A Distance-Decay Based Interaction Index to Measure Residential Segregation
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Source: *Area*, Vol. 15, No. 3 (1983), pp. 211-217
Published by: The Royal Geographical Society (with the Institute of British Geographers)
Stable URL: https://www.jstor.org/stable/20001935

area *1983 Volume 15 Number 3*

A distance-decay based interaction index to measure residential segregation

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Summary. *A new interaction index to measure segregation is proposed. PC*, an extension of P*, employs rates of distance-decay to assess the probability of inter- and intra-group interaction on a city-wide, rather than intra-tract, basis. Methods of estimating the probability of two individuals meeting are discussed. It is noted that PC* may be standardised in the same way as P* to produce two symmetrical measures that vary between 0 and 1·0. The relative advantages of spatial and aspatial indices are discussed.*

Substantial advances have been made in understanding the relationship between social distance and spatial distance in the fifty or so years since Park (1926, 20) first noted that ' social relations are so frequently and so inevitably correlated with spatial relations '. Most of these analyses have employed the index of dissimilarity (D), a measure of the unevenness of two residential distributions, as a surrogate measure of the spatial distance between population groups. D has proved a serviceable index, but the debate over the measurement of residential segregation has been rejoined in recent years. There has been both renewed debate over whether D is independent of variables which may be studied as correlates of segregation (for example, Winship, 1977; Johnston, 1981; Morgan, 1980, 1982), and two noteworthy new developments. First, Lieberson (1980, 1981) has demonstrated the value of using interaction indices (P^*), which are behaviourally more significant, and, to complement, Robinson (1980) has provided a British case-study. Secondly, Jakubs (1981) and Morgan (1983a) have proposed two distance-based segregation indices, which incorporate the degree of spatial concentration and the unevenness of two residential distributions in one measure. The present note follows on from these advances. It proposes a new interaction index, an extension of P^*, which takes account of residential patterns to assess the probability of inter- and intra-group interaction on a city-wide basis.

Interaction indices

The interaction index, an unstandardised measure of segregation, was first proposed by Bell (1954). Using Lieberson's (1980) notation, it may be defined in its most general form as:

$$_aP^*_b = \sum_i (a_i/\sum_i a_i)\ (b_i/t_i)$$

where $_aP^*_b$ = probability of a member of group A interacting with a member of group B,

a_i = number of group A in sub-area i,

b_i = number of group B in sub-area i,

and t_i = total population in sub-area i.

If the concern is with intra-group interaction, a_i replaces b_i in the equation. $_aP^*_b$ may be interpreted as an approximation of the probability that the next person a random individual from group A will meet *in the neighbourhood* is from group B. These measures are highly sensitive to population composition and, except where the two groups are the same size, the indices are asymmetrical; that is, the likelihood of, for example, a black meeting a white is not the same as that of a white meeting a black. Therefore, four P^* indices are usually necessary to describe fully the interaction between two groups: ${}_aP^*_a$, ${}_bP^*_b$, ${}_aP^*_b$, ${}_bP^*_a$.

Lieberson (1981) advances two major arguments in favour of their use. First, population composition is a critical factor in the effect of segregation. He cites the example of the effect of the composition of local neighbourhoods on the propensity of an immigrant group to learn the host society's language. He argues that the P^* index satisfactorily measures this composition. Second, there are times when the asymmetric quality of group interaction is important. Lieberson demonstrates this by showing that the sharp increase in segregation in northern cities in the early part of the twentieth century may be viewed as an outcome of whites trying to maintain the same level of isolation from blacks who were forming an increasing proportion of the total population.

The present author accepts Lieberson's reasoning and welcomes it as the first major attempt to break urban ecology out of the self-imposed strait-jacket of over-reliance on D. However, P^* indices only describe the probability of contact within a limited area. In reality, most individuals' contacts, although locally concentrated, extend throughout the urban area. Conceptually, the principle of P^* indices may easily be extended to take account of these city-wide contacts, as is demonstrated in the next section.

A more general approach to interaction indices

The likelihood of two individuals meeting outside the sphere of the workplace is inversely related to distance since, in addition to getting to know neighbours, people are likely to meet through local institutions, such as clubs, churches and schools. Furthermore, the cost of maintaining friendships once they have been made is less over a short distance. In contrast, the number of potential contacts tends to increase with distance. Most studies of distance decay employ concentric bands of constant width. If the population is evenly distributed, the number of potential contacts increases with distance since the area of zones expands in direct proportion to the radius of their inner boundary. The density of population varies in cities and their boundaries have an influence, but empirical analyses suggest that the number of opportunities increase

Table 1. Marriage distances in Christchurch, New Zealand, 1971

Distance (km)	Mean no. of brides available per groom	Marriages per 1,000 available brides	Probability of marriage
0·00 to 0·99	118	2·032	0·2398
1·00 to 1·99	304	0·736	0·2237
2·00 to 2·99	363	0·568	0·2062
3·00 to 3·99	295	0·597	0·1760
4·00 to 4·99	191	0·386	0·0736
5·00 to 5·99	88	0·558	0·0491
over 6·00	67	0·471	0·0316

Source: Morgan, 1981, Table 2.

quite sharply at least over short distances (for example, Catton and Smircich, 1964). The likelihood of contact between an individual in tract i and someone in zone j is, therefore, a function of two countervailing factors: the probability that an opportunity to meet will arise and the number of potential contacts. This is illustrated in Table 1 with data for the pre-marital residential propinquity of spouses in Christchurch, New Zealand (Morgan, 1981). The mean number of brides available per groom (col. 1), a measure of the number of potential contacts, increases up to a distance of three km, whereafter it begins to decline. In contrast, the marriage rate per 1,000 available brides (col. 2), which is a reflection of the probability of two individuals meeting, decreases over the first three km, rapidly at first but then at a diminishing rate. The probability that a groom will marry a bride from a given distance zone (col. 3), which is a combination of these two influences, decreases with increasing distance, but much more gently over short distances than the standardised marriage rate.

With this background, it is possible to specify the new interaction index (PC^*):

Let C_{ij} = estimated contact rates between tract i and zone j per 1,000 population in zone j,[1]

and let t_j = population of zone j.

Now $_aPC^*_b = \sum_i (a_i/\sum_i a_i) \; [\sum_j P_{ij} \; (b_j/t_j)]$,

where $P_{ij} = C_{ij} \, t_j / \sum_j (C_{ij} \, t_j)$

such that $\sum_j P_{ij} = 1 \cdot 0$

It may be interpreted as the probability that the next person a randomn individual from group A will meet *anywhere in the city* is from group B. The calculation comprises two parts. For illustrative purposes, suppose we wish to estimate the probability of a white interacting with a black. For each tract (i), the probability of a white resident interacting with a black if he or she met someone from zone j (b_j/t_j) is weighted by the probability of him or her meeting someone from zone $j(P_{ij})$. The weighted probability of inter-group contact for white residents of tract i is in turn weighted by the proportion of the white population living in it ($a_i/\sum a_i$). P^* will be larger than PC^* for intra-group contact but smaller for inter-group contact since a higher proportion of the members of other groups will be resident in an individual's contact field than in his immediate neighbourhood.

There is one more important difference between P^* and PC^*. P^* is founded on the notion that every person in a tract has an equal chance of meeting every other person. It, therefore, measures the probability of random interaction. Bell (1954) recognised that deviations from random interaction favour greater in-group contact, and suggested that $_aP^*_a$ should be interpreted as the ***minimum*** probable intra-tract contact amongst members of group A. By the same token, $_aP^*_b$ may be interpreted as the ***maximum*** likelihood that a member of group A will meet a member of group B. PC^* is hybrid in this respect. Although (b_j/t_j) measures the probability of random contact, C_{ij} is based on empirically observed levels of interaction and may be influenced by individuals maintaining more contacts with members of the same group. The distance-decay gradient of C_{ij} generally reflects levels of personal mobility, but it may be modified by the disposition of residential areas. If areas of similar social composition are close and dissimilar areas distant, C_{ij} is likely to be larger in the first zone and fall off more steeply with distance on account of greater in-group interaction than if there is either little residential segregation or a limited relationship between social distance and spatial distance.

Specifying the probability of contact

It remains to discuss the choice of a variable to measure interaction and how C_{ij} should be specified. In addition to data for marriage distances which have been discussed, three types of data have been employed for studies of spatial interaction: data for migration (Stouffer, 1940), for telephone calls (Hagerstrand, 1965), and for face-to-face contacts (Marble and Nystuen, 1962). Migration is not considered a good surrogate for social contacts and data for telephone calls is generally not available for small sub-areas in the city. Data for face-to-face contacts are only available from ad hoc surveys, with the result it can only be obtained for specific places at particular times. Furthermore, it frequently includes trips to shops in addition to social trips to friends and relatives. Marriage distances are therefore considered to be an adequate surrogate measure for interaction rates.[2] Although only a small proportion of contacts will lead to marriage, Shannon and Nystuen (1976, 27) found 'marriage distance . . . to be a most valid substitute for data on the location of social contacts' in the Detroit SMSA. Current marriage licences, which detail the addresses of the spouses, are generally available for inspection. Furthermore, old marriage licences can be studied in archives, which facilitates historical analysis.

C_{ij} may be specified by two methods: first, on the basis of observed interaction rates; second, from 'best-fit' functions. Both methods have drawbacks. Observed interaction rates are subject to sample error. Distance-decay functions smooth out the irregularities that may be encountered with the first method, but the choice of the optimum function is difficult since there is no theoretical basis for choosing between models. The Pareto model, log-normal model, exponential model and square-root exponential model have all been experimented with for marriage data (Morrill and Pitts, 1967; Taylor, 1971). Other analyses have specified the optimal gradient of the model from a linear regression analysis in terms of least squares criteria (Ikle, 1956). If the distance transformation and slope gradient are empirically defined, there are an infinite number of possible models. Taylor (1971) has suggested an algorithm for achieving an optimal solution based on minimising the standard error of prediction. His work lends support to the view that a 'single-log'[3] model of the following form provides the optimal solution for modern marriage distances:

$$\log C_{ij} = a - b\, d_{ij}^{\,m}$$

where d_{ij} = the distance from tract i to zone j,

$m \leq 0 \cdot 5$,

and a and b are constants.

In the author's view, provided the sample size is sufficient to iron out marked irregularities, the empirically observed rates may be satisfactorily employed in one-off studies of individual cities. However, it will be a time-consuming task to analyse marriage distances prior to calculating PC^*. In the medium-term, the aim must be, on the basis of samples of urban areas, to specify distance-decay models which adequately describe the effect of distance on the intensity of interaction for census years.

Two standardised indices

P^* indices were standardised by Bell (1954) to produce two indices that are symmetrical and vary between 0 and $1 \cdot 0$—the revised index of isolation (I_1) and revised group segregation ratio (I_2). They may be defined as follows;

$$I_1 = ({}_aP^*_a - A)/(1-A) = ({}_bP^*_b - B)/(1-B) = 1\cdot0 - I_2,$$
$$I_2 = {}_aP^*_b/B = {}_bP^*_a/A = 1\cdot0 - I_1$$

where A = proportion of total population in group A,
and B = proportion of total population in group B.

Since $I_1 + I_2 = 1\cdot0$, I_2 which expresses the probability of inter-group contact as a proportion of the likelihood of such contact if there were no segregation will be employed in subsequent discussion. It may simply be modified to take account of city-wide contacts by substituting PC^* for P^*. That is,

$$IC_2 = {}_aPC^*_b/B = {}_bPC^*_a/A = 1\cdot0 - IC_1$$

D and I_2 have been viewed as comparable measures of the unevenness of residential distributions (for example, Taeuber and Taeuber, 1965), with D being favoured on account of its perceived independence of proportion black. As a consequence, I_2 has rarely been used. In the author's view, this is unfortunate since it cannot be algebraically specified in terms of D and as a standardised measure of the homogeneity of sub-areas it offers a different perspective on segregation—one that is arguably more behaviourally significant. Their spatial equivalents, the distance-based index (*DBI*; Jakubs, 1980) and the modified distance-based index (*MDBI*; Morgan, 1983a) in the case of D and IC_2, underline their structural differences. Once the misconception that it is possible to measure segregation independently of population composition is laid to rest (Morgan, 1983b), standardised interaction indices may assume their rightful place as useful measures of segregation. Segregation is essentially a symmetrical concept (Taeuber and Taeuber, 1965). Whereas P^* and PC^* indices may prove useful as independent variables measuring the effects of segregation, I_2 and IC_2 may be considered the alternatives to D and *MDBI* when segregation is the dependent variable since the same processes that lead to blacks being segregated from whites lead to whites being segregated from blacks.

Discussion

It is not suggested that city-wide interaction indices should replace P^* and I_2; the two sets of indices should be considered complementary. In some instances, the probability of contact in the local neighbourhood is obviously the more pertinent measure. For example, P^* would be a far better indicator of the problems school boards in the United States face in designing school desegregation programmes, and would also probably be a better measure for understanding the effect of segregation on immigrants' language behaviour. PC^* may be more appropriate to assess the extent to which segregation in northern cities in America in the early part of the twentieth century may be viewed as an outcome of whites trying to maintain the same level of isolation from the growing number of blacks.

However, a substantial volume of empirical work must be completed before the relative merits of city-wide and local interaction indices can be assessed. Much of Park's (1926) writing on the relationship between spatial distance and social distance emphasised the importance of proximal contacts in the local neighbourhood. Aspatial measures such as D and P^* although tract-based are presumably good measures of social mix in the wider local community; certainly the residential dissimilarity between two groups is a good predictor of their rates of inter-marriage (for example, Peach, 1980). However, P^* will probably overestimate the overall level of intra-group contact in the city as a whole.

In contrast, PC^* will probably underestimate it. While there is abundant evidence that contact rates decline with distance, the residential areas in a city are seldom disposed in a way that is consistent with a close relationship between social distance and spatial distance (Morgan, 1981). Unfortunately, there have been few analyses of how residential patterns in the city influence social networks, and to what extent they distort the simple distance-decay model. Boal (1969, 1971) found a higher rate of contact between distant but 'like' areas in Belfast than between adjacent, socially dissimilar areas. In contrast, Klatsky (1974) in an American study of visiting patterns with relatives found that distance was the principal predictor of contact. Once distance was controlled, the effects of religion and ethnicity were minor. It appears fair to conclude that residential patterns influence social interaction as a consequence of the friction of distance, but that at any given distance, there will be greater contact between 'like' areas than 'unlike' (Morgan, 1981). However, an assessment of the relative importance of these two effects must await the results of further analyses.

Despite his emphasis on contacts within the local community, Park (1926) entitled his seminal paper 'The urban community as a spatial pattern and moral order'. For the first time, the urban ecologist has a range of indices at his disposal—*DBI, MDBI, PC*, IC_2*—which incorporate spatial pattern. It is the author's belief that they will yield important new insights into the relationship between the spatial structure and social structure of cities.

Notes

1. It must be stressed that the estimate of C_{ij} is based on the whole population, not on interaction between the two groups under study.
2. Partners who are co-habiting are generally excluded from consideration.
3. So-called because only C_{ij} is logged.

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Mile-high geographers

Some personal observations on the Annual Conference of the Association of American Geographers, Denver, Colorado, 24–27 April 1983

While there certainly continues to be some concern about the future of American geography (see also Haigh and Freeman, 1982, *Area,* 14, 185), participants at AAG Meetings seem able to forget this problem for a few days for the sake of enjoying the annual gathering of the clans. Two departments have already been closed, others are subject to severe budget constraints, and others are under review, but there was no obvious evidence of despondency at the meeting. There is still a healthy transfer market for academic staff between departments, and assistant professors are still being hired for new posts. Large numbers of graduate students were very much in evidence in all the conference proceedings; many were there to explore, or to be interviewed for, job opportunities offered by both private and public sector employers. The Convention Placement Service (CoPS) continues to be much in demand and at least offers the prospect of employment, albeit more limited than usual, for graduate students and others in a way which would undoubtedly be envied by their colleagues here in Britain.

Despite all, guarded optimism seemed to prevail amongst those present; a mood perhaps engendered by the setting for the meeting. Optimism has certainly provided the impetus for the phenomenal growth of Denver since the mid-1960s, and the mile-high city, as it likes to promote itself, was an interesting venue for the 79th AAG Meeting which attracted a diverse group of mainly North American geographers with a small representation from Europe and the Antipodes. Apart from requiring the preparation of a special bill from the Colorado Legislature which would allow the Local Arrangements Committee to receive the State Governor's approval to put up a 'Welcome Geographers' banner at the airport, the meeting seemed to attract little attention from local interests. This was a pity because many of the sessions at the meeting covered themes with potentially substantial local relevance: energy, recreation studies, water resource management, and environmental management.

The papers, poster sessions and field excursions revealed the very eclectic interests of North American geographers; from folk geography to geography and the Bible, from cityscapes to images and myths of the American West, from general circulation modelling to research methods in spatial biology, from the China speciality group to the Native American speciality group. By IBG standards of course, the AAG Meeting is a very large gathering which this year involved eight Workships, 21 field trips, two Special Events (one of which was a CBD Jogging Tour for those energetic enough to be able to rise by 6.30 am), seven Poster Sessions and over 200 Paper Sessions. There were also some pre-Meeting events involving, for example, the IGU Commission on Industrial Systems.

With so many papers to be condensed into such a short period it is inevitable that quality suffers at the expense of quantity. Most speakers have no more than 20 minutes to put over their material and to receive questions; inevitably the latter suffer and few sessions, apart from those (mainly Special Sessions) with fewer papers, therefore generated any interesting or