as the initial, tentative measures of low density.

The density cutoffs being used are 350 housing units per square mile (first quartile) and 611 units per square mile (median). These are 0.55 units per acre and 0.95 units per acre respectively. In terms of population densities, using the national value of 2.34 persons per unit used for the urban area definition, these would be approximately equivalent to densities of 819 persons per square mile and 1,430 persons per square mile.

Alternative measures for low-density sprawl are considered next. First is the use of percentage of land area less than the density thresholds rather than percentage of housing units. The correlations of the new variables with the corresponding housing-unit percentages were 0.92 and 0.96, so not much difference between the 2 sets. Percentage housing units less than density levels seems more reasonable and percentage area less than density would not constitute a significant addition.

The next possibilities were the percentages of both housing units and land areas below density quartiles from all tracts calculated by weighting by the housing units in the tracts. Because more housing units are concentrated in the higher density tracts, these values are higher than the area-weighted density quartiles used in the previous cases. These quartiles were more closely related to the overall density measures. This was expected given the same was the case for the percentages less that the third area-weighted density quartile.

Finally, the area- and housing-unit-weighted quartiles for the individual urban areas were used directly as measures of the density distributions. Once again, these generally were more closely related to the overall density measures, adding less information. Several showed somewhat different patterns, but these differences were strongly influenced a few outliers, making their value as measures questionable.

As a result, the percentages of housing units less than the first density quartile and the median density for all suburban tracts (area-weighted) are used as the two measures of low-density sprawl. While related to the overall density, they add some unique variation to the more general measurement of suburban area density and sprawl.

The Final Set of Density Measures and the Sprawl Indices

Four variables have been selected as the measures of density for use in the measurement of sprawl. Two are measures of the overall density of the suburban areas, the standard measure of density as total housing units divided by area and housing-unit-weighted density. The others are measures of low densities, the percentages of housing units in tracts with densities less than the first density quartile and the median density across the tracts for all of the suburban areas.

Table 1 presents basic summary statistics for these measures of density for the 59 suburban areas in 2010. The results show considerable variation in densities across the areas. The mean (conventional) density is 866 housing units per square mile, varying from a low of less than 500 per square mile for the least-dense suburban area to a density of over 1,800 for the highest density area. Looking at this in other units, this is a mean of about 1.4 units per acre, ranging from 0.75 to 2.7 units per acre, or 1.3 acres per unit to about one-third of an acre per unit. Estimated approximate population densities would go from just over 2,000 persons per square mile to nearly 5,000 persons per square mile. This is quite a wide range for the suburban development across the 59 areas. (Note that these are all gross densities including all land area—streets, non-residential uses, and vacant land—along with residential area.) The mean housing-unit-weighted density of about 1,400 is just over 60 percent higher than the mean conventional density (and it must necessarily be higher). The low and high values are also correspondingly higher.

Table 1. Summary Statistics for Density Measures in 2010.

Variable	Mean	Minimum	Maximum
Density	866	477	1,834
Housing-Unit-Weighted Mean Density	1,408	618	2,861
Percent Housing Units Less Than First Quartile Density	8.9	0.0	24.0
Percent Housing Units Less Than Median Density	25.7	2.5	63.5

On average less than 10 percent of the housing units fall into the lowest-density category with densities less than the first density quartile across all areas. One area had no tracts and housing units with this low a density while the area with the most very low-density development had nearly a quarter of all housing units in such areas. A mean of about a quarter of housing units were in tracts with densities less than the density median for all areas. This also ranged widely, from 2.5 percent to over 60 percent.

Principal components analysis was used to examine the extent to which the 4 density variables captured distinct aspects of the variation in densities across the areas. The first 2 components extracted accounted for 97 percent, virtually all, of the variance in the 4 measures. These 2 components were rotated to provide a clearer pictures of the relationships among the variables. Table 2 gives the component loadings on the rotated components. The results are unambiguous. The first component had loadings (correlations) of 0.59 and 0.79 on the 2 measures of overall density. The larger loading (in terms of magnitude) for the low-density variables was about -0.15. The second component was then the low-density component, with loadings of 0.80 and 0.58 on the 2 low-density variables with the greater magnitude overall density loading being -0.14. Furthermore, the first component accounted for 50 percent of the total variance while the second accounted for nearly an equal amount, 48 percent. It is clear that the set of 4 density measures are capturing 2 distinct aspects of the variation in density across the 59 suburban areas.

To combine these 4 measures into an overall measures of sprawl, the values for 2010 are each converted to standardized scores (*z*-scores) with means of 0 and standard deviations of 1. The variables measure sprawl in opposite directions. For the overall density measures, increases are associated with lower levels of sprawl, while for the percentages less than the quartile and median, higher values mean greater sprawl. So

Table 2. Component Loadings of 2010 Density Measures on Rotated Principal Components.

Variable	Component 1	Component 2
Density	0.589	-0.135
Housing-Unit-Weighted Mean Density	0.788	0.106
Percent Housing Units Less Than First Quartile Density	0.102	0.798
Percent Housing Units Less Than Median Density	-0.147	0.577
Proportion of Total Variance Accounted for	0.496	0.476

the direction of one of the sets must be reversed to combine them into a single index. Because this is intended to be a measure of sprawl, it seems reasonable that higher values should reflect higher levels of sprawl, so the signs for the overall measures of sprawl are reversed. (This is the opposite of many of the studies combining multiple measures into a sprawl index which set higher levels to mean less sprawl, possibly because they view less sprawl as better and therefore deserving of higher values.)

The total sprawl index is then the mean of the *z*-scores for the 2 low-density measures and the negative values of the 2 overall measures of density. Since these are the means of the standardized variables, they are no longer themselves *z*-scores with means of 0 and standard deviations of 1. However, the mean of the sprawl index is extremely close to zero and the standard deviation is just less than 1, 0.94. Values for the sprawl index in 2010 ranged from a high for 1.8 for the suburban area with the highest level of sprawl down to -2.4 for the least-sprawling area.

Because the variables fall into 2 distinct groups measuring different aspects of sprawl, subindices were also created. The overall density index is the mean of the (negative) *z*-scores for those 2 density measures, density and housing-unit-weighted density. Similarly, the mean of the *z*-scores for the 2 low-density measures, percentages less than the first quartile and the median, gives the low density index. Of course the total sprawl index is then also the mean of these 2 subindices.

For the years from 1950 to 2000, the 4 density variables were transformed using the same values used in converting the 2010 values into z-scores. The resulting values for these years are therefore not *z*-scores. But this makes the values comparable to the 2010 values for combining them to form the sprawl indices for those earlier years.

Measures of Sprawl Over Time

The original plan was to examine changes in levels of sprawl over time across the period from 1960 to 2010 as well as to look at the patterns of sprawl in 2010. Seeing the results showed a problem for doing this. Table 3 presents the mean of the sprawl index values across the 59 suburban areas for each decade over this period. (The mean housing-unit densities are also presented for comparison and as a check.) The mean sprawl index declines from 1960 to 1990 and then remains fairly constant for the remaining periods. The drop is especially dramatic for the first two decades. Lest there be any doubt about the reasonableness of this behavior of the sprawl index over time, the mean housing-unit densities show a comparable pattern.

The explanation for these declines lies in the way the urban areas are defined and the way urban areas develop. Areas (census tracts in the current research) contiguous to the urban area in any given year have densities lower than the minimum urban density threshold. This is not unique to this research. The same is true for the definition of the Census Urbanized Areas and other definitions of the extent of urban areas.

As development takes place in areas at the fringe, densities increase and new areas (tracts) are added to the urban area. But this does not require and will generally not involve the complete development of all of the land in a census tract. A limited amount of new development may be sufficient to increase the density of a tract above the urban minimum, leaving much of the land vacant and undeveloped at the time the tract is added to the urban area. Development can continue, new housing units can be added, and the density of a tract can increase in subsequent decades as build-out is approached. The complete development of an area and its transition from rural to complete development can take multiple decades.

Table 3. Mean Sprawl Index and Suburban Area Density, 1960-2010.

Year	Mean Sprawl Index	Mean Suburban Area Density (units per square mile)
1960	2.12	492
1970	0.97	648
1980	0.29	797
1990	0.02	873
2000	0.04	867
2010	0.00	866

This can account for what is happening with the mean sprawl index values and densities shown in Table 3. The suburban areas have been defined as consisting of those areas added to the urban areas after 1950. Thus the suburban areas in 1960 will include only tracts that have exceeded the urban density threshold in the previous decade. Most of these tracts will have been only partially developed by 1960. Therefore the densities will be very low and the sprawl index values very high. Over the succeeding decades, development in these tracts added during the period from 1950 to 1960 will continue, increasing their densities and the densities of the entire suburban areas and decreasing the values of suburban sprawl.

Of course exactly the same thing will be happening with the areas added in the next decade from 1960 to 1970. These are likewise likely to be only partially developed and have very low densities. But this is offset in part by the increases in densities in the tracts added in the prior decade from 1950 to 1960, raising overall density and decreasing sprawl. The process continues in the following decades until a sort of equilibrium is reached, with the increased densities in all of the areas added in earlier decades just offsetting the lower densities due to partial development in the most recently added decade. And this may be why the mean levels of sprawl and densities can be relatively constant after 1990.

This interaction between urban areas being defined as consisting of smaller areas meeting a relatively low minimum density threshold and the full development of an those areas occurring over multiple decades makes the phenomenon of sprawl much more complex. Measures of the urban pattern at a single point in time will fail to capture this. One can certainly talk about and measure urban sprawl as it exists at any given time. But consideration of sprawl and its changes over time will require more detailed analysis. For this reason, the current analysis is limited to the examination of urban sprawl at the end of this period in 2010.

Sprawl of Large Urban Areas in 2010

This section examines sprawl in the 59 large urban areas in the United States in 2010 using the sprawl index (and subindices) for the suburban portions of those areas. The areas that sprawl the most and the least are considered first along with the levels of sprawl in the largest urban areas. The overall density and low density subindices are shown to capture distinctive aspects of the pattern of sprawl. The relationship of sprawl to the size of the suburban area, the region of the country, and barriers to urban expansion are then examined.

The first question most will ask is which areas sprawl the most and which are the least sprawling. Table 4 lists the urban areas with the 10 highest and 10 lowest values on the sprawl index in 2010. Greenville-Spartanburg is the area with the highest sprawl but is closely followed by Albany-Schenectady-Troy. So high levels of sprawl are not limited to newer urban areas. Nor are they limited to these somewhat smaller urban areas, as Boston-Providence and Pittsburgh are also on the list of the 10 most sprawling areas.

Table 4. Areas with the Highest and Lowest Levels of Sprawl, 2010.

Highest Levels of Sprawl

Area	Sprawl Index
Greenville-Spartanburg	1.80
Albany-Schenectady-Troy	1.77
Harrisburg-York	1.68
Pittsburgh	1.65
Raleigh-Durham	1.27
Knoxville	1.24
Rochester	1.12
Boston-Providence	1.12
Birmingham	1.04
Grand Rapids	0.99

Lowest Levels of Sprawl

Area	Sprawl Index
Las Vegas	-2.39
Miami-Fort Lauderdale-West Palm Beach	-1.88
San Francisco-Oakland-San Jose	-1.55
Los Angeles	-1.38
Phoenix	-1.29
San Diego	-1.16
New Orleans	-1.11
Sacramento	-1.09
Albuquerque	-1.03
Denver	-0.99

Nine of the 10 urban areas on the list are located in either the Northeast or the South. Grand Rapids is the exception.

The presence of Boston-Providence will certainly be a surprise to many, as this area is known for its classically dense urban core. But remember that if sprawl refers to the pattern of development that has taken place in the suburbs since 1950, this is not referring to what the city of Boston looks like, nor, for example, Cambridge, Brookline, Newton, or Salem. The same, of course, is true for Pittsburgh, another larger, older urban area many might not associate with high levels of sprawl.

Even more surprising will be the list of the urban areas with the lowest levels of sprawl, topped by Las Vegas and followed by Miami-Fort Lauderdale-West Palm Beach. Indeed, numbers of the areas on the list are those often assumed to be exemplars of sprawl such as Los Angeles and Phoenix. Eight of the 10 least sprawling areas are located in the West, with Miami and New Orleans in the South.

Many will be especially interested in the levels of sprawl in the largest urban areas, which are listed in Table 5. Boston has already been noted as being among the most sprawling areas, while Miami-Fort Lauderdale-West Palm Beach, San Francisco-Oakland-San Jose, and Los Angeles have the second, third, and fourth lowest levels of sprawl. Dallas-Fort Worth, Houston, and Washington-Baltimore are also fairly low in terms of sprawl. New York and Philadelphia had slightly above average levels of sprawl and Chicago was right at the mean.

Table 5. Sprawl Index and Rankings for the 10 Largest Urban Areas, 2010.

Area	Sprawl Index	Sprawl Rank	Low Sprawl (Inverse) Rank
New York	0.34	23	37
Los Angeles	-1.38	56	4
Chicago	-0.08	33	27
Washington-Baltimore	-0.64	44	16
Miami-Fort Lauderdale-West Palm Beach	-1.88	58	2
Boston-Providence	1.12	8	52
San Francisco-Oakland-San Jose	-1.55	57	3
Philadelphia	0.44	20	40
Dallas-Fort Worth	-0.75	48	12
Houston	-0.65	46	14

Sprawl is being measured using a composite of 4 different measures of density, 2 measures of overall density and 2 measures of low density. Does including the multiple density variables actually affect the extent to which different urban areas are considered to be sprawling? The two subindices were calculated for overall density and low density. The levels of these can be compared to assess how much the different aspects of density vary and affect the final measurement of sprawl.

The subindices are, of course, strongly related, with a correlation of 0.83. This is expected. as having more low-density areas will necessarily cause overall densities to be reduced. The question is the extent to which specific urban areas are affected by differences. The subindices were created by taking the means of the standardized scores of their 2 constituent variables and as a result, they also have means very close to 0 and standard deviations near 1. Numbers of urban areas differ significantly in the values of their overall and low density subindex values. The magnitudes of these differences, however, is not an especially good indicator of the degree to which an area is considered to have more or less sprawl. Some of the areas with very high or low values on the indices have large differences that have little or no effect on the positioning of the areas in terms of levels of sprawl with respect to the other urban areas. Las Vegas and Miami-Fort Lauderdale-West Palm Beach differ by over 1 on their subindex values but have exactly the same ranking among the 59 urban areas on both of those indices. Pittsburgh and Harrisburg-York also differ by over 1 but vary by only 3 places each in their rankings. Values for the total sprawl index, the subindices, and the housing unit density for each of the urban areas are listed in the appendix.

More useful for considering the extent to which differences in the subindices affect their position in terms of sprawl is to consider the differences in their rankings on the subindices. Table 6 lists the urban areas that differ by at least 9 positions in their ranks. Jacksonville is close to the mean for overall density (29th) but is about a standard deviation below the mean in the low density index (in 50th position), a differences of 21 ranks on the 2 indices. Including the measures of low density results in Jacksonville being ranked lower in term sprawl (38 versus 29). Boston-Providence shows just the reverse pattern. The overall density index of 0.4 is somewhat above average but not extremely high. The value for the low density index of 1.8 is very high, 4th highest among all urban areas. It is the extent of Boston’s low-density development that places it among the top 10 urban areas in terms of sprawl. New Orleans is just the opposite, below average on the low density index and extremely low with respect to overall density. And Dayton goes in both directions, being well above average in terms of overall density while at the same time having a low density index that is below the mean.

For urban areas having both subindex values closer to the mean where more of the areas are clustered together, relatively small differences can mean larger variation in terms of rank. For example, the New York area is somewhat above average on overall

Table 6. Overall Density and Low Density Sprawl Subindices for Areas with Rank Differences of 9 or More.

Area	Overall Density Index	Low Density Index	Index Difference	Difference in Rank
Jacksonville	0.15	-0.98	1.14	21
Boston-Providence	0.43	1.80	-1.38	-18
Dayton	0.67	-0.23	0.90	15
New Orleans	-1.55	-0.68	-0.87	-14
New York	0.23	0.45	-0.22	-10
Fresno	-0.73	-0.65	-0.08	-10
Kansas City	0.44	-0.20	0.65	9
Minneapolis-St Paul	0.36	-0.58	0.94	9
Washington-Baltimore	-0.64	-0.63	-0.02	-9
Austin	-0.08	-0.04	-0.04	-9
Detroit	-0.12	-0.81	0.68	9
Philadelphia	0.39	0.50	-0.10	-9

density and a little higher with respect to low density, with a difference of only about 0.2 between the values but there is a differences of 10 in the ranking on the two subindices. Most of the areas do perform similarly in terms of both types of density. For 39 of the 59 areas the ranking on the 2 subindices differ by 5 places or fewer. And 37 of the areas differed in their subindex values by less than 0.4. But for a smaller number of areas, differences significantly changed the ranking of the area in terms of sprawl.

The listings of the areas with the highest and lowest levels of sprawl included more very large urban areas in the lower-sprawling group. This raises the question as to whether sprawl might be related to size, either for the suburban area or for the urban area as a whole. A modest negative correlation exists between the sprawl index for 2010 and the number of housing units in the suburban area in the same year, -0.41, significant at the 0.01 level. The correlation with the size of the entire urban area (again housing units in 2010) is smaller in magnitude, -0.23, and is not statistically significant at the 0.05 level.

Looking more closely at the relationship of sprawl to the size of the suburban area, Table 7 presents the results of the regressions of the sprawl index and the 2 subindices on the number of housing units in 2010. An increase of 1 million housing units (of course a very large amount) is associated with with a decrease of 0.64 in the sprawl index, over one-half of a standard deviation. So a substantively significant inverse relationship exists between the level of sprawl and the size of the suburban area. The regressions for the subindices show that the relationship to suburban area size is somewhat stronger for the overall density increase, with a change in 0.74 per million housing units versus 0.54, with corresponding differences in R^2 and the levels of statistical significance.

The size of the suburban area in 2010 is the amount of suburban growth that has occurred since 1950, so the relationship to suburban size is also the relationship to suburban growth. The amount of suburban growth is very highly correlated with both the amount of growth of the entire urban area over the period from 1950 to 2010 and the percentage increase in urban area housing units. Therefore sprawl is inversely related to total urban growth as well.

The relationship of the levels of sprawl to the amounts and rates of suburban and urban area growth may make sense. Faster growth would be associated with greater demand for housing. This could increase land prices and then result in higher densities of development. Also, more rapid growth might result in faster development of areas as they become urban. This could lead to full development of those areas occurring more rapidly, resulting in less vacant land and higher densities.

An additional question is whether the level of sprawl might be related to the density of the portion of the urban area that was not suburban—the density of the 1950 urban area. Is it possible that denser urban areas might produce less sprawling suburban development? Examining the correlation of sprawl with the density of the

Table 7. Regression of Sprawl Index and Subindices on Number of Suburban Housing Units, 2010 (standard errors in parentheses).

	Total Sprawl Index	Overall Density Index	Low Density Index
Suburban Area Housing Units in 2010 (millions)	-0.64 **	-0.74 ***	-0.54 *
	(0.19)	(0.19)	(0.20)
Constant	0.42 *	0.49 **	0.36
	(0.17)	(0.17)	(0.18)
R^2	0.17 **	0.21 ***	0.11 *

* Significant at the 0.05 level

** Significant at the 0.01 level

*** Significant at the 0.001 level

1950 urban area shows the answer to be clearly that there is no relationship. The correlation is 0.03. So the earlier pattern of development does not appear to be associated with variation in suburban development and sprawl after 1950—in either direction. This illustrates the problem with using measures of the pattern of the entire urban area as a measure of sprawl. The pattern of the earlier development from before 1950 is simply not related to the levels of sprawl in the suburban areas.

The lists of the urban areas with the highest and lowest levels of sprawl definitely suggest a relationship between the region of the country in which an urban area is located and its degree of sprawl. Urban areas in the Northeast and South were 9 of the 10 most sprawling, while 8 of the 10 least sprawling urban areas were in the West. The mean values for the sprawl index and the subindices for the urban areas in each region are shown in Table 9. The results are not unexpected. The urban areas in the Northeast had by far the highest average level of sprawl, with a mean just over 1. And the West region urban areas were just the mirror image, with a mean sprawl index that was exactly the negative of the mean for the Northeast. The averages for the the other 2 regions were close to the mean for all areas with those in the Midwest being slightly higher.

The means by region for the sprawl subindices show some interesting variation. While the average values for the Northeast were high for both, those areas had especially high levels of sprawl as measured by the low density index. This measure had a mean for the areas in the Northeast of 1.33 as compared with 0.77 for the overall density index. Areas in the Northeast have extremely low-density and scattered suburban development. In the opposite direction, the areas in the Midwest were more sprawling in terms of the overall density index, 0.45 as compared to virtually zero for the low density index. On average, the urban areas in the South and the West differed by relatively small amounts in their subindex values.

Table 8. Mean Sprawl Index Values by Region.

Region	Total Sprawl Index	Overall Density Index	Low Density Index
Northeast	1.05	0.77	1.32
Midwest	0.22	0.45	-0.01
South	0.06	0.11	0.02
West	-1.05	-1.15	-0.95
Significance	$p < 0.05$	$p < 0.01$	$p < 0.01$

Prior research has suggested that the densities of entire urban areas and levels of sprawl measured for such areas could be related to the presence of barriers to urban expansion such as mountains, and wetlands that increased the intensity of development (Burchfield, *et al.* 2006; Bereitschaft and Debbage 2014; Paulsen 2014). A study of urban area densities with the data being used here likewise showed that mountains and wetlands were positively related to those densities in 2010 (Ottensmann 2015). Others have suggested that government-owned land could be a barrier to development or that arid climates limits the availability of water, forcing reliance on public water supplies, limiting urban expansion (El Nasser and Overburg 2001; Lang 2002; Bereitschaft and Debbage 2014; Lopez 2014). It is therefore reasonable to consider the extent to which the existence of such barriers to development might be related to the extent of sprawl.

The primary focus here is on the presences of mountains and wetlands serving as barriers to urban expansion, resulting the decreased levels of sprawl. Urban areas are identified where mountains or wetlands are located near significant portions of the current boundary of the urban area and thus could be seen as limiting the growth of the area. This produced a set of 10 urban areas bounded by mountains and 2 more by wetlands.[3] This was necessarily a subjective judgment but more generous inclusion of areas produced similar findings.

Table 9 gives the mean sprawl index and subindex values for areas for which mountains or wetlands were or were not present. The differences are dramatic and statistically significant. The average levels of sprawl were -1.1 for the areas with mountains and -1.5 for the areas affected by wetlands. The areas without these barriers

Table 9. Mean Sprawl Index Values by Presence of Barriers to Suburban Expansion.

Barrier		Number	Total Sprawl Index	Overall Density Index	Low Density Index
Mountains	Present	10	-1.12	-1.27	-0.98
	Not Present	49	0.23	0.26	0.20
	Significance		$p < 0.001$	$p < 0.001$	$p < 0.001$
Wetlands	Present	2	-1.50	-2.01	-0.99
	Not Present	57	0.05	0.07	0.03
	Significance		$p > 0.05$	$p < 0.01$	—

[3] The areas limited by mountains were Albuquerque, Denver, El Paso, Las Vegas, Los Angeles, Phoenix, Salt Lake City-Ogden-Provo, San Diego, San Francisco-Oakland-San Jose, and Tucson. The areas limited by wetlands were Miami-Fort Lauderdale-West Palm Beach and New Orleans.

had means close to the mean for all areas, near zero. While means for the overall density index and the low density index were also very low, the barriers seemed to especially influence overall density, which had the lower average levels.

Since other authors had suggested that the presence of large amounts of government-owned land or arid conditions could limit expansion and increase density and sprawl, these were examined as well. The presence of government land was established subjectively as with mountains and wetlands. Arid climate was defined as having an average annual rainfall of less than 15 inches. Urban areas with both conditions also had comparably higher levels of sprawl. However, because many of the areas affected by government land or arid climate were also surrounded by mountains, separating the effects of these was not possible.

The size of the suburban area and the presence of mountains and wetlands were associated with the levels of sprawl. Multiple regression was used to examine the combined influence of these factors on the sprawl index and the subindices. The model results are presented in Table 10. The 3 variables account for half of the variation in the sprawl index (R^2 equal to 0.49). They perform better for the overall density index (0.62)

Table 10. Regression Model Predicting Sprawl Indices Using Suburban Area Size and Barriers to Expansion (standard errors in parentheses).

Independent Variables	Dependent Variable		
	Total Sprawl Index	Overall Density Index	Low Density Index
Suburban Area Housing Units in 2010 (millions)	-0.43 **	-0.49 ***	-0.38 *
	(0.15)	(0.14)	0.19
Mountains as Barrier to Expansion	-1.31 ***	-1.49 ***	-1.12 ***
	(0.24)	(0.22)	0.29
Wetlands as Barrier to Expansion	-1.56 **	-2.09 ***	-1.03
	(0.50)	(0.46)	0.61
Constant	0.56 ***	0.65 ***	0.48 **
	(0.14)	(0.12)	0.16
R^2	0.49 ***	0.62 ***	0.31 ***

* Significant at the 0.05 level

** Significant at the 0.01 level

*** Significant at the 0.001 level

than for the low density index (0.31). The 3 R^2 values are statistically significant at the 0.001 level. All 3 of the predictors are significant for the prediction of the total sprawl index and the overall sprawl index. Wetlands are not significant for the low density index but remember that this includes only 2 urban areas so this is not surprising. The major conclusion is that these 3 measures do well in a simple model, accounting for a major portion of the variation in sprawl.

Conclusions

The results for levels of sprawl in the large urban area are at variance with many preconceptions regarding where sprawl is prevalent. Older urban areas in the Northeast had some of the highest levels of sprawl, while areas in the West topped the list of those sprawling the least. Sprawl was on average somewhat lower in areas with more suburban development and was far lower in areas in which urban expansion was limited by barriers in the form of mountains or wetlands.

The extent of sprawl has been measured using multiple measures of housing unit density. Other approaches could be taken for the measurement of sprawl in the suburban areas. This could include different density variables or, if using more spatially disaggregated data, measures of scattered development. Additional aspects of sprawl might be identified, viewing sprawl is a phenomenon having multiple dimensions. The above critique of the such approaches was not intended to dismiss the possibility of having multiple dimensions for the measurement of sprawl. It was only intended to point out the inappropriateness of using some variables such as the variation in density or centralization that are not necessarily related to sprawl.

Other ways of defining the suburban areas impacted by sprawl could be considered. This would involve both the definition of the urban area and the subsequent definition of the portion considered to be suburban and therefore the locus of sprawl. The choices made here were constrained by the data being used. The urban area definition sought to approximate the Census Urbanized Area definition using tract data. Other possibilities could include the Extended Urban Area proposed by Wolman, *et al.* (2005). Likewise, definitions other than the area not urban in 1950 could be used for delineating the suburban areas, such as those used by Cox (2018), Gordon (2018), and Kolko (2018).

One objection to the measurement of sprawl by looking at patterns in the suburban areas is that this does not consider the impact of sprawl on the entire population of the urban area. Measuring sprawl by looking at the pattern of the entire urban area is not the answer. To revisit the argument for focusing on suburban development and not the whole area in yet another way, consider this example: One would not want to say that highly urban Beacon Hill and Cambridge in the Boston area and the Lincoln Park and Hyde Park-Kenwood neighborhoods of Chicago are sprawling compared to the Upper East Side of New York. Yet these areas are far less dense than the Upper East Side. If the density of the entire urban area is being used as at least one measure of sprawl, then the lower densities in these areas would be contributing to making levels of sprawl higher in Boston and Chicago than in the New York urban area.

If it is important to consider the extent to which the people in the urban area are affected by the degree of sprawl, one possibility would be to combine the measure of sprawl with the proportion in the suburban area. This was easy enough to do for the 59 urban and suburban areas and the measures of sprawl in 2010. The value of the sprawl index was multiplied by the proportion of housing units in the suburban area, giving a measure of the extent to which people were impacted by sprawl. The correlation of this "sprawl impact" measure with the total sprawl index was 0.98, so very little difference. This new index did little in altering the rankings of the urban areas. Rochester and Buffalo had their sprawl ranks drop by 7 and 6 places respectively when taking into account the proportion in the suburban area. The ranks for Charlotte and Los Angeles increased by 6 and 5 positions. All other differences in rank were less than these. Taking into account the proportion in the suburban area has only a limited effect.

The finding of high levels of sprawl and low density in the earlier years raises important questions for further research. The hypothesis is that this stems from the gradual development and infill over numbers of decades of those areas at the urban fringe that are added to urban areas. Understanding the nature of this process will require examination of patterns of development over multiple decades of those areas added to urban areas in any given year. The dataset used for this research will be employed to address these issues.

Many will be bothered by the conclusion that the Boston-Providence area is considered to be among the most sprawling areas while, for example, the Los Angeles area is considered to have one of the lowest levels of sprawl. Those who might therefore summarily reject this research, consider how you would account for these differences between the two areas: Comparing the suburban portions of the urban areas—those areas added to the urban areas since 1950—Boston's suburban area had a housing unit density in 2010 of 584 units per square mile. The density for the Los Angeles suburban area was 1,335 persons per square mile. In the suburban area of Boston, 46 percent of all suburban housing units were located in census tracts having densities less than the median for all of the suburban areas of 611 housing units per square mile (0.95 units per acre) compared with 9 percent in the Los Angeles area.

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Appendix. Sprawl Index Values and Suburban Area Housing Unit Density, 2010.

Area	Total Sprawl Index	Overall Density Index	Low-Density Index	Housing Unit Density
Albany-Schenectady-Troy	1.77	1.44	2.11	477
Albuquerque	-1.03	-0.94	-1.13	1,156
Atlanta	0.63	0.78	0.49	664
Austin	-0.06	-0.08	-0.04	842
Birmingham	1.04	1.08	1.00	582
Boston-Providence	1.12	0.43	1.80	584
Buffalo	0.66	0.53	0.79	654
Charlotte	0.87	0.93	0.80	624
Chicago	-0.08	0.12	-0.27	838
Cincinnati	0.63	0.84	0.42	663
Cleveland-Akron	0.62	0.74	0.51	660
Columbus	-0.38	-0.05	-0.71	902
Dallas-Fort Worth	-0.75	-0.62	-0.88	1,001
Dayton	0.22	0.67	-0.23	711
Denver	-0.99	-1.08	-0.89	1,159

Detroit	-0.46	-0.12	-0.81	927
El Paso	-0.64	-0.56	-0.73	1,065
Fresno	-0.69	-0.73	-0.65	1,081
Grand Rapids	0.99	0.86	1.12	633
Greensboro--Winston-Salem--High Point	0.97	1.08	0.86	589
Greenville-Spartanburg	1.80	1.46	2.15	486
Harrisburg-York	1.68	1.15	2.21	537
Hartford	0.63	0.58	0.69	653
Houston	-0.65	-0.61	-0.69	986
Indianapolis	0.44	0.59	0.28	710
Jacksonville	-0.41	0.15	-0.98	906
Kansas City	0.12	0.44	-0.20	776
Knoxville	1.24	1.29	1.18	534
Las Vegas	-2.39	-3.17	-1.61	1,834
Los Angeles	-1.38	-1.70	-1.06	1,335
Louisville	0.30	0.42	0.18	745
Memphis	0.12	0.41	-0.18	764
Miami-Fort Lauderdale-West Palm Beach	-1.88	-2.47	-1.29	1,449
Milwaukee	0.23	0.38	0.08	749
Minneapolis-St Paul	-0.11	0.36	-0.58	821
Nashville	0.74	0.89	0.59	630
New Orleans	-1.11	-1.55	-0.68	1,245
New York	0.34	0.23	0.45	729
Norfolk-Virginia Beach	-0.60	-0.40	-0.79	1,004
Oklahoma City	0.02	0.12	-0.08	825
Orlando	-0.06	0.06	-0.18	858
Philadelphia	0.44	0.39	0.50	704
Phoenix	-1.29	-1.36	-1.23	1,285
Pittsburgh	1.65	1.09	2.20	527
Portland	-0.93	-0.72	-1.13	1,145
Raleigh-Durham	1.27	0.97	1.57	585

Richmond	0.49	0.72	0.26	692
Rochester	1.12	1.06	1.17	593
Sacramento	-1.09	-1.12	-1.06	1,204
Salt Lake City-Ogden-Provo	-0.31	-0.12	-0.50	923
San Antonio	-0.63	-0.46	-0.80	1,019
San Diego	-1.16	-1.45	-0.87	1,236
San Francisco-Oakland-San Jose	-1.55	-2.01	-1.09	1,364
Seattle-Tacoma	-0.35	-0.24	-0.45	927
St Louis	0.43	0.60	0.26	717
Tampa-St Petersburg	-0.51	-0.44	-0.58	977
Tucson	-0.50	-0.33	-0.67	981
Tulsa	0.09	0.14	0.04	806
Washington-Baltimore	-0.64	-0.64	-0.63	1,003