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# Assessing spatial equity: an evaluation of measures of accessibility to public playgrounds

E Talen, L Anselin
Regional Research Institute, West Virginia University, PO Box 6825, Morgantown,
WV 26506-6825, USA; e-mail: etalen@wvu.edu; lanselin@wvu.edu
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**Abstract.** Geographical and political research on urban service delivery—who benefits and why—has proliferated during the past two decades. Overall, this literature is not characterized by a particular attention to the importance of method in drawing conclusions about spatial equity based on empirical studies. Specifically, there has been scant interest in the effect of geographic methodology on assessing the relationship between access and socioeconomic characteristics that are spatially defined. In this paper we take a *spatial analytical* perspective to evaluate the importance of methodology in assessing whether or not, or to what degree the distribution of urban public services is equitable. We approach this issue by means of an empirical case study of the spatial distribution of playgrounds in Tulsa, Oklahoma, relative to that of the targeted constituencies (children) and other socioeconomic indicators. In addition to the 'traditional' measure (count of facilities in an areal unit), we consider a potential measure (based on the gravity model), average travel distance, and distance to the nearest playground as indicators of accessibility. We find significant differences between the spatial patterns in these measures that are suggested by local indicators of spatial association and other techniques of exploratory spatial data analysis. The choice of access measure not only implies a particular treatment of spatial externalities but also affects conclusions about the existence of spatial mismatch and inequity.

## 1 Introduction

Geographical and political research on urban service delivery—who benefits and why—within the context of territorial justice (the relationship between provision and need) has proliferated during the past two decades (see Davies, 1968; Hay, 1995; Pinch, 1984; Smith, 1994). Some scholars have investigated what factors account for higher levels of service in certain neighborhoods (Cingranelli, 1981; Mladenka, 1989), and focused in particular on the role of distributive politics (Miranda and Tunyavong, 1994). Others have examined patterns of accessibility to certain services and the geographic relationship between service deprivation and area deprivation (Knox, 1978; Pacione, 1989). Until recently, this was predominantly explained by the notion of *unpatterned inequality* (Cingranelli, 1981; Mladenka, 1980; Mladenka and Hill, 1977). Current critiques of this theory (Meier et al, 1991; Miranda and Tunyavong, 1994) focus on the failure to take the political process properly into account and on problems with the definition of policy measures.

Overall, the empirical urban service delivery literature is not characterized by a particular attention to the importance of method, apart from a discussion of conceptual issues such as defining need versus provision (Boyne and Powell, 1991). Specifically, there has been scant attention to the effect of geographic methodology on conclusions about spatial equity drawn from empirical studies. For example, such concerns are absent from Hero's (1986) examination of weaknesses in the literature on urban service delivery. As any geographical analysis of spatial equity in this context relies on a measure of access to services, it is important to gain an understanding of the sensitivity of the conclusions to the conceptualization and measurement of accessibility. Typically, access is loosely defined on the basis of a simple count of facilities or services by some geographic unit, without regard to spatial externalities, the structure of the transportation network, the frictional effect of distance, properties of the supply side, and measurement issues related to the geographical scale of analysis. Such lack of attention to methodological aspects contrasts sharply with the recent surge of interest in defining, computing, interpreting, and visualizing accessibility in the literature on spatial analysis and geographic information systems (for example, Arentze et al, 1994a; 1994b; Frost and Spence, 1995; Geertman and Ritsema Van Eck, 1995).

In this paper, we take a *spatial analytical* perspective to evaluate the importance of methodology in assessing whether or not, or to what degree the distribution of urban public services is equitable. Specifically, we are interested in the sensitivity of perceived spatial patterns of (in)equity to the formal definition of the access measure used in the analysis. We approach this issue by means of an empirical case study of the distribution of playgrounds in Tulsa, Oklahoma, relative to that of the targeted constituencies (children) and minority populations. In addition to the 'traditional' measure of access (count of facilities in an areal unit), we consider a potential measure (based on the gravity model), average travel distance, and distance to the nearest playground as indicators of accessibility. We focus in particular on the similarities and differences between the spatial patterns in these measures that are suggested by local indicators of spatial association [LISA (Anselin, 1995a)] and other techniques of exploratory spatial data analysis (ESDA). In this paper we focus specifically on univariate and bivariate treatments because these are by far the most prevalent ones in the empirical literature.

In the remainder of the paper we first outline the various types of research and analytical methods currently in use in the analysis of the distribution of public facilities. The purpose of this taxonomy is to clarify the particular type of research and methodology we are concerned with in this paper, because there are many ways in which the problem has been approached. We next formally outline how measurement issues affect the characterization of access. Using various exploratory spatial data analysis techniques, we then illustrate how different characterizations of access can alter the results of an analysis of spatial equity for a case study of playgrounds in the City of Tulsa.

## 2 Spatial equity analysis in context

### 2.1 Research approaches

The question of who benefits and why in the provision of urban services and facilities embraces a wide variety of research dimensions. The multitude of concepts involved in equity issues was recently explored by Hay (1995). In contrast to his review, our concern is not with normative aspects of equity and fairness, but with the *empirical process*—the methodology—of discovering when and why spatial inequities exist. In this regard, our analysis begins with an understanding of the spatial *equality* that exists; when coupled with an investigation of need or social justice, the analysis becomes more appropriately termed spatial *equity.*(1)

The notion of equity is paramount in research that focuses on determining what factors account for, or are correlated with, territorial variation in service delivery. Accessibility, in turn, is a tool used to discover whether or not equity, variously defined, has been achieved. Taken together, these two concepts are the primary building blocks used to assess the spatial distribution or spatial pattern of public services. Specifically, an attempt is made to discover the access at a given point—the inherent geographic accessibility of a place. Of course, the two issues are not always related. For example, equity may have to do with dollars spent per facility, which is not a matter of

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(1) To avoid confusion, we opt to use the term *spatial equity* in our discussion; however, strictly speaking, the investigation does not become an exploration of equity until questions of need, fairness, or justice are more directly analyzed (which occurs later in the paper).

spatial equity or accessibility in the geographic sense per se. Accessibility may be used as a determinant of travel behavior, regardless of the equitability involved. Accessibility may also have more to do with social barriers, as opposed to physical distances, in which case spatial equity must be investigated with an entirely different logic.

Empirical research on the notion of equity in the distribution of public services has focused on defining and measuring what equity is, and on determining underlying causal factors in the distribution of services. Studies along the first dimension include evaluations of the geographic distribution of subsidies or public services (Cox, 1973; Hodge, 1988; Kirby et al, 1984; Pacione, 1989), assessments of fiscal equalization or various definitions of equity as bases for allocation (Lucy, 1981), normative studies of equity preferences (Wicks and Backman, 1994), or formal definitions of equity (Marsh and Schilling, 1994). In general, the importance and use of the notion of accessibility in these studies is substantive, in the sense that measures of accessibility have a defining role in determining what equity is.

Along the second dimension, the goal of the analyses is to assess whether or not political or other factors can be shown to account for distributional inequities. Factors implicated in the search for why certain distributional patterns exist include urban form (Hodge and Gatrell, 1976; McLafferty, 1982), organizational rules (Lineberry, 1977; Rich, 1982), citizen contacts (Mladenka, 1980; 1989), politics (Meier et al, 1991; Miranda and Tunyavong, 1994), and race (Cingranelli, 1981; Cingranelli and Bolotin, 1983; Mladenka and Hill, 1977). In a majority of these studies, accessibility is implicit: access is determined to be high for a given population if services are located within that population subgroup's district, ward, or census tract.

### 2.2 Methodological issues

An important methodological issue which remains largely unexplored in the analysis of public service distribution is the issue of how variation in the measurement of access can affect the results of empirical studies of spatial equity. In the first category of research discussed above—defining and measuring equity—few studies have incorporated rigorous formalized procedures that link accessibility to equity. Similarly, in representations of the second category—explaining equity—in the literature, there are very few instances where accessibility patterns are directly correlated with socioeconomic characteristics, and the exceptions typically ignore the importance of *spatial* patterns. In this respect, it is important to note that, so far, few studies in either tradition have exploited the spatial analytical opportunities available in a GIS environment (see Anselin and Getis, 1992; Fotheringham and Rogerson, 1994; Goodchild et al, 1992).

If the goal of research is to ascertain whether or not public service distributions are equitable and to identify what factors correlate with certain observed spatial patterns, then the methodologies employed may be particularly sensitive to—indeed determined by—issues of measurement and scale. In this respect, it is important to distinguish between the discrete notion of access implied by the 'container' view predominant in the (political science) literature, and accessibility indices that are continuous over space, such as the gravity potential or average travel distance. The container view is defined narrowly and constrains the notion of access to the presence or number of facilities in the unit of observation. For example, in the studies of Rich (1982) and Mladenka (1989), both the dependent variable (for example, parks and libraries) and the explanatory variables (for example, median income, percentage vote for current mayor) were measured by ward or census tract. This approach implies a particular objective function or social welfare function in which the benefits of a public service are only allocated to the residents of the corresponding tract or ward. In other words, spatial spillovers or spatial externalities to other tracts are excluded from consideration. Clearly, this may be appropriate when resources are allocated by the political process on the basis of the relevant unit, and when the market or service area matches this unit. For example, this would be the case in studies of the allocation of community development block grant funds in which the amount of the resulting services is correlated with the socioeconomic and political attributes of the census tracts (for example, Miranda and Tunyavong, 1994). However, for true public goods, when service provision is not limited to specific geographic boundaries, the exclusion of spatial externalities from the analysis is inappropriate. This is particularly relevant in studies of the provision of public infrastructure such as parks, libraries, health care facilities, and sometimes educational facilities. As people cannot be explicitly excluded from using a park or library in any part of a city on the basis of their residential location, a measurement of access based on the container view is misleading. This is equally limiting from a behavioral or political perspective because decisionmakers do not often locate facilities on the basis of the boundaries of artificial areal units of observation such as census tracts. In such cases where designated 'market' areas do not exist, it may be appropriate to broaden the measure of accessibility.

The use of a container view of access in empirical studies may also increase the likelihood of finding unpatterned inequality. Indeed, the selection of a unit of observation (for example, census tract) that does not match the actual service area of the facility may result in the impression of a spatially random pattern of access, in the sense that there is no 'significant' spatial structure (either clustered or regular). In contrast, most urban socioeconomic phenomena that would be used as explanatory variables for the pattern of access are characterized by a high degree of spatial structure, such as clustering by income and/or race (for example, Knox, 1987). Consequently, the explanation of a spatially random pattern (access) by a spatially nonrandom pattern (socioeconomics) is unlikely to yield a strong statistical relationship. In other words, the indication of unpatterned inequality is likely, irrespective of the true underlying relationships.

We suggest that a broader view of access that incorporates spatial externalities should be included in any analysis that seeks to capture a potential match between the spatial distribution of facilities and socioeconomic explanatory variables. Such a view would tend to result in a nonrandom spatial pattern by design, because the use of distance to facilities as a metric will yield similar values for access in neighboring locations (both will be roughly the same distance away from facilities that are not in their immediate vicinity). Of course, if such a nonrandom spatial pattern is found for access, it remains an empirical matter whether this corresponds to the spatial pattern of socioeconomic characteristics, or instead suggests the existence of a spatial mismatch. The main point is that the conclusions may be sensitive to the definition of accessibility. Alternative definitions imply different 'weights' for mobility (ease of movement from residence to the facility) in the social welfare function, and the relation or lack of relation between access measures and socioeconomic characteristics have interesting consequences for public policy. We explore this more formally in the next section.

## 3 Definition of accessibility

The analysis of spatial equity is concerned with comparing the locational distribution of facilities or services to the locational distribution of different socioeconomic groups. We approach the former by defining a measure of accessibility between residential locations (proxied by the centroids of census tracts) and the public service facilities in an urban area. Our sensitivity analysis focuses on how this accessibility is measured. Obviously, not every possible aspect related to the measurement of spatial equity could be considered. Our intent is to capture some of the main methodological variations that come into play by comparing two broad approaches to the measurement of access (and several different accessibility measures) as listed in table 1. To ensure comparability of our results with the bulk of the empirical literature, we consider the census tract as the unit of analysis and treat only univariate and bivariate characteristics.

In order to relate the spatial distribution of public service facilities and population groups to each other in a meaningful way, some definition of access between residential locations and the locations of facilities must be adopted. This is not unambiguous, because several alternative measures may be used. For example, accessibility may include the consideration of residential mobility, for example, the availability of public transport or automobile ownership (as demonstrated by Pacione, 1989), networks of interacting services and agglomeration economies (White, 1979), or the issue of multipurpose travel (Arentze et al, 1994a; 1994b). In our analysis, we ignore these complicating factors and use a simple distance metric. Although this is not without its limitations, it is nevertheless well established in accessibility analysis (see McLafferty, 1982). Distance, of course, can be computed in a variety of ways. In our empirical case study we use distance based on an actual street network, or 'network distance'. Specifically, distance is measured by means of a shortest path algorithm applied to the existing street network between the centroids of census tracts (as a proxy for residential location) and the coordinates of public service facilities (in our example, playgrounds, proxied by the centroid of the park in which they are located). This is generally considered to be a better approximation of actual travel time between two urban locations than, for example, a straightline distance measure (for example, Geertman and Ritsema Van Eck, 1995). Also, it avoids the debate on the appropriateness of Euclidean versus Manhattan metrics to approximate actual travel distance (for example, Rushton and Thill, 1989; Thill and Rushton, 1992; Von Hohenbalken and West, 1984).

We consider a total of four accessibility indices. Specifically, we compare the standard measure of access used in the political science literature (that is, number of services per ward, neighborhood, tract, etc) with three alternative accessibility indices that take into account distance, road network, and/or facility characteristics (adapted from Hodgart, 1978). This is summarized in table 1, where the standard approach to facility access is highlighted.

We refer to the first index as a *container* index in table 1. The use of the census tract as the unit of analysis is convenient, as census variables are typically used as explanatory factors to capture the socioeconomic characteristics of the residents. However, in this approach a count of facilities (or measure of services provided) by any geographic unit—ward, planning, district, etc—would be equally valid. Formally, a container index $Z_i^{\mathrm{C}}$ for location (tract) $i$ may be expressed as

$$Z_i^{\mathrm{C}} = \sum_j S_j, \qquad \forall j \in I,$$

**Table 1.** Spatial equity components: variations in measurement.

| Measurement approach | |
|---|---|
| **'Container approach'** | **Number of facilities or services contained within a given unit (for example, census tract or political precinct)** |
| Access characterized by the relationship between origin and destination | Accessibility measures:<br>gravity potential<br>average travel cost<br>minimum distance |

where the number or aggregate size, $S_j$, is summed for those facilities located within the boundaries $I$ of $i$.

The second index is the well-known *gravity potential* expression, in which facilities are weighted by their size and adjusted for the 'friction of distance'. For each location (tract), the computed accessibility score characterizes the potential supply of services by every facility in the urban area; hence the higher the score, the greater the available supply. This measure has seen numerous geographic applications (examples in the urban service literature include Knox, 1978; Pacione, 1989). Formally, it is expressed as

$$Z_i^{\mathrm{G}} = \sum_j \frac{S_j}{d_{ij}^{\alpha}},$$

where, as before $S_j$ reflects the number of facilities or their size, but now at each facility location $j$; $d_{ij}^{\alpha}$ is a distance decay factor, with distance $d_{ij}$ between tract $i$ and facility $j$, and friction parameter $\alpha$.

There are two methodological problems associated with the use of the gravity potential measure. One is the choice of the magnitude of the friction parameter $\alpha$. Whereas the best practice is actually to calibrate this parameter for a particular application (for example, based on specific travel behavior), in the current study the parameter is set to a value of 2. Admittedly, this is arbitrary, but it is also common practice and it constitutes a valid use of the index for comparison purposes. Also, as the linkage between the friction parameter and specific travel behavior is not without its detractors (for example, Arentze et al, 1994a; Breheney, 1978), we avoid this debate as it is not central to the purposes of our analysis. The second methological problem is the issue of self-potential, or the determination of the potential when $d_{ij} = 0$ (for example, Bröcker, 1989; Frost and Spence, 1995; Geertman and Ritsema Van Eck, 1995). Although several adjustments have been suggested to deal with this instance, they are unnecessary in our application because no facility location coincides with the centroid of a census tract or block.

The third index is a measure of *travel cost*, adapted from locational optimization models. It is simply a measure of the total or average distance between each origin (census tract) and all destinations (public facilities). Whether total or average is chosen is a matter of taste, as long as the number of destinations is the same for each origin. In our example, this is obviously the case. One advantage of using average travel cost is that the resulting value is expressed in simple distance units. In contrast to the gravity and container measures, a lower index value reflects better accessibility, because the goal is to minimize the average cost of travel. Formally, this index is expressed as

$$Z_i^{\mathrm{T}} = \sum_j d_{ij}, \qquad \text{or} \qquad \bar{Z}_i^{\mathrm{T}} = \sum_j \frac{d_{ij}}{N},$$

where, as before $d_{ij}$ is the distance between a residential location $i$ and facility $j$, and $N$ is the total number of facilities.

The final measure is termed *minimum distance*, and is sometimes referred to as an *equity* model in locational analysis (Hodgart, 1978). The index reflects the distance from a residential location (tract) to the nearest facility:

$$Z_i^{\mathrm{E}} = \min|d_{ij}|,$$

in the same notation as before. As with the travel cost index, a lower value of the equity index reflects better access.

Each accessibility measure implies a different treatment of spatial externalities associated with public service facilities. Both the container index and the minimum distance measure mostly ignore these externalities, but in a slightly different manner.

The container index includes all facilities within a census tract so that, when there are multiple facility locations within the tract, their spatial externalities are included in a limited manner (in the sense that multiple facilities are available to the residents of the tract, but not to residents outside the tract). On the other hand, the minimum distance index never includes more than one facility, though that facility is not necessarily within the same tract. For example, when a tract does not contain a facility, the container index will be zero, whereas the minimum distance measure will give the distance to the nearest facility (in another tract). When there are multiple facilities in a tract, the container measure will include them all, whereas the minimum distance index will count only the distance to the facility closest to the tract centroid. Both the gravity potential and the travel cost measure capture the spatial externalities of all the facilities in the urban area, but with a steeper distance decay for the gravity potential.

## 4 Empirical comparison

To illuminate the sensitivity of the analysis of spatial equity to the use of different geographic measures of access, we utilize a case study of the location of playgrounds in Tulsa. Tulsa was selected on the basis of data availability, and also because it represents a growing mid-sized city with a diverse economy and population. In 1990 Tulsa's population was just over 500 000, a 25% increase over the 1970 population of roughly 400 000. Although Tulsa's economy and population boomed during the 1960s and 1970s, its growth slowed significantly following the oil bust of 1983–84. Since then, growth in the city can be characterized as moderate. The current location pattern of parks and playgrounds in Tulsa follows from development decisions that have occurred for over one hundred years, either as a result of formal park plans, public demand, or space availability. Recent park and playground development in the urbanized area of Tulsa has been fairly restrained, because of the slowing down of the region's economy.(2)

Playgrounds were selected for analysis for two reasons. First, the public provision of playgrounds represents a multidimensional equity issue, in the sense that besides the traditional factors of income and race, age and gender issues are highly relevant as well. In particular, for our bivariate analysis, this suggests an obvious target constituency of children, proxied by population under 18 years of age. Second, our choice has empirical relevance as well, because the spatial equity aspects of park and playground distribution have hardly been studied (Wicks and Backman, 1994).

The data on the number and location of playgrounds in Tulsa, Oklahoma were obtained from the Tulsa Metropolitan Area Planning Commission's *Park, Recreation and Open Space Plan 2005* (1989). We located 88 playgrounds on the basis of this report. The boundary files for census tracts and for the street network of Tulsa were extracted from the census Tiger files and implemented as layers in a GIS by means of GisPlus software (Caliper, 1992). The access measures were computed with SpaceStat Version 1.80 (Anselin, 1995b), using as distance inputs the shortest path distances over the actual street network between the centroids of each census tract and the centroids of the parks. The socioeconomic data by tract on the percentage nonwhite population, the percentage population under 18 years of age, and the median housing value were extracted from the 1990 census files. This resulted in a data set of 94 observations. All statistical analyses were carried out with SpaceStat software and the outcome maps were produced by means of the SpaceStat.apr interface with ArcView (Anselin and Bao, 1996; 1997).

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(2) Personal communication with a representative of INCOG, Tulsa's association of local governments, April 1995.

### 4.1 Spatial pattern of the container index

We start our analysis with the traditional perspective taken in the literature by summarizing the overall distribution of the container index at the tract level. Table 2 is the point of departure, in which the distribution of the 88 playgrounds by census tract is listed. Clearly, this is highly skewed and characterized by a large number of tracts without playgrounds (44 out of 94). Instead of a normal distribution, this suggests a $\chi^2$ or Poisson as the most appropriate approximation. A test for normality strongly confirms this [rejecting normality at $p < 0.00001$ (see Anselin, 1992, chapter 20, for a description of the technical details of the test)]. On the other hand, a square root transformation of the container index yields a variate that may reasonably be approximated by a normal distribution (the normality test is rejected at $p < 0.08$). Using 1.5 times the interquartile range (IQR) as a criterion to determine outliers (outliers are thus defined as values larger than the third quartile plus 1.5 times IQR), all observations with three or more playgrounds would be considered as such (there are 6 such outliers). By contrast, for the square root transformed variate, only one observation remains as an outlier (a single tract with 9 playgrounds).

**Table 2.** Playground units per census tract.

| Playground units | Census tracts | Playground units | Census tracts |
|---|---|---|---|
| 0 | 44 | 4 | 1 |
| 1 | 27 | 5 | 1 |
| 2 | 17 | 9 | 1 |
| 3 | 3 | | |

A visual representation of the spatial distribution of the 88 playgrounds is given in figure 1, a map of the number of playgrounds in each tract. Two tracts stand out, one with 9 playgrounds, in the southwest corner of the city, and one with 5, to the north and east of downtown Tulsa. The many tracts with zero values seem predominantly concentrated in the south and east part of the city, and the nonzero ones to the north and west, suggesting a pattern of spatial clustering. However, a more rigorous analysis of

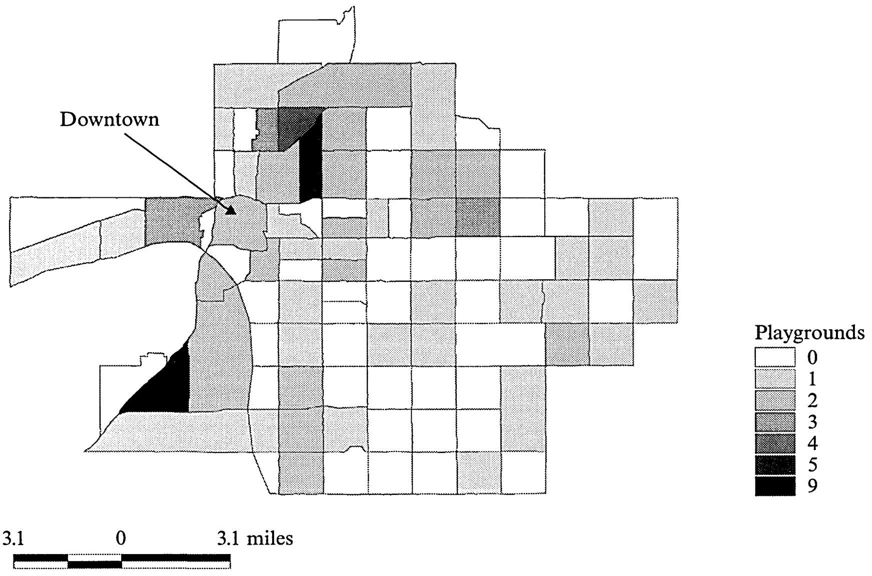


**Figure 1.** Tulsa playgrounds by census tract.

spatial autocorrelation does not corroborate this suggestion. As the original container index is clearly integer valued, we did not consider it in the usual fashion. Instead, we applied Moran's $I$ statistic to the square root transformed container index, using a first-order contiguity weights matrix (in row-standardized form) as well as two row-standardized distance-based contiguity matrices, one with a distance cutoff of 1.5 miles and one of 2.0 miles (details on Moran's $I$ are given in Cliff and Ord, 1981; see also Anselin, 1992, chapter 22). None of the statistics was significant, yielding standardized $z$-scores of 0.39, 0.30, and 0.53, respectively (with the randomization approximation). This strong indication of spatial randomness was confirmed by a series of join-count statistics for a binary transformation of the container index, using the same spatial weights (for technical details see Anselin, 1995b, pages 37–38). Empirical pseudo-significance levels for a BB join-count statistic (count of neighboring tracts that both have playgrounds), based on 999 permutations yielded 0.35, 0.56 and 0.39, respectively.

As we argued earlier, a spatially random pattern in the container index, as found for playgrounds in Tulsa, will tend to bias the results of bivariate and multivariate analyses towards unpatterned inequality. We next consider the extent to which this is the case for the geographic access measures.

### 4.2 Global association in access measures

In figures 2 and 3 (see over), we visualize the spatial distribution of the geographic access measures for tracts by means of a so-called box map. A box map is simply a choropleth quartile map augmented with the identification of outliers, that is, those observations in the lowest and highest quartile that fall outside the fences (1.5 times IQR higher than the third quartile or lower than the first quartile). As such, a box map forms the counterpart in exploratory spatial data analysis (Anselin, 1994; 1997) of the familiar box-plot exploratory data analysis tool (Cleveland, 1993, pages 25–27).

The box maps reveal some interesting and distinctive patterns compared with the map of the container index in figure 1. The outliers are shown by the darkest shading in the figures. The gravity potential measure [figure 2(a)] shows considerable variance and has even more outliers than the container index (9 instead of 6). On the other hand, the travel measure has no outliers [figure 2(b)] and the distance index only one (figure 3). Note that the darkest shadings in figures 2(b) and 3 represent those tracts with the least access, and the outlier in figure 3 is indeed a tract without playgrounds, surrounded by four other tracts without playgrounds, and neighboring a large tract with only one. Interestingly, then, neither travel nor minimum distance show outliers on the low end (that is, with high accessibility).

The box map for the gravity potential shows a concentration of high values (and high outliers) in a roughly square area centered on downtown Tulsa (to the west and north from the center of the map). The map shows a smoothing of the access measures compared with figure 1, which is to be expected, because the gravity measure takes into account all playgrounds in the urban area. This leads to some interesting differences, where several tracts without playgrounds score in the upper quartile on the gravity measure, some even as outliers. The tract with 9 playgrounds is also an outlier for the gravity potential, but the one with 5 playgrounds is not. Figure 2(a) also suggests a clustering of low access values roughly below an imaginary diagonal line going from the lower left to the upper right corner.

The box map for travel cost shows the most regular pattern, suggesting three concentric rings around the center of the map, where the highest access is found. This is not surprising, because the spatial randomness of playground locations would imply that, on average, the central locations would have the best access. This is clearly borne out by figure 2(b).

Figure 2. Box map for (a) gravity index, (b) travel cost index.

The box map for minimum distance in figure 3 shows some degree of similarity to the container index and the gravity potential, especially in the area of the downtown and immediate surroundings. Most tracts in this area score in the lowest quartile, but the tract with 5 playgrounds does not. Below the imaginary diagonal mentioned for gravity, the pattern for minimum distance is much less regular, showing tracts in all four quartiles (including the outlier). Interestingly, several tracts with 2 playgrounds are in the worst (highest) quartile for minimum distance.

The different patterns between the access measures suggested by the maps are confirmed by simple Pearson product moment correlation coefficients. Between the square root transformed container index and the three geographic measures, these are

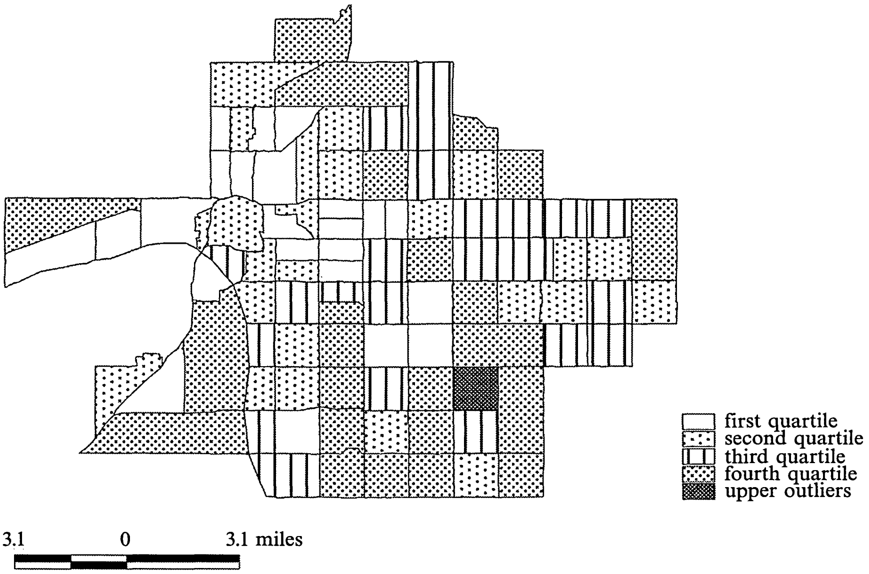


**Figure 3.** Box map for minimum distance.

0.260 for gravity, −0.067 for travel, and −0.488 for minimum distance. As expected, minimum distance is closest to the container index and travel the most dissimilar. However, when the log of the gravity measure is considered, to smooth out the extreme variance, the correlation coefficient becomes 0.449, much closer to the minimum distance measure in absolute value. This is confirmed by a correlation coefficient of −0.765 between ln(gravity) and minimum distance, much higher than between any of the untransformed geographic access measures (the coefficients are: −0.234 between gravity and travel; −0.402 between gravity and minimum distance; and 0.395 between travel and minimum distance). Clearly, the log transform smooths out the extreme variance for the gravity measure, which, because of the steeper distance decay relative to travel, makes it similar to the nearest neighbor criterion.

In terms of global spatial association, as indicated by Moran's *I* statistic, the gravity measure is distinct from the other two. In table 3 the statistics and their associated *z*-values (with the randomization approach) are listed for the same three weights matrices as used before. No significant spatial autocorrelation is found for the gravity measure, whereas travel and distance show strong and positive spatial autocorrelation, travel extremely so. This is to be expected, given the concentric pattern illustrated in figure 2(b). However, the apparent spatial randomness of the gravity measure is surprising and can possibly be attributed to the value of the distance decay parameter (yielding a more local weighting and thus becoming closer to the spatial randomness of the

**Table 3.** Moran's *I* test for global association ($N = 88$).

| Access | Contiguity | | Distance, 1.5 miles | | Distance, 2 miles | |
|---|---|---|---|---|---|---|
| | *I* | *z* | *I* | *z* | *I* | *z* |
| Gravity | 0.035 | 1.04 | 0.047 | 1.56 | 0.040 | 1.68 |
| ln(gravity) | 0.475 | 6.82 | 0.497 | 8.47 | 0.475 | 9.88 |
| Travel | 0.834 | 11.6 | 0.829 | 13.7 | 0.803 | 16.2 |
| Distance | 0.246 | 3.55 | 0.228 | 3.92 | 0.225 | 4.72 |

pattern of playgrounds, rather than the global weighting reflected in the travel measure). Again, when the log transform of the gravity measure is taken, its pattern of association changes, indicating highly significant positive spatial autocorrelation.

### 4.3 Local association in access measures

Global measures of spatial association often hide interesting local patterns in the data, in the form of small clusters or outliers. The recently suggested class of local indicators of spatial association, or LISA statistics (Anselin, 1995a; see also Getis and Ord, 1992; Ord and Getis, 1995), provides an alternative perspective by focusing on patterns surrounding individual observations. According to the definition of Anselin (1995a),

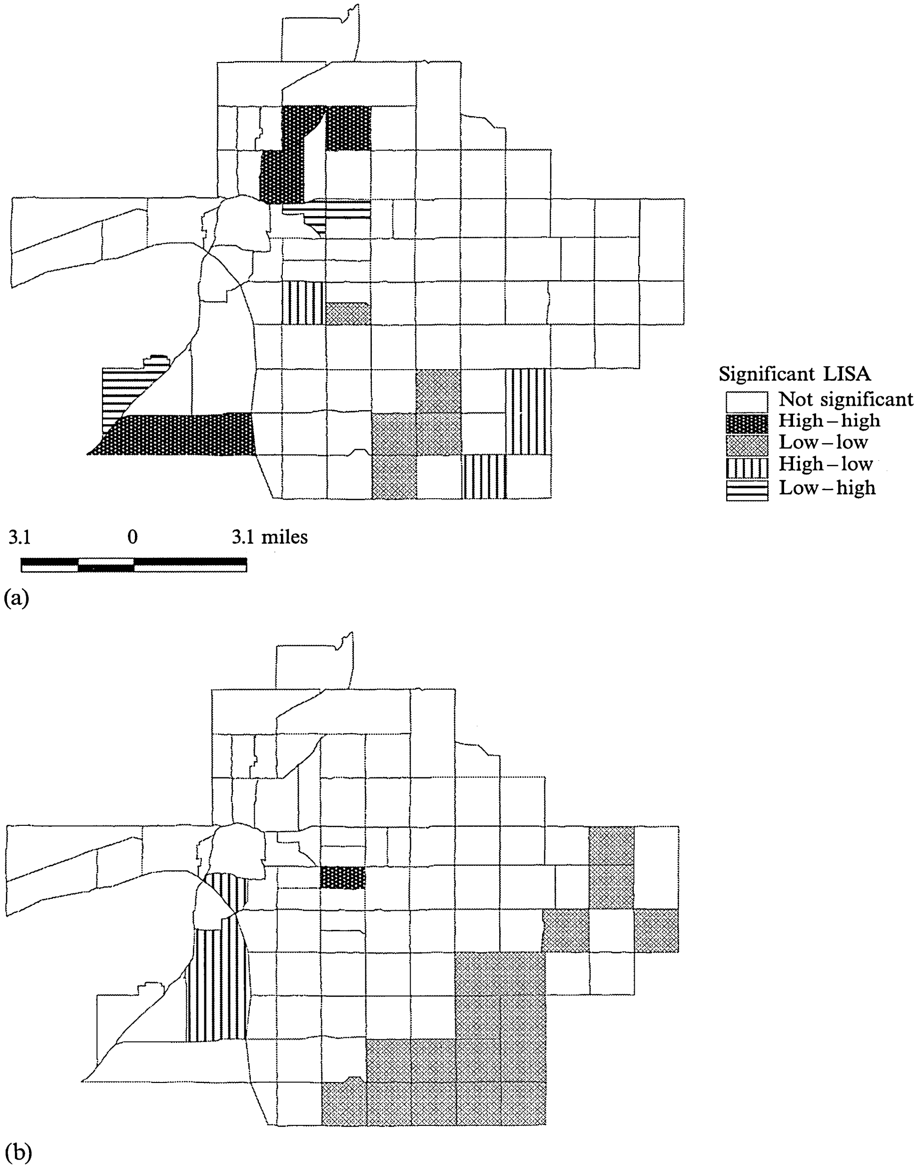
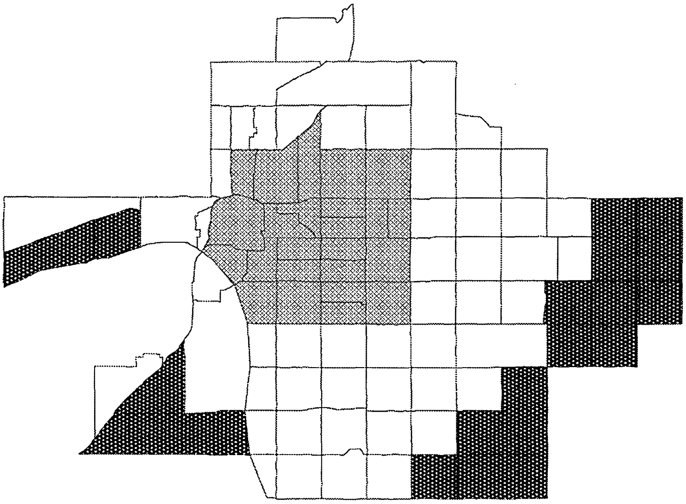


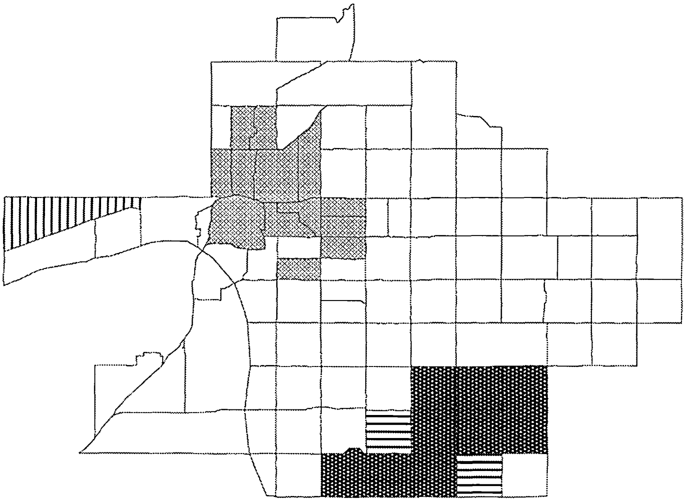
**Figure 4.** LISA (local indicators of spatial association) map for (a) container index, (b) gravity index, (c) travel cost index, (d), minimum distance.

a LISA is an indicator that achieves two objectives: (a) it allows for the detection of significant patterns of local spatial association (that is, association around an individual location, such as hot spots and spatial outliers); and (b) it can be used as a diagnostics for stability of a global statistics (that is, to assess the extent to which the global pattern of associations is reflected uniformly throughout the data set). Several familiar global spatial autocorrelation statistics, such as Moran's *I*, Geary's *c*, and the gamma statistics have local counterparts (for technical details, see Anselin, 1995a; 1996). Here, we apply a local version of the Moran statistic to the container index and the three geographic access measures. Formally, the local Moran statistics $I_i$ for observation *i* is expressed as

$$I_i = \frac{z_i}{m_2} \sum_j w_{ij} z_j ,$$



(c)



(d)

**Figure 4** (continued).

with

$$m_2 = \sum_i z_i^2 ,$$

and where the variables $z_i$ and $z_j$ are expressed in deviations from the mean, and the summation over $j$ is such that only neighboring values are included (by using the spatial weights $w_{ij}$). As shown in detail in Anselin (1995a), inference about the local Moran statistics can be based on a conditional permutation strategy. Note that this statistic is very similar to Getis and Ord's (1992) $G_i^*$ statistic, though the interpretation is different. The particular form of the local Moran allows it to be easily associated with the decomposition of spatial association in a Moran scatterplot (Anselin, 1996). This decomposition provides information on the relative importance of four types of spatial association: high values (above the mean) associated with high neighboring values; low values (below the mean) associated with low neighboring values; high values associated with low neighboring values; and low values associated with high neighboring values. The first two reflect positive spatial association, or local spatial clustering of similar (high or low) values. In contrast, the second two are examples of spatial outliers, in the sense that they point to locations that are different from their neighbors. The mapping of locations with significant LISA statistics, together with an indication of the type of local spatial association as given by the quadrants in the Moran scatterplot, provides the basis for a substantive interpretation of spatial clusters or spatial outliers (for examples, Anselin and Bao, 1997; Barkley et al, 1995).

Census tracts with significant local Moran statistics are highlighted in figure 4 for the corresponding access measures. Significance for LISA statistics should be interpreted with caution, because of problems of multiple comparisons and inherent heterogeneity (for a technical discussion, see Anselin, 1995a; Ord and Getis, 1995). As our purposes are primarily exploratory and illustrative, we selected a conventional 0.05 as a cutoff value. This may tend to exaggerate the notion of local spatial clusters and therefore bias our analysis towards finding spatial overlap between the indices. This is acceptable, because our main argument is that there is no such overlap. Four shadings are used, matching the four quadrants of the Moran scatterplot (darkest is high – high association, next is low – low, followed by high – low and low – high). Note that, for figures 4(c) and (d), high values of the index correspond with poor accessibility.

Although neither the container index (more precisely, its square root transformation) nor the gravity measure exhibited global spatial autocorrelation, both show 18 tracts with significant local association (for gravity potential, 8 of these are highly significant at $p < 0.01$; for the container index, 5 tracts fall into that category). Importantly, for the gravity measure, the LISA map [figure 4(b)] highlights the existence of a strong local cluster of low-access tracts in the southeastern part of the city. Only one tract (to the south and east of downtown Tulsa) is significant for a high value (at $p < 0.05$). Two outliers (high values associated with low neighboring values or vice versa) for gravity are for low access tracts on the west – south side of the city. The pattern for the container index [figure 4(a)] is much less structured, with more than half of the significant local Morans pertaining to spatial outliers. Three high-access tracts are co-located around the tract with 5 playgrounds (which itself does not show a significant local Moran) and one adjoining the tract with 9 playgrounds. Four low-access tracts are located in the southern part of the city (but only three of them match the ones found for gravity).

The pattern for the travel cost measure [figure 4(c)] is the most regular, mimicking the concentric rings found in figure 2(b). A strong cluster of high-access tracts is located around the center of the map, and low-access clusters are found at the perimeter. No spatial outliers are identified as significant. The minimum distance measure [figure 4(d)] shows aspects of the local patterns in both the gravity and travel measures, reflecting a strong cluster of high-access tracts to the north and east of downtown Tulsa and a cluster of low-access tracts in the southeastern corner. Three tracts are identified as spatial outliers.

Overall, the results for the local Moran statistics confirm our main argument. There is very little overlap between the local spatial clusters and spatial outliers indicated for each of the four access measures. Not a single significant tract is found that is common to all four indices, and very few are shared by three. In one instance, there is even a conflict, where a tract is significant as a high-access value according to the travel measure and a low value according to the container index. This discrepancy is greatest with respect to clusters of high-access tracts. On the low end, all indices point to a general problem cluster in the southeastern corner, although there is no exact match in terms of which tracts belong to the cluster.

In other words, the different ways in which spatial externalities are formally incorporated into the access indices are reflected in clearly distinct spatial patterns. It is therefore not a straightforward matter to reach consensus on the characterization of spatial equity in the provision of playgrounds in the case study. We next turn to the extent to which this correlates with the spatial patterns exhibited by some relevant socioeconomic variables.

### 4.4 Spatial patterns of target constituencies

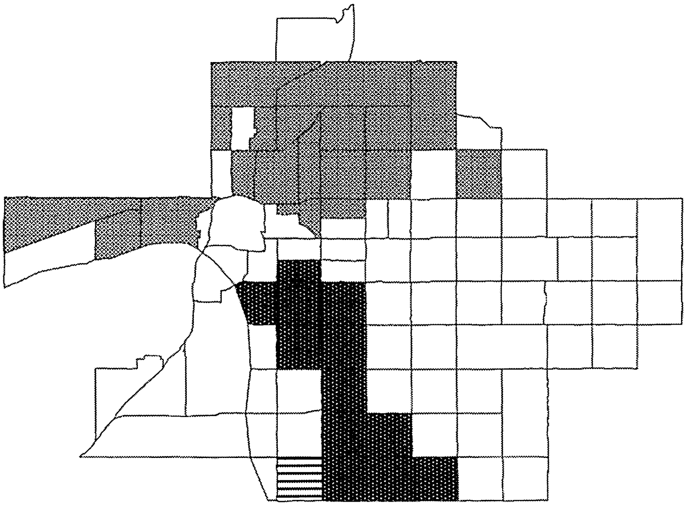
In figure 5 (see over) we map the tracts with significant local Moran statistics for the percentage population under 18 years of age, percentage nonwhite population (as a proxy for race), and median housing value (as a proxy for income) in a highly preliminary and exploratory investigation of the spatial association between access and socioeconomic characteristics. By linking access to target populations directly, the exploration of spatial *inequality* takes on added meaning and becomes an exploration of spatial *inequity.*

Both housing value [figure 5(c)] and nonwhite population [figure 5(b)] show two distinct spatial clusters, one to the northeast, associated with low housing values and high percentage nonwhite, and one south of downtown, associated with the opposite. Both patterns are highly homogeneous (only one outlier for housing values and none for nonwhite) and conform to the conventional wisdom about spatial stratification by income and race in US cities. These two patterns only partially match the spatial clusters for tracts with young populations [figure 5(a)] precluding any ready association of need in a narrow sense (that is, demand for playgrounds by children) with race and income. Of the 8 significant high-value tracts for population under 18, only two belong to the nonwhite cluster and three to the low-income one.

There seem to be three spatial concentrations of tracts with a high proportion of children: one to the north and east of downtown, one in the eastern end of the city and one in the southwestern corner. The two tracts with the highest number of playgrounds (9 and 5 in figure 1) belong to these clusters, but other tracts with two or more playgrounds do not. There is only a partial match with the clusters of high-access tracts identified in figure 4, with travel cost providing the closest fit. The minimum distance measure matches two of the three northern high-child tracts, but misses the outlying areas. The travel cost and to a lesser extent the gravity index identify the outlying areas as low-access tracts, suggesting a form of spatial mismatch. Interestingly, gravity and minimum distance indices both also indicate a high access for a tract near the center of the city with a significant local Moran for low percentage under 18, suggesting another form of mismatch (high provision, but no need).

**Figure 5.** LISA (local indicators of spatial association) map for (a) percentage of population under 18, (b) percentage nonwhite population, (c) median housing value.

Overall, the results indicate that only a portion of the distributive characteristics of any of the access measures—the container index as well as the other three access measures—correlate with the spatial distribution of selected social characteristics. It may be tempting at this point to characterize the distribution of playgrounds in Tulsa as 'unpatterned inequality', but such a conclusion would mask the complexity of the spatial patterns of access and their correlation with socioeconomic indicators (as illustrated by the maps). Any more substantive interpretation would have to go beyond the exploration carried out in this paper and explicitly consider the multivariate interaction between explanatory variables and the potential endogeneity of variables such as housing value.



(c)

**Figure 5** (continued).

## 5 Conclusion

Studies of public service delivery rely heavily on the notion of access to services and facilities, although this is not always dealt with explicitly. Often, the measure of access used is one-dimensional, where the presence or absence of a given service or facility is measured by virtue of whether or not it is 'contained' within a given defined boundary. In fact, access to services is a multidimensional issue. The exploratory spatial data analysis presented above shows that the issue of access to public facilities is complex. In our case study of playgrounds, we illustrated how the characterization of access in which blocks with 'high access' and 'low access' are differentiated can vary significantly depending on how access is defined.

The main point of the paper is that the choice of access measure has to be considered very carefully when trying to analyze the spatial equity of a given resource distribution. Depending on research goals, the primary issue to be determined is: what characterization of access is most suitable? Largely, this boils down to a decision about how distance between the use and the facility should be characterized, and what assumptions about travel behavior are most appropriate. These assumptions will vary depending on the type of service involved. For example, in the case of playgrounds, a minimum distance approach may be most warranted because the service area of playgrounds tends to be highly localized. Spatial externalities are thus circumscribed, in the sense that the degree to which playgrounds in one location serve the needs of residents in other locations is fairly limited.

In the gravity, travel cost, and minimum distance access measures used in this paper, the value of the facility to the user is expressed as a function of distance. Beyond this, there are marked differences between the three measures. The gravity measure emphasizes the effect of distance as a deterrent, and assumes that, although consumers can travel anywhere within the city to visit any facility, they are less likely to travel to further locations. Alternatively, the travel cost measure characterizes the distribution of facilities as an average of all distances. Thus the consumer can travel to any facility regardless of its distance, and therefore the resources of a city are viewed as a complete package of public goods. If the assumption is made that consumers are likely to patronize the facility closest to them (as is the case with playgrounds), then the research goal would be to assess how to minimize the inequality of nearest distance between origin and destination, and therefore a minimum distance measure may be more applicable.

Alternatively, if the researcher is certain that the sphere of influence of a given service is confined to a specific geographic boundary, then the traditional unidimensional approach to accessibility—counts by unit—may still be appropriate. However, we hope to have shown conclusively that the mechanical application of such an approach can lead to a fairly narrow interpretation of access and therefore suggest potentially false conclusions about spatial equity.

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