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An exploratory spatial data analysis approach to understanding the relationship between deprivation and mortality in Scotland

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Abstract

This paper considers the spatial characteristics of the relationship between deprivation and mortality rates in Scotland. Scotland not only has higher average mortality rates than England and Wales but the greatest spatial concentrations of the poorest health areas in Britain. Recent analysis has suggested that degree of deprivation alone cannot explain the majority of Scotland's 'excess' poor health relative to England and Wales, a finding referred to as the 'Scottish effect'. This analysis considers if the spatial *patterning* of deprivation could be significant to understanding of high mortality in Scotland.

Exploratory spatial data analysis methods are implemented to study the spatial relationships between deprivation and standardised mortality ratios (SMRs) in post-code sectors in Scotland. Deprivation was measured using the 2001 Carstairs score, and the total number of deaths during a 3-year period around the 2001 census was used to calculate SMRs. A strong spatial relationship is observed between deprivation and mortality. Deprivation impacts mortality levels not only within the same areas but also in spatially proximate areas. It is concluded that, further research on the 'Scottish effect' can benefit from new methodological approaches which assess the variation in both the extent and spatial arrangement of deprivation and mortality in small areas.

Keywords: Deprivation; Mortality rates; Exploratory spatial data analysis; Scottish effect; Scotland; UK

Introduction

Scotland has established a reputation for poor health, with markedly worse health than the rest of Britain and currently one of the lowest life expectancies among men and women in Western Europe (Leon, Morton, Cannegieter, & McKee, 2003). Whilst Scotland enjoyed relatively good health, in comparison to England, until about the 1920s, in recent decades it has experienced a significant deterioration in its relative health record (Davey Smith, Dorling, & Shaw, 2001; Dorling, 1997; Hanlon et al., 2005). In comparison to England and Wales, Scotland now has higher mortality rates in almost all age groups (Fitzpatrick, Griffiths, & Kelleher, 2000) and from a wide range of causes including lung cancer, ischaemic heart disease, strokes, accidents, suicide and alcohol-related mortality (Griffiths & Fitzpatrick, 2001).

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Although well known, the poor health record of Scotland is little understood (Hanlon et al., 2005; Mitchell, Fowkes, Blane, & Bartley, 2005). Analysis in the 1980s by Carstairs and Morris (1989) considering wards and post-code sectors suggested higher mortality rates in Scotland compared to the rest of Britain could be accounted for almost entirely by higher rates of deprivation in the country. More recent analysis however has found that rates of deprivation alone can no longer explain the majority of Scotland's higher rates of mortality (Hanlon et al., 2001, 2005; Scottish Council Foundation, 1998) or morbidity (Mitchell et al., 2005), though see Popham (2006) for contrasting evidence on self-reported morbidity. The term 'Scottish effect' has been used to describe this unexplained 'excess' poor health in Scotland relative to England and Wales after 'controlling' for area levels of deprivation (Hanlon et al., 2001; Scottish Council Foundation, 1998; Scottish Executive, 2005). The term implies that there is currently a 'missing factor' in our understanding of public health in Scotland, but it is not clear whether this missing factor is literally an unknown risk factor for disease, an unusual vulnerability among the Scottish population, or some wider social or physical environmental factor.

In exploring the 'Scottish effect' there are reasons to believe however that a more nuanced understanding of the relationship between area deprivation and mortality in Britain may help. It is notable that Scotland not only has higher average mortality rates than England and Wales but also the largest concentrations of the very poorest health areas, with 7 of the 10 highest mortality rate parliamentary constituencies in Britain during the 1990s located in Scotland, all in Glasgow (Shaw, Dorling, Gordon, & Davey-Smith, 1999). Analysis by Hanlon et al. (2005) comparing the relationship between mortality rates and deprivation in Scotland and England and Wales in 1981, 1991 and 2001 has also found that mortality rates in the most deprived areas in these countries have diverged over time, so that by 2001 Scotland's 'excess' mortality relative to the rest of Britain was greatest in its most deprived areas.

One possibility is that indicators do not measure deprivation in Scotland as well as that in England. Perhaps the relatively crude variables which comprise deprivation indicators are not sensitive enough to capture the greater depth of poverty experienced in Scotland. Another possibility lies in the *geography* of poverty in Scotland. Geographical theory on the relationship between society and space has long postulated that physical and social space is mutually constructive; that is to say that the characteristics of people and place have an important influence on each other (Harvey, 1982; Lefebvre, 1991; Soja, 1980, 1989). Following this idea, research has shown that the social and economic characteristics of neighbourhoods exert an influence on health (Chandola, Clarke, Wiggins, & Bartley, 2005; Mitchell, Gleave, Bartley, Wiggins, & Joshi, 2000; Pickett & Pearl, 2001). So, if exposure to a deprived area can have a negative influence on health, over and above individual level poverty, one hypothesis might be that opportunities to regularly 'escape' a deprived environment, to experience socially and physically other types of place, could be important in determining the strength of the negative influence which deprivation might exert on health. Therefore, in understanding area level relationships between deprivation and mortality it might be important not to treat each of the units (post-code sectors in the paper) as "islands" that are not influenced by neighbouring units. The physical extent of the deprivation which "surrounds" (both within the same area and spatially proximate areas) an individual might be important in determining the degree of influence which deprivation exerts on health. This hypothesis would, in turn, suggest that the actual spatial arrangement, the spatial *patterns*, of deprivation may be significant to understanding high mortality rates in Scotland.

While the above arguments are presented in a multilevel framework (encompassing both areal and individual levels), our interest in this paper is restricted to an areal level study of the relationships between deprivation and mortality using an exploratory approach. A hypothetical example that can help explicate the problem discussed in this paper is as follows: consider area "i" with neighbouring areas "j," "k" and "l." While much of the research relating deprivation to mortality has clearly shown that area level deprivation within area "i" is related to mortality in the same area "i." (e.g. Hanlon et al., 2005), research has been more limited on linking deprivation in area "i" to neighbouring areas "j," "k" and "l." This relationship between deprivation levels in area units and mortality rates in spatially contiguous units is the subject of this paper. The focus in this analysis is post-code sectors in Scotland, unlike the

hypothetical example, the "spatial connectivity" will differ across the post-code sectors. The number of neighbours for each of the post-code sectors can range from 0 (e.g. island post-code sectors) to with more than 10 neighbouring units (e.g. post-code sectors in a city with numbers of neighbouring post-code sectors).

Exploratory spatial data analysis (ESDA) methods (Anselin, 1995, 1998) are implemented to study this spatial relationship. ESDA is an extension of exploratory data analysis (EDA) that focuses on detecting spatial patterns in data and the generation of hypotheses based on the spatial patterns in the data (Haining & Wise, 1997).

The formal term for the suggested influence of spatial concentration of a characteristic is spatial autocorrelation.[1] Its role in explaining the geography of deaths associated with air pollution, cancer and infectious disease has been analysed in a number of studies (e.g. Greene, Ionides, & Wilson, 2006; Jerrett et al., 2003; Krewski et al., 2003; Rosenberg, Sokal, Oden, & DiGiovanni, 1999). The limited analysis of spatial autocorrelation that has focused upon the relationship between deprivation and mortality has suggested this is a worthwhile subject of further enquiry. For example, an analysis of mortality, the Townsend index and measures of income and population density in Belgian municipalities found that spatial autocorrelation has a significant impact on the relationship between mortality and the socio-economic variables (Lorant, Thomas, Deliège, & Tonglét, 2001).

While our focus in this paper is only on Scotland, the aim of the overall research agenda is to examine whether the differences in spatial patterning of deprivation between Scotland and England and Wales can help explain a part of the 'Scottish effect'. However, in order to make this argument we need to determine whether mortality in Scottish communities is influenced by the spatial pattern of deprivation. Once this linkage is established, the role of the differences in spatial arrangement of deprivation between Scotland and England and Wales in influencing mortality can be examined.

[1]See Frei (2005): "Spatial autocorrelation is when the value at any one point in space is dependent on values at the surrounding points. That is, the arrangement of values is not just random."

Methods

Measures

The two key measures in this analysis are the 2001 Carstairs score (a measure of deprivation) and standardised mortality ratios (SMRs) for deaths at ages under 75 years. The SMRs have been standardised using age and sex specific death rates for Scotland for age groups 0–4, 5–14, 15–24, 25–34, 35–44, 45–54, 55–64 and 65–74 years. Death rates were based upon deaths registered during a three-year period around the 2001 census and population denominators from the 2001 census. The exclusion of deaths at ages 75 years and over focuses the analysis on relatively premature mortality and also removes the influence of statistical ceiling effects (that is to say, mortality rates among the oldest age group (75+) is skewed because everyone in this group dies). Several studies have found premature mortality to be more closely associated with area deprivation than deaths at older ages (e.g. Carstairs & Morris, 1991; Townsend, Whitehead, & Davidson, 1988) although this finding is disputed (O'Reilly, 2002). Hanlon et al.'s (2005) analysis also suggests that the proportion of excess deaths in Scotland in comparison to England and Wales are relatively lower at age 75 years and over than at younger ages. The exclusion of deaths at ages 75 years and over will also reduce the influence that the presence of nursing homes may have on the death counts within small areas (Williams, Dinsdale, Eayres, & Tahzib, 2004).

The data for this study were obtained from ISD Scotland and are the same as that used in the Hanlon et al. (2005) study. Data on mortality originate from the Office for National Statistics and General Register Office for Scotland while the other measures in the study were from the 2001 census (Hanlon et al., 2005).

The geographic scale of the analysis had the potential to influence the results to a great extent. In this study, we were interested in the physical arrangement of communities and there was a wish to model this at the finest geographical scale possible in order to avoid some of the 'smoothing' of population characteristics which may occur when using physically large areal units. However, physically small areal units often contain small residential populations, few deaths and correspondingly unstable mortality rates. Scotland's fragmented landscape also presents problems for analyses focused

on the spatial arrangement of population characteristics; administrative units are often physically split (across islands, for example). For this exploratory study, we therefore restricted the statistical analyses to post-code sectors with population of 1000 or more and to a single physical segment for each sector (the segment with the largest area was chosen for the analysis). This gave a total of 840 post-code sectors (from a total of 1040) included in the analysis.

Analysis

A three step process is followed in conducting the analysis: (i) visualization: first the spatial distribution of both the SMR and Carstairs is visualized. These are shown in Figs. 1a and b, each mapped by quintile of the distribution. As the maps show, the physical size of post-code sectors in Scotland can be highly heterogeneous. For example, several of the very small post-code sectors around Glasgow are barely discernable and consequently, high or low values of SMR around Glasgow are hard to distinguish. One possible solution to this problem is the cartogram (Dorling, 1996). A cartogram makes the representation of each areal unit proportional to the variable of interest (for example, population or mortality rate), rather than proportional to the physical size of the areal unit, as in a conventional map. However, in doing so, a cartogram distorts and changes the spatial arrangement of areal units. Since spatial arrangement is the focus of this analysis, it was decided to adopt an alternative 3D visualisation. In Fig. 1c, the viewer is positioned above the border of Scotland, looking north. The 'height' of each post-code sector is shown proportionally to its SMR value, with increasing height denoting higher SMR, and the shading denotes the Carstairs score using the same legend as Fig. 1b. This kind of map has the advantage of drawing attention to areas with high values, but retaining the spatial arrangement of the post-code sectors. (ii) Next, non-spatial descriptive statistics were deployed. The relationship between deprivation and mortality was studied using the Pearson product–moment correlation. (iii) ESDA was completed. The ESDA focused on three aspects of the spatial pattern: the overall "global" spatial clustering in mortality and deprivation, the bivariate spatial relationship between mortality and deprivation and the "local" relationships between mortality and deprivation. The differences between the global and local spatial statistics are described below.

The Global Moran's I (Anselin, 1995) was used as a measure of the overall clustering and is assessed by means of a test of a null hypotheses. Rejection of this null hypothesis suggests a spatial pattern or spatial structure. Significance was tested by comparison to a reference distribution obtained by randomly permuting the observed values (see Anselin, 1995). Spatial connectivity was incorporated by means of a spatial weights matrix "W" (Anselin, 1995). In other words, the spatial weights matrix operationalises definitions of "neighbours." As described in Anselin, Sridharan, and Gholston (in press):

> Each row i of matrix W has elements w_{ij} corresponding to the columns j. The structure of the w_{ij} expresses a prior notion of which locations are important in driving the spatial correlation, in the sense that non-zero values represent "neighbors." Many different perspectives exist on which the values of the w_{ij} can be based. In practice, it is near impossible to choose a "best" weights matrix and typically one assesses the sensitivity of the results to the selection of weights. Common specifications are simple contiguity (sharing a common border), either of a "rook" variety (only pure borders) or of a "queen" variety (both borders and common vertices). These terms are derived from an analogy to a chess board, where the rook neighbors would be the four locations to the North, South, East and West, and the queen neighbors would also include the corner elements (for a total of eight neighbors).

The analysis in this paper was initially conducted using the queen's contiguity matrix. The robustness of the results was checked using the rook contiguity and the six nearest neighbour matrices (Anselin et al., in press).

The Moran's I can be visualized as the slope in a scatterplot of the spatially lagged variable[2] on the original variable. As described in Anselin et al. (in press) such a Moran's scatterplot "provides an easy way to categorize the nature of spatial

[2]The spatially lagged value of a measure is the value of that measure averaged across neighbouring locations. Technically a spatially lagged variable is "a sum of spatial weights multiplied with values for observations at neighboring locations" (see Anselin, 2002, p. 5).

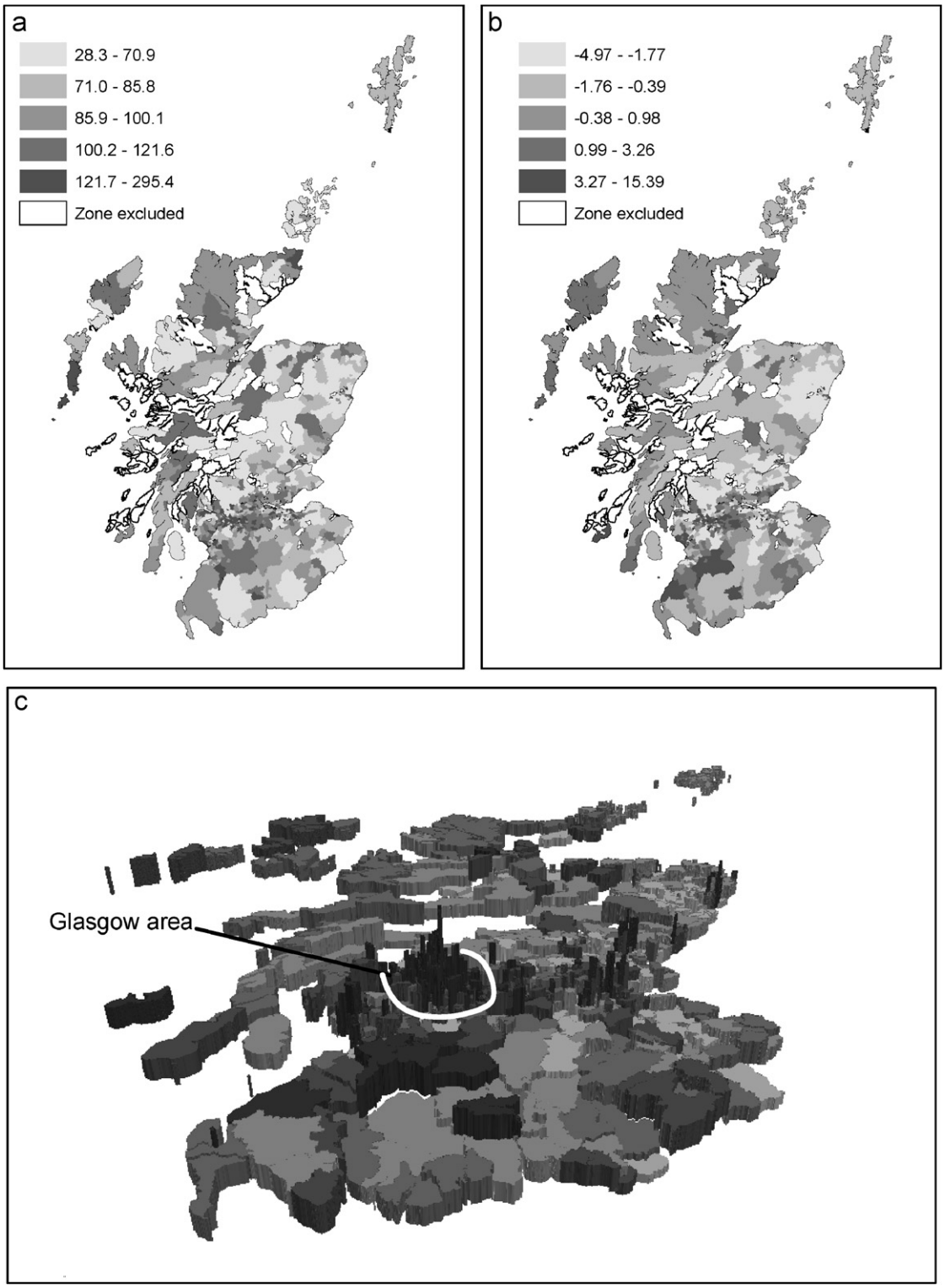

Fig. 1. (a) SMR <75, (b) Carstairs score (quintiles) and (c) 3D rendering of SMR, shaded by Carstairs score.

autocorrelation into four types, corresponding to spatial clusters and spatial outliers." The scatterplot can be interpreted as follows: observations in the lower left (low-low) and upper right (high-high) quadrant represent potential spatial clusters because these relate to values physically surrounded by neighbouring areal units with similar values. Observations in the upper left (low-high) and lower right (high-low) suggest potential spatial outliers because they relate to values whose neighbours are dissimilar. The classification in the Moran scatter does not indicate whether the clusters or outliers are statistically significant.

The bivariate spatial relationship between deprivation and mortality is studied using the bivariate Moran's I (Anselin, Syabri, & Smirnov, 2002). The bivariate Moran's I can be visualized as the slope in a scatterplot of the spatially lagged values of the SMR on the variable for the Carstairs score. In other words, the value of the SMR averaged across neighbouring locations is plotted against the Carstairs score. If the slope in this scatterplot is significantly different from zero, then there is a bivariate spatial relationship between deprivation and mortality.

While Moran's I provides a measure of the overall clustering, it does not indicate "where the clusters or outliers are located, nor what type of spatial correlation is most important (e.g. correlation between high or between low values)" (Anselin et al., in press). Local measures of spatial association provide a measure of association for each unit and help identify the type of spatial correlation—these are implemented using the Local Indicators of Spatial Association (LISA; Anselin, 1995). The Local Moran's I is used as an indicator of local spatial association.[3] The Moran significance map builds on the Moran scatterplot and incorporates information about the significance of "local" spatial patterns. Complex permutation methods (Anselin, 1994, 1995) are used to conduct the tests of significance. In practice, this is carried out by randomly permuting the observed values over all the locations and calculating the local Moran statistic for each new permutation (Anselin, 1995). The significance of the local Moran statistic is determined by generating a reference distribution using 999 random permutations.

As described earlier, the Moran scatterplot helps identify the nature of spatial autocorrelation between post-code sectors so they can be categorised into four groups. For the SMRs these are:

- *High-high*: *high value* of SMR in a post-code sector, neighbouring post-code sectors have *high* values of SMR (positive association).
- *Low-high*: *low value* of SMR in a post-code sector, neighbouring post-codes sectors have *high* values of SMR (negative association).
- *Low-low*: *low value* of SMR in a post-code sector, neighbouring post-code sectors have *low* values of SMR (positive association).
- *High-low*: *high value* of SMR in a post-code sector, neighbouring post-code sectors have *low* values on the outcome measure (negative association).

A typology of this form is constructed for both the SMRs and the Carstairs score. The Moran significance map builds on the Moran scatterplot and incorporates information about the significance of "local" spatial patterns. Thus, the Moran Significance Map results in a spatial typology consisting of five categories of post-code sectors: "high-high", "low-low," "low-high" and "high-low" and "not significant." The relationship between the spatial arrangement of mortality and deprivation is studied by a cross-tabulation of spatial typologies of SMR and Carstairs score.

Software

ESDA is implemented through the *GeoDa* software (Anselin, Syabri, & Kho, 2006). GeoDa provides a very user-friendly environment to implement ESDA methods and is freely downloadable.[4]

[3]The global measure of Moran's I is defined as:

$$I = \sum_i \sum_j w_{ij}(x_i - \mu)(x_j - \mu) / \sum_i (x_i - \mu)^2$$

where w_{ij} is the row-standardized contiguity matrix, x_i is the risk scale measure at county I, and x_j is the risk scale measure at county j, and μ is the average level of risk.

The local measure of Moran's I is defined as:

$$I = \frac{(x_i - \mu)}{\sum (x_i - \mu)^2} \sum_j w_{ij}(x_j - \mu)$$

[4]GeoDa version 0.9.5-i was used. The software is available for free downloading from https://geoda.uiuc.edu.

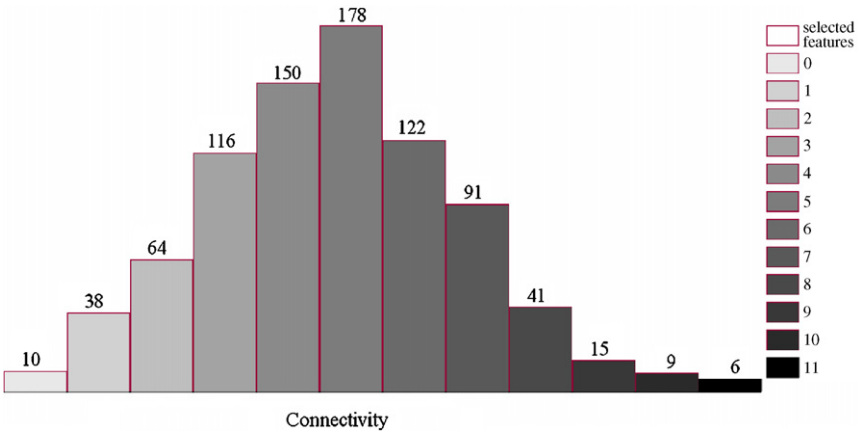

Fig. 2. Connectivity of the queen contiguity matrix.

Results

Visualization

Figs. 1a and b give a general impression of the spatial distribution of SMR and deprivation in Scotland and the degree to which these are spatially related. However, the central belt of Scotland, which contains much of its population, is physically small and it is hard to discern any particular patterning there, other than a general concentration of both deprivation and higher mortality rate. Fig. 1c eases this visual problem and shows clearly that the areas with higher SMR (those which appear to be extruded most from the map) tend also to be those with greater deprivation (those which are shaded in darkest grey). This should be of no surprise. Fig. 1c also shows the great spatial concentrations of both deprivation and mortality, particularly in the Glasgow area and its surroundings.

Descriptive statistics

The correlation between SMR and Carstairs across the 840 post-code sectors is 0.85 ($p<0.001$).

Global association

Fig. 2 describes the spatial connectivity of the queen contiguity matrix. As can be seen, the queen contiguity matrix ranged from 10 post-code sectors with no "contiguous" neighbours to 6 post-code sector with 11 "contiguous" neighbours. The modal category was 5 neighbours: 178 of the 840 post-code sectors had 5 neighbours by the queen contiguity criterion.[5]

Table 1
Moran's I statistic for spatial autocorrelation in SMR and Carstairs score (p-value in parentheses)

Spatial weights	SMR	Carstairs
Queen contiguity	0.4985 (0.001)	0.5162 (0.001)
Rook contiguity	0.4944 (0.001)	0.5232 (0.001)
Nearest neighbours (6)	0.4502 (0.001)	0.4525 (0.001)

The extent to which the spatial patterns exhibited in SMR are compatible with a notion of randomness (the null hypothesis), or show a significant spatial structure, is then analysed. As described earlier, as this refers to the overall pattern in the data, this is referred to as *global* association. The results for Moran's I test for spatial autocorrelation are given in Table 1, with pseudo-significance values (based on a permutation approach) listed in parentheses. As we would expect, the results suggest significant and positive spatial autocorrelation across all spatial weights, or in simple terms, that mortality rates in Scotland do have some kind of organised spatial pattern to them. The systematic variation of SMR across space would suggest that spatial pattern should be taken into account.

[5]The rook contiguity matrix ranges from 10 post-code sectors with no "contiguous" neighbours to three places with 11 "contiguous" neighbours. By definition, each post-code in the six nearest neighbours matrix has six neighbours.

Spatial relationship between Carstairs and SMR

Table 2 describes the bivariate Moran's *I* for the three spatial weight matrices. Using the queen contiguity matrix, the bivariate Moran's *I* between Carstairs and SMR is 0.48 ($p<0.001$); Fig. 3 describes this relationship. This result suggests that deprivation in any given post-code sector is actually associated with SMRs in neighbouring post-code sectors. This relationship is consistent across the multiple spatial matrices.

Table 2
Bivariate Moran's *I* between SMR and Carstairs (*p*-value in parentheses)

Spatial weights	Bivariate Moran's *I*
Queen contiguity	0.4786 (0.001)
Rook contiguity	0.4845 (0.001)
Nearest neighbours (6)	0.4395 (0.001)

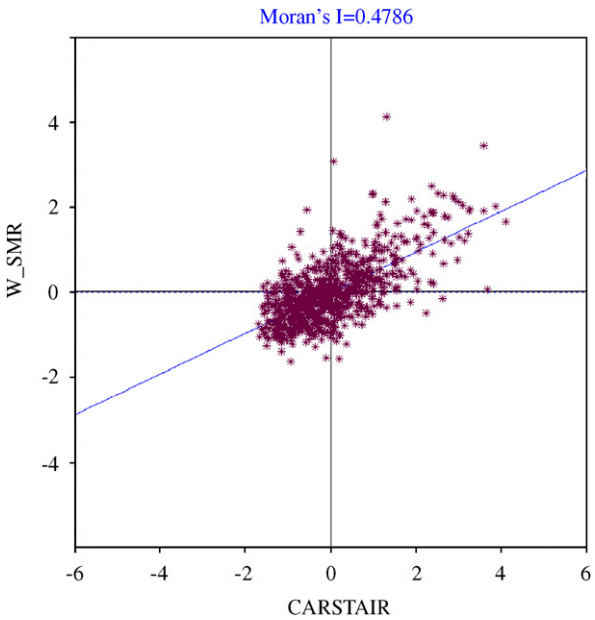

Fig. 3. Bivariate Moran's *I* between Carstairs and SMR.

Local association

So far, the analyses have suggested non-randomness in the overall spatial pattern of both SMR and Carstairs score. More information on what kinds of clustering may be present is provided by an analysis of LISA.

The five cluster spatial typology described earlier (high-high, low-low, etc.) is developed for both SMR and the Carstairs score. As described earlier, the spatial typology helps categorise the nature of spatial autocorrelation in the SMR and Carstairs score, *respectively*, into five categories. The relationship *between* the spatial autocorrelation in the SMR and the Carstairs score is studied by examining the cross-tabulation between the spatial typologies of SMR and the Carstairs score. Note that a majority of the units for both of these measures fall into the "non-significant" category. The chi-squared test indicates a highly significant relationship between the spatial typologies of SMR and the Carstairs score ($p<0.0001$). As further evidence of the similarities in the patterns of spatial autocorrelation in SMR and the Carstairs score, consider the percentage of cases that fall within the diagonal of Table 3. Out of the 89 cases that fall in the "high–high" category of Carstairs score, 74 (83%) are also in the "high–high" category of the SMR. Similarly, out of the 114 that fall in the "low–low" category of Carstairs, 79 (69%) fall within the "low–low" category of the SMR. Out of the 19

Table 3
Cross-tabulations between the spatial typologies of postcode sector Carstairs scores and SMR

	Spatial typology for Carstairs score					Total
	Not significant	High-high	Low-low	Low-high	High-low	
Spatial typology for SMR						
Not significant	536	13	28	5	2	584
High-high	25	74	0	1	0	100
Low-low	40	0	79	0	4	123
Low-high	2	2	0	13	0	17
High-low	6	0	7	0	3	16
Total	609	89	114	19	9	840

cases in the low–high category of Carstairs, 13 (68%) are also in the low–high category of SMR. Out of the 9 cases in the high–low category of Carstairs score, 3 (33%) are also in the high–low category of SMR. Some of these off-diagonal elements in Table 3 are worthy of future study and might be indicative of resilient communities. As an example, there are two post-code sectors that fall into the high-high category of Carstairs score but in the low-high category of SMR. Understanding the characteristics of such communities might reveal additional complexities in the relationship between deprivation and mortality. As this is outside the scope of this paper, we do not pursue this issue further in this paper.

Discussion

The key question investigated in this paper is whether the spatial patterning of deprivation is related to all-cause mortality in Scotland. As presented in Tables 1–3 and Fig. 3, the consistent answer obtained in this paper is that the spatial *patterning* of the Carstairs score was strongly associated with mortality. This is *not* the same as finding an association between mortality and deprivation across Scotland. It suggests that the actual spatial patterns of deprivation in Scotland may be implicated in the levels of mortality.

The result is consistent with a growing body of knowledge that argues that spatial proximity matters in a number of social and health problems (Anselin et al., in press; Sampson, 2003, 2004). Sampson and Morenoff's (2006, p. 200) finding in a study of neighbourhood change in Chicago is consistent with this result: "… neighborhoods that changed the most were those that were spatially proximate to initial concentrations of poverty, so poverty change was geographically systematic—*so much so that spatial proximity to change in poverty matters as much as the internal characteristics of a neighbourhood, including its initial level of poverty*" (emphasis added).

The social and health mechanisms by which disadvantage can be further exacerbated through the presence of a number of poor contiguous neighbourhoods are currently poorly understood: "if 'neighbourhood effects' of concentrated poverty on health exist, presumably they stem from social processes that involve collective aspects of neighbourhood life such as social cohesion, spatial diffusion, local support networks, informal social control, and subcultures of violence. Yet we know little about these and other social mechanisms, especially how to measure them at the community level" (Sampson, 2003, p. S56). Spatial dimensions of the health service delivery system and to access to health services might also be complicit in such a production of spatial disadvantage. Much theoretical and empirical work still needs to be done to understand the spatial aspects of social and health dimensions of the deprivation–mortality linkages. One potentially fruitful area might be to explore the empirical evidence for, and theoretical perspectives on, the role which place can play in the construction of other aspects of society and identity, such as crime or social class. Urban sociology and geography have long researched and theorised the role which space may play in these phenomena (Hubbard, 2006). We urge a marriage between epidemiology and socio-spatial theory to take these ideas further.

While we have established that spatial patterning might matter in mortality, this research does not directly address whether differences in spatial patterning in deprivation between Scotland and England and Wales help explain differences in their mortality. However, two implications of a spatial perspective may be relevant to understanding the "Scottish Effect": (i) *Spatial heterogeneity*: does the relationship between deprivation and mortality differ across the *countries* of the United Kingdom? The relationship between deprivation and mortality may not be uniform in the three countries. Spatial econometricians (Anselin, 1988) have termed such variations in relationship between variables across space as spatial heterogeneity. Goodchild (2006, p. 259) in a discussion of the significance of Geographical Information Systems (GIS) argues for the importance of spatial heterogeneity in social and physical processes: "… spatial heterogeneity, or the fact that the Earth's surface exhibits what a statistician would call non-stationarity, flies in the face of a scientific tradition that insists that no result is useful unless it applies everywhere at all times … in this context the recent growth of interest in GIS reflects a fundamental departure, towards a new kind of scientific thinking in which the variation of things from place to place is of primary importance …" (ii) *Spatial dependence*: the spatial relationship between deprivation and mortality found in this analysis also suggests that it may also be important not to treat each post-code sector as an independent unit. Consider Goodchild (2006, p. 259) once again

for the implications of such spatial dependence: "… here again we find that trying to apply traditional scientific thinking to space is fraught. The methods of inferential statistics … were based on controlled experiments, such as fields planted with different crops, where it is reasonable to assume that each sample in the experiment is essentially independent of each other sample. But Tobler's First Law states that exactly the opposite is normally the case in space; that the assumption of independence is untenable. Again what appears to be no more than a simple tool for analysing maps turns out to represent a profound departure from the traditional ways we humans have approached scientific questions."

Hanlon et al. (2005, p. 203) end their analysis of the 'Scottish Effect' by stating: "The truth is that we don't know what is causing this phenomenon." These results suggest however, that it might be important that methodological frameworks that seek to explain the 'Scottish Effect' investigate not only the relationship between deprivation and mortality but also the *spatial arrangement* of deprivation and perhaps also the spatial dynamics (Sampson, 2003) that might connect deprivation to mortality.

This paper represents an exploratory analysis and has a number of limitations. A spatial relationship between deprivation and mortality might simply represent the "inexact correspondence between the neighborhood boundaries imposed by census geography and the ecological properties" (Sampson, 2004, p. 164) that might shape health processes. The choice of a post-code sector as the unit of analysis was driven in large part by the availability of data at this level and not due to a priori theoretical considerations. Additionally, the analysis here focused on all-cause mortality. Further analysis needs to more specially understand the relationship between deprivation and mortality for specific causes of deaths. Given our exploratory focus, the analysis between deprivation and mortality has taken place in a bivariate framework. Future analysis also needs to be conducted in a multivariate framework in which other measures of climate, migration and community-level measures such as local-support networks are included to more fully understand relationships between deprivation and mortality rates.

Most analysis linking deprivation to mortality has tended to treat each of the units as "islands" that are unaffected by neighbouring units. We have demonstrated in this paper that the spatial patterning in deprivation can matter in understanding mortality rates. A focus on the spatial arrangement of deprivation might help explain *part* of the 'Scottish Effect'.

References

Anselin, L. (1988). *Spatial econometrics: Methods and models*. Dordrecht: Kluwer Academic Publishers.

Anselin, L. (1994). Exploratory spatial data analysis and geographic information systems. In M. Painho (Ed.), *New tools for spatial analysis* (pp. 45–54). Luxembourg: Eurostat.

Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical Analysis*, *27*, 93–115.

Anselin, L. (1998). Exploratory spatial data analysis in a geocomputational environment. In P. Longley, S. Brooks, B. Macmillan, & R. McDonnell (Eds.), *GeoComputation: A primer* (pp. 77–94). New York: Wiley.

Anselin, L. (2002). Under the Hood: Issues in the specification and interpretation of spatial regression models. *Agricultural Economics*, *17*, 247–267.

Anselin, L., Sridharan, S., & Gholston, S. (2007). Using exploratory spatial data analysis to leverage social indicator databases: The discovery of interesting patterns. *Social Indicators Research*, *82*, 287–309.

Anselin, L., Syabri, I., & Kho, Y. (2006). GeoDa: An introduction to spatial data analysis. *Geographical Analysis*, *38*, 5–22.

Anselin, L., Syabri, I., & Smirnov, O. (2002). *Visualizing multivariate spatial correlation with dynamically linked windows*. Urbana, IL: University of Illinois, Urbana-Champaign.

Carstairs, V., & Morris, R. (1989). Deprivation: Explaining differences in mortality between Scotland and England and Wales. *British Medical Journal*, *299*, 889–996.

Carstairs, V., & Morris, R. (1991). *Deprivation and health in Scotland*. Aberdeen: Aberdeen University Press.

Chandola, T., Clarke, P., Wiggins, R. D., & Bartley, M. (2005). Who you live with and where you live: Setting the context for health using multiple membership multilevel models. *Journal of Epidemiology and Community Health*, *59*(2), 170–175.

Davey Smith, G., Dorling, D., & Shaw, M. (2001). *Poverty, inequality and health: 1800–2000—a reader*. Bristol: The Policy Press.

Dorling, D. (1996). *Area cartograms: Their use and creation*. CATMOG 59, Institute of British Geographers.

Dorling, D. (1997). *Death in Britain: How local mortality rates have changed 1950–1990s*. York: Joseph Rowntree Foundation.

Fitzpatrick, J., Griffiths, C., & Kelleher, M. (2000). Geographic inequalities in mortality in the United Kingdom during the 1990s. *Health Statistics Quarterly*, *7*(4), 18–31.

Frei, A. (2005). *Notes on spatial autocorrelation and regression*. 〈http://www.geography.hunter.cuny.edu/~afrei/gtech702_fall03_webpages/notes_spatial_autocorrelation.htm〉.

Goodchild, M. F. (2006). Afterword-and now to bed. In D. Z. Sui, & M. Ball (Eds.), *Geospatial matters: Exploring the implications of a digital earth* (pp. 256–259). San Francisco: GeoTec Media.

Greene, S. K., Ionides, E. L., & Wilson, M. L. (2006). Patterns of influenza-associated mortality among US elderly by

geographic region and virus subtype, 1968–1998. *American Journal of Epidemiology*, *163*(4), 316–326.

Griffiths, C., & Fitzpatrick, J. (2001). *Geographic variations in health* DS No. 16. London: HMSO.

Haining, R., & Wise, S. (1997). Exploratory spatial data analysis. *NCGIA core curriculum in GIScience*. 〈http://www.ncgia.ucsb.edu/giscc/units/u128/u128.html〉, posted December 05, 1997.

Hanlon, P., Lawder, R. S., Buchanan, D., Redpath, A., Walsh, D., Wood, R., et al. (2005). Why is mortality higher in Scotland than in England and Wales? Decreasing influence of socioeconomic deprivation between 1981 and 2001 supports the existence of a 'Scottish Effect'. *Journal of Public Health*, *27*(2), 199–204.

Hanlon, P., Walsh, D., Buchanan, D., Redpath, A., Bain, M., Brewster, D., et al. (2001). *Chasing the Scottish effect—why Scotland needs a step change in health if it is to catch up with the rest of Europe*. Glasgow: Public Health Institute of Scotland.

Harvey, D. (1982). *The limits to capital*. Chicago: University of Chicago Press.

Hubbard, P. (2006). *The city: Key ideas in geography*. Abingdon, Oxford: Routledge.

Jerrett, M., Burnett, R. T., Willis, A., Krewski, D., Goldberg, M. S., DeLuca, P., et al. (2003). Spatial analysis of the air pollution–mortality relationship in the context of ecologic confounders. *Journal of Toxicology and Environmental Health A*, *66*(16–19), 1779–1782.

Krewski, D., Burnett, R. T., Goldberg, M. S., Hoover, B. K., Siemiatycki, J., Jerrett, M., et al. (2003). Overview of the reanalysis of the Harvard six cities study and American Cancer Society Study of particulate air pollution and mortality. *Journal of Toxicology and Environmental Health Part A*, *66*(19), 1507–1552.

Leon, D. A., Morton, S., Cannegieter, S., & McKee, M. (2003). *Understanding the health of Scotland's population in an international context; a review of current approaches, knowledge and recommendations for new research directions*. A report by the London School of Hygiene and Tropical Medicine Commissioned and funded by the Public Health Institute of Scotland.

Lorant, V., Thomas, I., Deliège, D., & Tonglét, R. (2001). Deprivation and mortality: The implications of spatial autocorrelation for health resources allocation. *Social Science & Medicine*, *55*(12), 1711–1719.

Mitchell, R., Fowkes, G., Blane, D., & Bartley, M. (2005). High rates of ischaemic heart disease in Scotland are not explained by conventional risk factors. *Journal of Epidemiology and Community Health*, *59*, 565–567.

Mitchell, R., Gleave, S., Bartley, M., Wiggins, D., & Joshi, H. (2000). Do attitude and area influence health? A multilevel approach to health inequalities. *Health and Place*, *6*(2), 67–79.

Pickett, K. E., & Pearl, M. (2001). Multilevel analyses of neighbourhood socioeconomic context and health outcomes: A critical review. *Journal of Epidemiology and Community Health*, *55*(2), 111–122.

Popham, F. (2006). Is there a "Scottish effect" for self reports of health? Individual level analysis of the 2001 UK census. *BMC Public Health*, *6*, 191.

Rosenberg, M. S., Sokal, R. R., Oden, N. L., & DiGiovanni, D. (1999). Spatial autocorrelation of cancer in Western Europe. *European Journal of Epidemiology*, *15*(1), 15–22.

Sampson, R. J. (2003). The neighborhood context of well being. *Perspectives in Biology and Medicine*, *46*(3 Suppl.), S53–S64.

Sampson, R. J. (2004). Networks and neighbourhoods: The implications of connectivity for thinking about crime in the modern city. In H. McCarthy, P. Miller, & P. Skidmore (Eds.), *Network logic: Who governs in an interconnected world?* (pp. 157–166). London: Demos.

Sampson, R. J., & Morenoff, J. (2006). Durable inequality: Spatial dynamics, social processes, and the persistence of poverty in Chicago neighborhoods. In S. Bowles, S. Durlauf, & K. Hoff (Eds.), *Poverty traps* (pp. 176–203). Princeton: Princeton University Press.

Scottish Council Foundation, Health Public Policy Network. (1998). *The Scottish effect?*. Edinburgh: Scottish Council Foundation.

Scottish Executive. (2005). *Health in Scotland 2004*. Scottish Executive: Edinburgh.

Shaw, M., Dorling, D., Gordon, D., & Davey-Smith, G. (1999). *The widening gap: Health inequalities and policy in Britain*. Policy Press: Bristol.

Soja, E. W. (1980). The socio-spatial dialectic. *Annals of the Association of American Geographers*, *70*(2), 207–225.

Soja, E. W. (1989). *Postmodern geographies. The reassertion of space in critical social theory*. London: Verso.

Townsend, P., Whitehead, M., & Davidson, N. (Eds.). (1988). *Health and inequalities in the North*. London: Croom Helm.

Williams, E. S., Dinsdale, H., Eayres, D., & Tahzib, F. (2004). Impact of nursing home deaths on life expectancy in small areas. *Journal of Epidemiology and Community Health*, *58*, 958–962.