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# Macro-Scale Stability with Micro-Scale Diversity: Modelling Changing Ethnic Minority Residential Segregation – London 2001-2011

Ethnic residential segregation is a frequent issue raised in commentaries regarding British cities, with many claims that it is increasing and posing a threat to social cohesion. Most academic studies of ethnic residential segregation there have shown that it has decreased recently, however, although the statistical significance of their findings is not evaluated. In addition, those studies very largely ignore issues of spatial scale, both in the measurement of segregation and the processes leading to its creation. The present paper rectifies that situation by, for the first time, modelling ethnic segregation in London at the 2001 and 2011 censuses within a Bayesian statistical framework at three scales, which allows for the statistical significance of any changes to be formally assessed – something not possible heretofore. It finds that for most of the seven ethnic minority groups studied segregation was as great, if not greater, at the macro- as at the micro-scale, with both measures larger than at the meso-scale, and with significant reductions in segregation across the decade, especially at the micro-scale.

**Key words.** ethnicity, residential segregation, scale, modelling, London

## Introduction

The issue of ethnic minority residential segregation occasionally attracts considerable media attention in the UK (on which see Finney and Simpson 2009). This was the case again in spring 2016 with a television documentary and an associated newspaper article regarding the social, cultural and political attitudes of Muslim residents.<sup>1</sup> This stimulated a full-page banner headline in a tabloid newspaper proclaiming WARNING ON UK MUSLIM GHETTOES,<sup>2</sup> and a Labour MP, Chuka Umunna, proclaimed – as reported in the same newspaper’s online version – that ‘Britain is becoming more ethnically segregated, with “widening cracks in our communities” ... people may seek “Donald Trump style” solutions if politicians did not act first’.<sup>3</sup>

Such claims – that Britain, according to Umunna, has ‘become more ethnically segregated as a nation as immigration has risen over the past decades’ – led to the establishment in March 2016 of an All-Party Parliamentary Group on Social Integration, whose stated purpose was to ‘drive forward a cross-party conversation on policy solutions to break down barriers to integration and create opportunities for people from all walks of life to build bonds of trust’.<sup>4</sup> And yet academic studies of ethnic minority residential segregation have shown that those barriers have been reduced over recent decades, that the groups usually categorised as Black Minority Ethnic (BME) have become less segregated and many urban neighbourhoods ethnically more diverse (Catney 2016; Johnston et al. 2015) – although one commentator has

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<sup>1</sup> The Channel 4 programme, can be watched on <http://www.channel4.com/programmes/what-british-muslims-really-think/on-demand/62315-001>; the newspaper article appeared in The Sunday Times - [http://www.thesundaytimes.co.uk/sto/Magazine/Features/article1685107.ece?CMP=OTH-gnws-standard-2016\\_04\\_09](http://www.thesundaytimes.co.uk/sto/Magazine/Features/article1685107.ece?CMP=OTH-gnws-standard-2016_04_09).

<sup>2</sup> It appeared in the *Daily Mail* - <http://www.dailymail.co.uk/news/article-3533041/Warning-UK-Muslim-ghettoes-Nation-nation-developing-says-former-equalities-watchdog.html>. For an early, non-technical, response to that claim see Johnston et al. (2016).

<sup>3</sup> <http://www.dailymail.co.uk/wires/pa/article-3603928/UK-ethnically-segregated-Chuka-Umunna.html>

<sup>4</sup> <http://www.publications.parliament.uk/pa/cm/cmallparty/160428/social-integration.htm>.

claimed that although ‘There is more mixing in some parts of our society ... there is undoubtedly also more segregation in residential areas, more segregation in schools, and more segregation in workplaces’.<sup>5</sup>

Almost all of those studies of ethnic residential segregation have two major limitations: they are conducted at a single spatial scale only; and they are descriptive only – lacking any base in inferential statistics that allows robust statements to be made regarding the extent and intensity of any change. This paper thus extends those earlier studies with an examination of changing ethnic minority residential segregation in London between 2001 and 2011 using a recently-developed procedure that introduces a simultaneous multi-scalar approach based on inferential statistical modelling. The results provide new material relevant to the ongoing debates regarding the changing intensity of segregation of London’s seven largest ethnic minority groups – Bangladeshi, Indian and Pakistani from South Asia, Chinese, Black African, Black Caribbean and Black Other. In turn, these stimulate discussion regarding that segregation’s multi-scalar layers and the location-decision-making processes which produced and reproduce them.

## **Segregation and Scale**

Is scale important in the analysis of urban ethnic residential patterns (as Fowler 2015 has recently argued), and if so, how can it be formally measured? Did London’s ethnic groups become significantly more or less segregated over the 2001-2011 decade, and were similar patterns of change observed at various scales?

It is implicit – and occasionally explicitly stated – that segregation levels are higher, the smaller the scale of resolution of the areal units deployed in its measurement. (Logan et al. 2015, 1070, for example, state that the purpose of their study of American Black ghettos is ‘not to demonstrate that segregation is higher at a finer spatial scale, which is already well known.’) Most of the explicit studies reach this conclusion, however, by assessing segregation levels at two (rarely more) spatial scales independently of each other (as in Woods 1977 and Peach 1996). Other studies also using single-figure indices produce comparable findings (e.g. Krupka 2007), as do more recent investigations which although multi-scale in their structuring treat each scale as an independent realisation rather than an element in a multi-scale spatial process (as in Reardon et al. 2008 2009 and Östh et al. 2015; see also Wright et al. 2011a 2011b).

This finding regarding scalar variations – although never formally tested – appears counter-intuitive. Although it is almost invariably the case that where ethnic groups are spatially concentrated into particular urban neighbourhoods, it is also almost invariably the case that those neighbourhoods are concentrated into particular larger-scale segments of the residential fabric only; neighbourhood segregation at the micro-scale is embedded within district-level segregation at the macro-scale. Maps of the distribution of ethnic minorities within cities – whether schematic as in the early diagrams associated with the Chicago School or the myriad published choropleth depictions of particular cities – almost all show that the neighbourhoods where a segregated group’s members are concentrated tend to be clustered together in particular parts of a city only. It was for this reason that early critics of the commonly-used indices – of dissimilarity and segregation, and less so of isolation and exposure – pointed out

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<sup>5</sup> <http://www.theguardian.com/world/2016/may/23/britain-more-segregated-15-years-race-expert-riots-ted-candle>.

that they are aspatial and should be enhanced by taking account of the spatial location of the areal units where the concentration occurs (e.g. Morgan 1993; Morrill 1991). These studies (and many others undertaken since, as in, for example, Wong 1993 2014) indicate that although the five dimensions of segregation identified by Massey and Denton (1988) may be conceptually – if not empirically (Johnston et al. 2007) – independent, nevertheless investigations of the outcome of the (usually inferred) segregation processes need to take more than one of them into account – in particular clustering and/or concentration plus unevenness and/or isolation. (On the relationship between the outcomes and processes, see Simpson 2004; Johnston et al. 2005.)

Furthermore, the empirical finding that segregation is greater at smaller scales is also potentially statistically incorrect since calculation of the level of segregation at any one scale necessarily incorporates, to an unknown extent, segregation at any higher scales as well. This argument was initially made by Duncan et al. (1961, 84) – ‘if one system of areal units is derived by subdivision of the units of another system, the index computed for the former can be no smaller than the index for the latter, and usually will be larger. Thus the index of concentration on a county basis will exceed the index on a State basis, because the county index takes into account interstate concentration’. Basically, if any spatial distribution results from the operation of processes at two or more scales, then they have to be explicitly recognised through a variance decomposition or similar approach – as clarified by Haggett’s classic papers (1964 1965, following Krumbein and Slack 1956; see also Reardon et al. 2000; Voas and Williamson 2000; Johnston et al. 2003). Subramanian et al. (2001) and Browne et al. (2005) have placed this realisation in a geographical multilevel modelling framework which, unlike the earlier studies, can cope with imbalance (that is, different numbers of lower level units in higher-level units) and model non-continuous data, such as discrete counts, correctly. Any analysis of a process – such as that of determining where to live – that is multi-scalar in the dimensions of its resultant patterns must recognise this; by missing-out a level in such a spatial hierarchy, an over-emphasis is likely to be placed on variation at its lower levels: the micro- may well be stressed at the expense of the macro- (Tranmer and Steel 2001). The results from a standard non-multilevel analysis will be misleading as the segregation from multiple scales will be confounded in the single-scale analysis.

As many cartographic representations produced since the pioneering Chicago School studies of the 1920s-1930s show, members of ethnic minority groups tend to cluster in particular parts of a city only – in an inner zone, for example; or in a particular sector; or in a suburban enclave (see, for example, Johnston et al. 2014a for maps of ethnic clustering in London in 2001 and 2011). Within those areas they are then concentrated in certain neighbourhoods but (relatively) absent from others. To investigate this multi-scale phenomenon formally, we deploy a modelling procedure which investigates segregation at a number of scales, each net of segregation at larger scales, thereby gaining purchase on the relative importance of segregation at those scales.

This modelling procedure not only allows analysts to explore the scale issue but also has other advantages over both the traditional single-number index measures and recent developments of alternative procedures. The great majority of the latter are descriptive only<sup>6</sup> – very few studies make any attempt to evaluate segregation patterns using statistical

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<sup>6</sup> As are alternative procedures using classification approaches (e.g. Wright et al. 2011; Johnston et al. 2015) which do not assess whether the population structures of areas differ significantly from each other, although some do assess whether different types are spatially autocorrelated in their distributions (e.g. Poulsen et al. 2011).

modelling and significance testing (the main exceptions are Allen et al. 2015; Lee et al. 2015: see also Leckie et al. 2012, Gorard et al. 2013, and Jones and Johnston 2013 regarding comparable studies of ethnic segregation in schools).<sup>7</sup> Because that great majority of studies lacks any inferential statistical foundation, it is not possible to assess the extent of any differences – between the levels of segregation for one group and another at a particular scale, for example; or between the level for one group at different dates (at one or more scales). Do such differences, as portrayed, for example, in Catney (2015a 2015b), occur as a result of chance only, reflecting natural variations in the distribution of population counts and the statistical unreliability of analyses of data – especially percentages and other ratios – with observed small numbers in many of the observation units? (On this, see, for example, Winship 1977 1978; Carrington and Troske 1997; and Voas and Williamson 2000.) Being able to obtain confidence intervals for a measure of the degree of segregation is particularly important when examining change, lest chance fluctuations are misinterpreted as genuine differences. As Lee et al. (2015, 82) express it, a measure of uncertainty is a desirable accompaniment to any index of segregation to ensure that any observed pattern is unlikely to be the outcome of simply random sampling variation, but previous attempts to develop one – using the same, Bayesian, statistical framework as deployed here – have been unsuccessful (see Mulekar et al. 2008). Indeed, they argue that ‘the creation of uncertainty intervals ... a cornerstone of statistical inference and should be routinely constructed for segregation measures’ (Lee et al. 2015, 94): the method exemplified here has been developed to meet that demand. Lee et al.’s (2015) approach to the problem also takes into account the spatial autocorrelation evident – though rarely measured – in most patterns of ethnic residential segregation through standard measures of such patterns (e.g. Moran’s *I*). Our approach, using a spatial hierarchical structuring of the data, differs from theirs but addresses the same issue – spatial autocorrelation is explicitly implicated in our models (the nesting of OAs into MSOAs, for example).<sup>8</sup>

Substantively we investigate the changing multiscale geography of ethnicity in Greater London using census data for 2001 and 2011, focusing on the seven largest BME groups – Bangladeshi, Indian, Pakistani, Chinese, Black African, Black Caribbean and Black Other. London is an increasingly multi-ethnic city and cartographic descriptive studies have shown that at both of those dates each of the main ethnic groups was concentrated in certain segments of the urban area only (Johnston et al. 2014a) whilst between the two censuses there was considerable change, characterised as increased (though different) ethnic diversity in both the neighbourhoods where the White populations formerly predominated and those where Non-Whites formed the majority (Johnston et al. 2015a). The methodology applied here explores that patterning in greater depth and statistical rigour than heretofore; full details of the statistical procedures are available elsewhere (Jones et al. 2015) so the present paper focuses on introducing the underlying concepts and illustrating how the outputs are interpreted. A technical Appendix specifies the model used in the analysis.

Application of this multi-level modelling approach to the study of segregation patterns explicitly recognises the argument – recently stressed by Fowler (2015) – that urban

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<sup>7</sup> The lack of any indication of statistical significance does not apply only to those studies using the standard single-number indices – such as those of dissimilarity and segregation (though see Allen et al. 2015; Lee et al. 2015) – but also those using typologies of neighbourhood population structures (e.g. Johnston et al. 2015; Wright et al. 2011).

<sup>8</sup> Note also Allen et al.’s (2015, 64) conclusion that where minority sizes and the areal units analysed are both small, ‘the level of segregation observed is known to be significantly greater than systematic segregation’; in the London data analysed here, the median number of members of any one ethnic group in an OA in 2011 is only 6.

residential patterns are multi-scalar in their outcomes. Secondly, it uses measures of the intensity of segregation at those multiple scales that have a firm statistical basis so that differences in their value – both across groups at any one date and between different dates within groups – can be assessed and their statistical significance evaluated; in particular the statistical significance of any changes between 2001 and 2011 can be assessed, to establish whether segregation increased or decreased then, and to what extent at various scales. Thirdly, these statistically rigorous findings are used to extend appreciation of the residential decision-making processes. By placing studies of residential change on a firmer, more statistically rigorous footing than heretofore, both description and understanding of the spatial structure of one of the world's most multi-ethnic cities is substantially enhanced.

### **Modelling multi-scale segregation**

The modelling procedure applied here has five main advantages over traditional descriptive procedures. First, it analyses the geographies of all of the designated ethnic groups simultaneously, thereby providing a single synoptic view of their relative patterning. Secondly, it can incorporate data for more than one time period, facilitating rigorous analyses of change. Thirdly, it operates at more than one spatial scale, allowing appreciation of the extent of clustering and concentration at various levels of spatial resolution; its measures are not aspatial. Fourthly the distributions at each scale can be compared across time periods to identify the extent to which a particular ethnic group occupies the same space at different dates. Finally, it is based on the rigorous foundation of Bayesian statistics in characterising uncertainty.

The modelling procedure (set out in full in Jones et al. 2015; see also Manley et al. 2015a) builds on the pioneering work of Kish (1954) and Moellering and Tobler (1972) and develops on that by Leckie et al. (2012) and Leckie and Goldstein (2014). Because the data used – especially for areal units at the smallest scale – include small absolute counts (i.e. many areas have few residents in many of the ethnic groups studied), we use a Poisson model. The observed counts for each ethnic group in each of the areal units are compared with the expected counts for that group there if its members were evenly distributed across all areas in line with the distribution of the total population. The natural logarithms of the ratios of those observed:expected counts are modelled, in a multilevel framework. The London example analyses the distribution patterns at three scales – the census output area (OA – the smallest, or micro-, unit), the census middle level output area (MSOA – the intermediate, or meso-, scale), and the local authority (LA – the largest unit, or macro-scale) while taking account of the inherent Poisson variation in the counts.

Figure 1 illustrates the model structure, using a two-scale spatial structure only for simplicity of representation – the LA and the MSOA; the measure of segregation (MRR – see below) is on the vertical axis. The solid line in the centre of each of the three diagrams shows the ratio for London as a whole (i.e. the ratio between the observed and expected numbers, which are the same – hence the ratio is 1.0 in the raw data or 0 in its logged form). The thinner lines show the ratios for each of two LAs; the dashed lines show the ratios for three of the MSOAs in one of the LAs and the dotted lines show the ratios for three MSOAs in the other LA. In the left-hand diagram, there is a substantial difference between the two LAs – both from the London-wide situation and from each other; but there is much less variation in the ratios for the constituent MSOAs within each of the LAs: segregation appears to be greater at the macro-scale (inter-LA) than at the meso-scale (intra-LA), the latter holding the former constant. In the central diagram, the two LAs do not differ substantially either from London's

overall ratio or from each other but there is substantial variation across the MSOAs within each: segregation in this case is greater at the meso- than the macro-scale. Finally, the right-hand diagram shows substantial variation at both scales.

The goal of the modelling procedure is to evaluate the degree of segregation, for each of the seven ethnic groups, at each of the scales – macro-, meso- and micro- in the current example – net of its degree at the next larger scale. In the London case, therefore, it assesses the extent of segregation across the LAs around the London-wide ratio, the extent across all of the MSOAs (each assessed within the relevant LA), and the extent across all of the OAs (each assessed within the relevant MSOA). The key statistic for this evaluation is the Median Rate Ratio (MRR), which is derived from the modelled variances of the logged observed:expected ratios.<sup>9</sup> Each MRR value has associated Bayesian Credible Intervals (CIs), which – in the present example and following standard practice regarding statistical testing – encompass 95% of all the likely estimated values; unlike standard confidence intervals, however, these Bayesian measures are not based on asymptotic normality assumptions and so can be asymmetric. (The approach was originally developed by Larsen and Merlo (2005) for multilevel logit models – the Median Odds Ratio – and extended by Larsen (2006) to log Poisson models – the Median Mean Ratio. We prefer the term Median Rate Ratio as being more descriptive of what it measures, as do Chan et al. (2011). The term mean ratio comes from the use of the Poisson model in the analysis of mean incidence rates and Larsen was aiming to develop a comparable measure for the interpretation of random effects.)

Interpretation of the MRR values can be appreciated through the following example. Randomly select two areas for a particular ethnic group at a particular scale. These are draws of the observed:expected ratios on the log scale from a distribution with the estimated variance – the larger the variance the greater the segregation, and the greater the likelihood of a substantial difference between the ratios. Repeating this many times, selecting pairs of areal units at random, obtaining the log rates, exponentiating them, and then calculating the ratio of the largest value to the smallest, produces a frequency distribution for those ratios, from which we can derive the median value. If there is little or no segregation there will be little variation in the ratios; the median, or typical, ratio will be close to 1.0. If there is segregation at that scale, on the other hand, the median ratio will be greater than 1.0. The MRR values can be classified in the same way that Cohen (1988) suggested for the effect sizes of odds ratios: values greater than 4.3 indicate very large ratios, and hence high degrees of segregation (at that scale) – the ethnic group under consideration is substantially concentrated in some of the areas and relatively absent from the others; MRRs between 2.5 and 4.3 and between 1.5 and 2.5 indicate medium and small levels of segregation respectively; and MRRs less than 1.5 are considered low. Although valuable as a baseline, our focus here is largely on the relative size of the MRRs and their statistical significance rather than on Cohen's classification: further research is being undertaken to find a more-readily interpretable measure (such as a rescaling of the MRR).

### **London's ethnic populations**

The data used in the analyses here are taken from the 2001 and 2011 censuses of England and Wales. These are available at a variety of spatial scales, for which we have selected three: the

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<sup>9</sup> The calculation of the MRR is a simple transformation of the between-area variance for a particular group at a particular scale:  $MRR = \exp[\sqrt{2 * Variance} * 0.6745]$ ; the value 0.6745 is the 75<sup>th</sup> percentile of the cumulative distribution function of the Normal distribution with mean 0 and variance 1.

Output Areas (OA) which are the smallest available; which nest within the Middle-Level Super Output Areas (MSOAs); and which in turn nest within the 32 Local Authorities (LAs – the London Boroughs) – respectively, they represent local neighbourhoods, suburban and inner city districts, and the main administrative units within the city’s geography.<sup>10</sup> Most of the OAs (some 97% across all boroughs) were common at the two censuses, and using information provided by the Office of National Statistics (ONS) we have been able to reconstruct the map of those OAs that were changed between the two enumerations to create a common data set comprising 24,033 OAs, with mean populations of 298 in 2001 and 340 in 2011. These were nested into the 983 MSOAs – giving an average of 24 OAs in each: their mean population in 2011 was 8,315, with a standard deviation of 1,448. In turn, the MSOAs were nested within the 32 boroughs, whose 2011 populations ranged from 158,649 to 363,378; there was an average of 759 OAs in each borough.

The analyses of ethnic segregation in this three-scale hierarchy use the ONS classification into the eleven largest types taking into account changes in reporting self-identified ethnicity between the two censuses. Our focus here is on the seven named minority groups in the ONS classification – Bangladeshis, Indians, Pakistanis and Chinese plus Black Africans, Black Caribbeans and Black Other.<sup>11</sup> Those reporting a mixed ethnicity (mainly White-Asian and White-Black) are combined as are the various White sub-groups (in part because of the differing definitions in the two censuses); measures of their segregation are included below for comparative purposes only with attention focused on the seven groups.<sup>12</sup> The groups, with their total populations, are shown in Table 1. London’s population increased by just over 1 million during that decade (14 per cent). The White population declined, however, whilst all of the minority ethnic groups – with the exception of the longest-established Black Caribbeans – increased substantially, through a combination of natural increase and immigration. The modelling undertaken here allows an appreciation of the impact of that substantial shift to a more multi-ethnic city on population distributions: did the various groups become more or less spatially segregated, and if so at what scales?

The analyses reported below evaluate the MRR values, with their associated CIs, for each of those eleven groups, at each of the three scales – net of the higher scales – for each of the two censuses. In their interpretation, it is important to note that this is just one of a very large number of possible spatial realisations that could be deployed with these data, and that the usual caveats regarding the modifiable areal unit problem (MAUP) need to be taken into account. This applies in particular to the larger spatial units – the local authorities (LAs) – although these boroughs are meaningful entities within London, being responsible for a range of public services, such as education, and spatial variations in their provision are relevant to household location decisions. Given the clarity of the findings set out below, however, it is almost certain that whatever division of London was deployed at the largest scale the same general pattern would emerge, though this claim remains an important issue to be evaluated in future research; it may be too (as Fowler 2015, argues) that different configurations are relevant to different parts of an urban area – another issue for further research.

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<sup>10</sup> We do not treat the small City of London as a separate borough for these analyses.

<sup>11</sup> There is much debate about the validity of the ‘official’ classification of ethnic groups developed by the Office of National Statistics and used in most official, and some other, data collections: some groups are based on country of origin – such as Indian and Pakistani – and others on skin colour and continent of origin – such as Black African; see, for example, Berthoud (1998) and Sillitoe and White (1992).

<sup>12</sup> In 2001 there were three categories – White British, White Irish and White Other. The heterogeneity of the third was slightly reduced in 2011 by the separation out of Gypsy/Irish Traveller, but the group remains very heterogeneous. These latter are also the groups for which definitions changed between the 2001 and 2011 censuses (Catney 2015b, Table 1).

## The pattern of segregation

The MRR values for each of the ethnic groups, at each of the scales, and for both dates, have been arranged in two separate ways in order to illustrate fully the patterns of segregation revealed by the modelling.

### *Segregation by Ethnic Group and Scale*

In the first – Table 2 – they are organised by ethnic group and scale. No single, stylised fact summarises the segregation patterns portrayed there, but a number of important findings stand out. The first is that most of the MRR values were not particularly large on Cohen's scale. Only two (for Bangladeshis at the LA and OA scales) could be categorised as very large (i.e. greater than 4.3) in 2001 and none in 2011. Only seven more (out of a total of 33) fell into the large category (2.5-4.3) in 2001, and three in 2011. Indeed, excepting the Bangladeshis there was very little evidence of intense segregation; nevertheless, many of the MRR values exceed 2.0; at the OA scale for example, the ratio of the observed:expected number of members of the BME group in randomly-selected pairs of neighbourhoods indicates that on average concentration in some neighbourhoods is at least twice the rate it is in others.<sup>13</sup> Of the MRR indices greater than 2.5, across the two dates, seven occurred at the macro- (LA) scale and a further five at the micro- (OA, neighbourhood) scale, with none at the intermediate (or meso-scale) represented by the MSOAs.

For a majority of the seven groups segregation at the macro- (LA) scale was not significantly different in 2001 from that for the micro- (neighbourhood) scale.<sup>14</sup> Each group was concentrated in particular boroughs within London, and within those was clustered to the same extent in some neighbourhoods much more than others, suggesting a clear two-scale decision-making process regarding residential location. Segregation was significantly less at the meso-scale for most groups, however, suggesting that within each borough – whether a group was numerous there or not – there was relatively little variation in its distribution across the constituent districts (represented by the MSOAs); Figure 2 illustrates this general V-shaped pattern of substantially more segregation at the macro- and micro- than the meso-scales; the most marked differences across the three scales are for Bangladeshis, followed by Pakistanis and Black Others.

These general patterns apply to all seven of the main BME groups, with one exception. There was significantly greater segregation for the Black Caribbean population at the macro- than at the meso-scale, and then at the meso- than at the micro-scale. Of the main ethnic groups

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<sup>13</sup> At this pioneering stage of work using the modelling procedure it is difficult to establish a paradigm frequency distribution for the MRR values and it may be that ratios exceeding 4.3 are rare in all cities. To date, the only comparable investigation – of Auckland, New Zealand (Manley et al. 2015b) – has resulted in a very similar pattern of MRR values. See, however, a further study of Sydney, using a much more disaggregated set of ancestral groups, for which many of the MRR are much larger than observed for Auckland and London (Johnston et al. 2016).

<sup>14</sup> This conclusion is drawn by comparing the 95% CIs for the two MRR values. If they overlap, then it is very likely that the difference between the two values could have been a chance occurrence only. Thus in Table 2, for example, the distributions for Bangladeshis in 2001 at the Borough (3.48:7.85) and OA (5.88:6.33) scales clearly overlap, so that we cannot conclude that the MRR for the latter scale – 6.09 – is significantly larger than that for the former – 4.99. However, neither of those distributions overlap that for the MSOA scale (2.24:2.51) and so it can reasonably be concluded that segregation was higher at both the macro- and the micro-scales than it was at the meso-scale.

identified in the census, the Black Caribbeans have been in London in substantial numbers for the longest period – with the main wave of immigrants being initiated in the late 1940s to meet advertised labour demands. As Table 1 shows, by the twenty-first century growth of this group had almost ceased, with little immigration during the 2001-2011 decade. Over the fifty years those claiming Black Caribbean ethnicity had become more integrated into London’s economy and society than many of the later-arriving groups; they remained concentrated into particular boroughs (including those where they originally settled), as the relatively high MRR value for that scale indicates, but they were significantly less segregated at the smaller scales, indicative of a much wider distribution across their chosen districts (the meso-scale MSOAs) than was the case with the other specified groups then. Indeed, the Black Caribbean MRR at the OA scale was significantly smaller than that for all of the six ethnic groups above it in Table 1.<sup>15</sup>

Finally regarding the patterns in 2001, there is a division into two sets of ethnic groups, according to whether segregation was greater at the macro- or micro-scale. The first – including Bangladeshis, Pakistanis, and Chinese – are those more segregated at the latter, neighbourhood, scale. They are all – to a greater or lesser extent – concentrated into particular boroughs at the macro-scale, but within those boroughs’ districts they are (in most cases relatively strongly) clustered into particular micro-scale neighbourhoods. Among the seven BME groups, however, only for the Chinese is the micro-scale MRR value significantly larger than that for the macro-scale: in relative terms the Chinese are more widely distributed across the city’s boroughs than the Bangladeshis and Pakistanis, for example, but wherever they are concentrated at that scale they are significantly more segregated into particular neighbourhoods within individual districts.<sup>16</sup> The Black Caribbean, Black African and Black Other groups (both of the latter relatively heterogeneous in cultural backgrounds) were more segregated at the macro- than the micro-scale – but in all cases there is no significant difference between their borough and OA MRR values.

Turning to the situation for each group in 2011, shown in Table 2’s second set of columns, there is evidence of considerable change during the preceding decade. Among the seven largest minority groups only for the Chinese was segregation greater at the micro- than at the macro-scale – and significantly so. Higher MRR values at the macro- rather than the micro-scale (although not significantly so in five cases) suggests considerable diversification in local population composition at the neighbourhood scale during the decade. Relative to the changes at the borough scale, neighbourhoods became more diverse over the decade, notably for four of the BME groups: for Bangladeshis, for example, the micro-scale MRR fell from 6.09 to 3.57; for Pakistanis, Chinese and Black Others there was a decline of c1.0 in that MRR. Neighbourhood segregation in London clearly declined over the decade.

### *Segregation by Scale and Over Time*

To examine patterns of change in more detail, the data in Table 2 are reordered in Table 3. The ethnic groups are arranged within each of the scales according to their MRR values in

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<sup>15</sup> For comparable patterns in Manchester, over a longer time period, see Brown and Cunningham (2016).

<sup>16</sup> Interestingly, the more heterogeneous Indian population is not in this group – but its separate Hindu, Muslim and Sikh populations may well be more segregated at the neighbourhood scale, a hypothesis that cannot be tested because of the absence of data on religion by ethnicity at the OA scale. Indians as a collective entity congregate in particular boroughs, but do not congregate as much as other Asian groups in particular neighbourhoods.

2001. Where an MRR value is significantly smaller than that above it in the list for 2001, the two values are separated by a horizontal line to inquire whether there are significant differences in inter-group segregation levels: for example, at the MSOA scale the CIs for Bangladeshis and Black Other do not overlap; Bangladeshis were significantly more segregated than Black Others at that scale then. Secondly, where the MRR value for an ethnic group in 2011 is significantly smaller than that for 2001, the 2011 value (in the right-hand set of columns) is shown in bold; in the one case where the 2011 MRR value is the larger of the two (for Whites), this is shown in italics.

Several major findings emerge from this table. The first is that – in general, and in line with other studies using descriptive approaches – the South Asian ethnic groups (particularly the predominantly Muslim Bangladeshis and Pakistanis) were the most segregated. At the larger two scales – LA and MSOA – the three Black ethnic groups were also high up the listing, but they were less so at the OA scale; they are concentrated in particular boroughs but, unlike the Bangladeshis and Pakistanis, not also as concentrated in particular neighbourhoods within them.

A second major finding is that although there were substantial differences in levels of segregation at the borough scale across the groups at both dates – a ratio of over 4:1 in 2001 (4.99:1.24) and just under 3:1 in 2011 (3.80:1.31) – there was only one case of an MRR significantly different from the next largest (a function, in considerable part, of the small number of observations at this scale, producing much wider CI spans than at the other two<sup>17</sup>).<sup>18</sup>

At the meso-scale (MSOA) the MRR values are, as noted in the discussion of Table 1, much smaller, and there is also much less variation – a ratio between the largest and the smallest of only 1.87 in 2001 and 1.63 in 2011. Nevertheless, the much narrower CI spans mean that the differences between adjacent pairs in the ordering of ethnic groups in 2001 were more likely to be statistically significant and in five cases – including the three most segregated at this scale (Bangladeshi, Black Other and Pakistani) – there was a statistically significant fall in the level of segregation between 2001 and 2011. Consistent with arguments regarding socio-spatial mobility within those groups, they became significantly more widely distributed across the districts within each borough, resulting in locally more diversified populations at that scale.

This patterning of changes in the degree of segregation in terms of statistical significance is even clearer at the micro-scale. In all but two cases each group was significantly less segregated than that with the next highest MRR in 2001; and for all but one of the seven of the largest minority groups the level of segregation at this scale was significantly smaller in 2011 than in 2001: the exception was for the Black Caribbeans, for whom there was no change. At this finest scale, substantial de-segregation characterised the experience of most of London's largest ethnic minorities.

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<sup>17</sup> In this context it is important to have regard to Ziliak and McCloskey's (2008) argument regarding the over-attention paid to significance testing in the social sciences. The findings at the Borough scale show very substantial differences that should be recognised as such: that many of the differences are not statistically significant indicates the need for some caution in their interpretation – a situation that could only be overcome by simulation studies that grouped the MSOAs into 32 Borough-scale units many times. The MRR values for each could then be compared to see if those produced for the 'actual' Boroughs are representative of the simulation-derived frequency distributions.

<sup>18</sup> The argument developed in the previous footnote applies to the analyses of change over time as well.

### *Stability in Distributions*

As well as measuring the degree of segregation we are often also interested in the degree to which there is the same pattern of ratios for any one ethnic group across the observation units at a particular scale at two separate dates; have their spatial distributions changed over the period? A further output from the modelling procedure is a set of correlations – interpretable in the same way as standard product-moment correlation coefficients – between the logged ratios. Such correlations are shown in Table 4 for each of the ethnic groups being studied, at each of the three scales.

One finding stands out from this table: the correlations are on average very high (0.87) at both the borough and the MSOA scales, but much smaller (0.55) at the OA scale. For all of the groups, there was very little change in their distributions across London at the macro- and meso-scales (only two of the correlations were less than 0.83): each was found concentrated in very much the same boroughs and, within the boroughs, in the same districts as before. At those scales, London's ethnic geography changed very little. At the micro-scale, on the other hand, there was much more change, with most of the correlations substantially smaller than those for the higher two scales. London's macro- and meso-scale ethnic geographies may have changed very little over the twenty-first century's first decade, but the micro-scale geographies changed considerably; neighbourhoods were becoming ethnically more diverse in their ethnic structures – as Catney (2015a) and Johnston et al. (2015) have shown for the micro-scale only, though without placing such changes in the wider macro- and meso-scale contexts.

This finding is clearly consistent with those set out earlier in the analyses and discussion of the MRR values. Among the seven BME groups the greatest stability – at all three scales – was for Black Caribbeans; for many of the others – notably the Asian groups other than Indians – stability at the macro- and meso-scales was associated with considerable instability at the micro-scale. Individual small neighbourhoods were much more likely to see the ethnic composition of their populations change than were districts and boroughs – as a consequence, demonstrated by the MRR values in Tables 2 and 3, of greater diversification at that scale.

### **Discussion**

The findings from this pioneering modelling of multi-scale ethnic segregation in London over a decade when the city's Non-White population increased substantially have thrown greater light on the situation than most other studies, and indicated a requirement for what Lee et al. (2008, 785) identified as 'an even greater need for scale-specific theorizing about segregation' – a task that they however avoided. The reasons for that need are clear from this London case-study, which has shown that segregation there was as great at the macro- as at the micro-scale for most groups, and also greater at both of those than at the meso-scale. (A very similar set of findings emerged from a parallel application of the method to another, though very different, multi-ethnic city: Manley et al. 2015b.)

Why is it that – for this large city in particular and, probably, for many others although extensive further research is needed before any wider generalisations can be drawn – macro-scale processes are apparently as important an influence on the evolving residential mosaic as micro-scale processes for members of ethnic minority groups the majority of whose members' labour market situations mean that they are relatively disadvantaged in the housing

market, substantial segments of which are closed to them (on which see Khattab et al. 2015)? In a city as large as London, members of those groups nevertheless have considerable choice of where to live because there are multiple segments comprising relatively low-cost housing (private sector, public sector, or social) that they could afford. (On housing choice, see van Ham 2012.) In most cases, initial migrants in a particular group gravitate towards an area – such as the docklands districts to the north of the Thames in London’s East End for Bangladeshis – and others join them there through processes of chain migration. As the group grows the area in which it is concentrated expands into adjacent neighbourhoods whilst some members who are economically and socially mobile – especially those in the second and later generations, with their families – move away from those core neighbourhoods, but in many cases not too far. For many, their job situations may restrict their choice of destinations to the same city sector, where they may also want to remain so as to be in relative proximity to family, social networks and cultural institutions in the area where many of their co-ethnics remain concentrated. Within that favoured segment, therefore, there are micro-scale (neighbourhood) concentrations where members of the ethnic group form relatively large proportions of the local population, and others where they are relatively less numerous. Over time, the neighbourhood clusters become slightly less pronounced, as group members move not only to adjacent neighbourhoods but also to nearby districts within that favoured segment of the city.

For other groups – notably those categorised as White, whose residential patterns have not been a focus of the analyses here – decisions on which macro-segment of the city to live in probably reflect a slightly different set of factors, such as access to employment opportunities and/or social, educational and cultural facilities and institutions, plus housing densities and costs. There may also be negative influences suggesting they actively avoid certain segments of the spatial housing market – such as the presence there of substantial ethnic minority populations (Schelling 1969; Clark 1991). Once such a pattern is established, it then becomes self-sustaining; many people moving home tend to stay within the same general area of the metropolis.. (On search spaces in London, see Rae and Sener 2016.)

This sketch of multi-scale location decision-making provides the framework for an appreciation of the patterns revealed by the modelling reported here. Minority ethnic groups cluster, for a variety of reasons, in particular segments of the city – the macro-scale patterns illustrated by the high levels of segregation reported at the borough scale; in part this reflects housing market constraints because of income levels, but most groups are spatially more concentrated than their incomes would require (Johnston et al. 2016). Each group is concentrated in a few London boroughs only, and as a consequence, though to a lesser extent, so are those who are not involved in such clustering for cultural as well as economic reasons, notably Whites in the classification deployed here plus those in the heterogeneous Mixed and Other categories. Within each of the boroughs, there is little segregation at the meso-scale of the district, however. In those boroughs where a particular group is concentrated, they tend to form roughly the same proportion of the population across its MSOAs (or at least the variation is much less than it is across boroughs at the macro-scale), as is also the case (with much smaller percentages) in those where they are not clustered. In general, across each major segment of the city’s suburbs there is much less diversity in the ethnic composition of its districts’ populations than is the case when comparing those major segments with each other.

Within the meso-scale districts, however, there is considerable micro-level segregation, as indicated for the OAs in the present analyses. Most ethnic groups are clustered into particular

segments at the macro-scale, but they rarely predominate there (Johnston et al. 2014a); clustering is not necessarily associated with concentration and predominance within the local population. Nevertheless, within those macro-scale areas of clustering there are almost invariably – especially for the ethnic minority groups whose geographies are analysed here, such as London’s South Asians – neighbourhoods where they form a substantial proportion of the local population. Hence the bi-polar nature of the findings reported here: segregation, according to our modelled measure, is greatest at the macro- and micro-scales, reflecting the clustering of group members into particular segments of the urban fabric and their concentration into preferred neighbourhoods within those segments. Both macro- and micro-scale segregation declined over the decade studied, however: regarding the latter, there was significantly less variation across the OAs within individual MSOAs in the relative presence of members of almost all of the minority ethnic groups compared to what might be observed if they were evenly distributed. Neighbourhoods were becoming significantly less segregated – more so than boroughs; the macro-scale patterning of the mosaic was changing less than its micro-scale detail.

The modelling framework adopted here not only enables evaluation of this multi-scale sketch of residential segregation processes not available from the host of studies using single-number indexes at single scales only; it also throws greater light on changes to the residential mosaic. The statistical foundation for the modelling procedure provides the basic information. For example, not only are Black Caribbeans – the longest established of London’s main minority ethnic groups and the one that grew least between 2001 and 2011 – less segregated than most of the other BME groups but this is particularly marked at the micro-scale. They are still clustered into particular macro-scale segments of the city but, as expected of a long-established group that has experienced more economic and socio-cultural integration than other, more recent arrivals, they are not as concentrated into specific micro-scale neighbourhoods within those segments as members of those other groups. Increasingly, for the Black Caribbeans, macro- rather than meso- and micro-scale segregation is the dominant feature of their residential geography. Indeed, the findings for change over the 2001-2011 decade indicate that this is the emerging situation with all of those minority ethnic groups. Each was significantly less segregated at the micro-scale in 2011 than 2001: individual neighbourhoods where they are clustered are becoming more diverse in their ethnic composition.

## Conclusions

Residential segregation is a frequently-raised issue in discussions of Britain’s increasingly multi-ethnic, multi-cultural society, not simply as an aspect of its geography to be described but also because it is presented by some as raising problems within – even threats to – that society. Thus Professor Ted Cantle is quoted in the *Guardian* article referred to earlier saying that increased segregation ‘risks fuelling prejudice’ and that ‘growing divisions had led to mistrust within communities across the country’, adding that ‘We know that people who live in closed communities are more fearful of other and more likely to be prejudiced to people from other backgrounds’.<sup>19</sup> Accurate measurement of segregation and how it is changing is necessary to put such comments into context.

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<sup>19</sup> <http://www.theguardian.com/world/2016/may/23/britain-more-segregated-15-years-race-expert-riots-ted-cantle>.

The research on London reported here, using a statistically more robust procedure than other studies of segregation, has provided clear evidence that neighbourhood-level segregation of seven BME groups decreased over the 2001-2011 decade, but that this decrease has been set within a more stable geography of macro-scale segregation for each of those groups. All seven are concentrated in a small number of boroughs only – the Chinese less so than the other six groups – and this element of London’s residential fabric has changed less over the decade: each group is firmly established in some major segments of the metropolis only, but within those segments has become somewhat more widely dispersed over their constituent neighbourhoods. This does not, of course, necessarily imply that the problems identified by commentators as linked to segregation are also diminishing in their intensity and importance, but it does indicate that their presence cannot be associated with increasing segregation.

The modelling approach to the study of ethnic residential segregation employed here, on which those conclusions are based, was introduced as having five main advantages over the standard, single-scale descriptive indices normally deployed in such study, plus several of the more sophisticated procedures developed recently. The case study of London has illustrated those advantages, providing very substantial extensions to that appreciation. Its conclusions cannot be immediately applied to other places without empirical confirmation and it may be that (as shown by Krupka 2007 and Reardon et al. 2008 2009 for US cities and Johnston et al. 2014b 2015b for England and Wales: see also Catney 2016 – albeit all of them using descriptive measures of segregation only) the degree of segregation varies according to local circumstances within an urban system – as might the relative importance of segregation at different scales. But the patterns observed for London are consistent with what is generally known about household residential location-decision-making, including by members of ethnic minority groups (e.g. Simpson et al. 2008; Stillwell and Phillips 2006).

This paper has thus established the multi-scale nature of changing patterns of ethnic residential segregation in London on a rigorous statistical basis, allowing assessments of the significance of differences between the intensity of groups over time. Significant neighbourhood change, resulting in greater diversity of local population characteristics, has occurred for most of London’s seven largest ethnic minority groups between 2001 and 2011, but this has been set within much less evidence of comparable change at the meso-scale, and none of significant change at the macro-scale. Greater neighbourhood diversity has occurred within a matrix of little significant variation at the district and borough scales. The macro-scale outlines of London’s ethnic geographies remained largely unchanged over that decade – the different groups remained clustered in the same sections of the urban area – but within that broad pattern there was significant micro-scale change.

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## Appendix: Model Specification

Jones et al. (2015) discuss the general specification the Poisson multilevel level model for estimating the degree of segregation. Here, in practice, we fit a four-level random-effects Poisson model using data for eleven ethnic groups at four spatial scales at two time points, 2001 and 2011. To explicate the exact model that was used, while saving space, we show the formulation for only two example ethnic groups (Black African and Black Caribbean) and for just two geographical scales; OA and MSOA. This requires a three-level model:

$$O_{ijk} \sim \text{Poisson}(\pi_{ijk})$$

$$\text{Log}_e(\pi_{ijk}) = \text{Log}_e(E_{ijk}) + \beta_{1jk}Afric01_{ijk} + \beta_{2jk}Afric11_{ijk} + \beta_{3jk}Carib01_{ijk} + \beta_{4jk}Carib11_{ijk}$$

$$\begin{aligned}\beta_{1jk} &= \beta_1 + v_{1k} + u_{1jk} \\ \beta_{2jk} &= \beta_2 + v_{2k} + u_{2jk} \\ \beta_{3jk} &= \beta_3 + v_{3k} + u_{3jk} \\ \beta_{4jk} &= \beta_4 + v_{4k} + u_{4jk}\end{aligned}$$

$$\begin{bmatrix} v_{1k} \\ v_{2k} \\ v_{3k} \\ v_{4k} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma_{v1}^2 & & & \\ \sigma_{v12} & \sigma_{v2}^2 & & \\ & & \sigma_{v3}^2 & \\ & & \sigma_{v34} & \sigma_{v4}^2 \end{bmatrix}\right)$$

$$\begin{bmatrix} u_{1jk} \\ u_{2jk} \\ u_{3jk} \\ u_{4jk} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma_{u1}^2 & & & \\ \sigma_{u12} & \sigma_{u2}^2 & & \\ & & \sigma_{u3}^2 & \\ & & \sigma_{u34} & \sigma_{u4}^2 \end{bmatrix}\right)$$

$$\text{Var}(O_{ijk}|\pi_{ijk}) = \pi_{ijk}$$

where  $O_{ijk}$  is the long stacked vector of the observed count for ‘individuals’  $i$  in OA  $j$  in MSOA  $k$ . The other observed variables are the expected counts ( $E_{ijk}$ ) for the each ethnic group if their numbers were distributed evenly according to the total population size of the OA. There are also four separately coded dummy (0/1) variable (e.g.  $Afric01_{ijk}$ ) that identify which count represents which ethnic group in which year.

As is common with count data we assume that they come from an underlying Poisson distribution with a mean rate of  $\pi$ . However, it is the natural log of the underlying rate that is modelled and this is achieved by the use of an offset which is the log of the expected count with a coefficient constrained to 1 (McCullagh and Nelder 1989). There are four intercepts in the model,  $\beta_1$  gives the log average rate across London for Black Africans in 2001, while  $\beta_4$  is the equivalent average log rate for the Caribbean population in 2011. We anticipate that each of these estimates will when exponentiated give the all-London rate for the mean area as 1 as the sum of the observed counts will equal to the sum of the expected. Around these averages differentials are allowed to vary so that  $v_{1k}$  give the differential for MSOA  $k$  for Black Africans in 2001. If this value is positive there are more of such people than an even distribution suggests; while if the random differential is negative there are less. Additionally

there is another set of differentials at the OA level so that  $u_{4jk}$  is the differential for Black Caribbean for  $OA_{jk}$  from MSOA  $k$  which is itself a differential from the average ( $\beta_4$ ) across London for this group. In this way the observed values are ‘decomposed’ into an average and differentials at different scales in the hierarchy.

These differentials at each of the higher levels are assumed to come from a joint Normal distribution so that the variance  $\sigma_{v1}^2$  gives the segregation for Black Africans at the MSOA in 2001 level and we can test whether this is different from the variance for Africans in 2011,  $\sigma_{v2}^2$ . The higher-level covariance term (e.g.  $\sigma_{v12}$ ) will give when standardized (by the product of the square root of the associated variances) the correlation for the differentials at that level between the ethnicities at the two time points, indicating the extent to which the patterns are stable over time. There is another set of variance-covariances at the OA level which summarizes the within-MSOA between-OA differentials. The variances (e.g.  $\sigma_{u1}^2$ ) on the main diagonal are our measure of segregation for OAs (net of MSOA segregation) and the covariances on the off diagonal give an estimate of the stability of the differentials at the OA for the same ethnic group at the two time points.

The final line of the specification states that the variance of the observed counts conditional on the underlying rate is equal to the underlying rate (the mean and variance of a Poisson distribution are always exactly the same). This allows the other estimates in this generalized linear model to take account of the Poisson stochastic nature of the underlying counts. In practice in this three-level model there is exactly the same set of units – known as the ‘cells’ – at level 1 and level 2; that is, each level 2 unit has exactly one level 1 unit. This views the aggregated counts at level 2 as consisting of replicated responses for individuals at level 1. This use of a pseudo-level is explained in Browne et al. (2005) in relation to the binomial model and allows the separation of the variance into exact Poisson at level 1 and over-dispersion at level 2 and level 3 so that the higher-level variances summarize the ‘true’ differences between areas over and above those expected from a random variation due to the absolute size of the count. All the models were estimated in MLwiN software as Fully Bayesian models by using MCMC procedures (Browne 2012; Jones and Subramanian 2014), this allows the degree of support for the estimate, in the form of credible intervals to be obtained. As is common with Poisson models a long run of the MCMC simulation was needed after a long burn-in preceded by an initial quasi-likelihood estimation. We examined via diagnostics the reasonableness of the between cell Normality assumption and this was met in all the analyses.

**Table 1.** London's changing ethnic population, 2001-2011.

<u>Group</u>	<u>2001</u>	<u>2011</u>	<u>Group</u>	<u>2001</u>	<u>2011</u>
Bangladeshi	153,841	222,127	Black African	378,924	573,931
Indian	437,084	542,857	Black Caribbean	343,616	344,597
Pakistani	142,719	223,797	Black Other	60,311	170,112
Chinese	80,124	124,250			
Mixed	226,282	405,279	Asian Other	133,109	398,515
White	5,103,176	4,887,435	Other	112,812	281,041.
TOTAL	7,171,998	8,173,941			

**Table 2.** The MRR values, with associated Low and High CIs, for each ethnic group, at each scale, at each date

	2001			2011		
	LowCI	MRR	HighCI	LowCI	MRR	HighCI
<i>Bangladeshi</i>						
Borough	3.48	4.99	7.85	2.81	3.80	5.57
MSOA	2.24	2.36	2.51	1.98	2.06	2.17
OA	5.88	6.09	6.33	3.49	3.57	3.65
<i>Pakistani</i>						
Borough	2.45	3.17	4.40	2.35	3.01	4.10
MSOA	2.00	2.08	2.17	1.86	1.92	1.99
OA	3.27	3.35	3.43	2.37	2.41	2.45
<i>Indian</i>						
Borough	1.91	2.29	2.89	1.88	2.26	2.82
MSOA	1.76	1.81	1.87	1.72	1.76	1.81
OA	1.88	1.90	1.92	1.77	1.78	1.80
<i>Chinese</i>						
Borough	1.51	1.71	1.99	1.40	1.55	1.76
MSOA	1.60	1.65	1.71	1.57	1.61	1.66
OA	3.14	3.21	3.28	2.15	2.18	2.20
<i>Black African</i>						
Borough	2.07	2.55	3.02	1.71	2.01	2.47
MSOA	1.87	1.93	1.99	1.91	1.97	2.04
OA	2.04	2.06	2.08	1.91	1.93	1.95
<i>Black Caribbean</i>						
Borough	2.14	2.67	3.52	1.93	2.34	2.98
MSOA	1.80	1.85	1.91	1.74	1.79	1.84
OA	1.69	1.71	1.72	1.70	1.71	1.73
<i>Black Other</i>						
Borough	2.38	3.07	4.20	1.97	2.41	3.08
MSOA	2.01	2.09	2.18	1.82	1.87	1.93
OA	2.87	2.94	3.01	1.94	1.96	1.98
<i>Asian Other</i>						
Borough	1.80	2.13	2.64	1.55	1.76	2.07
MSOA	1.69	1.74	1.79	1.49	1.52	1.55
OA	2.35	2.39	2.42	1.67	1.68	1.69
<i>Mixed</i>						
Borough	1.33	1.44	1.60	1.27	1.36	1.49
MSOA	1.27	1.28	1.30	1.24	1.26	1.27
OA	1.64	1.65	1.66	1.51	1.51	1.53
<i>Other</i>						
Borough	1.83	2.18	2.71	1.68	1.95	2.34
MSOA	1.52	1.56	1.60	1.40	1.42	1.47
OA	2.29	2.32	2.36	1.71	1.72	1.73
<i>White</i>						
Borough	1.18	1.24	1.31	1.24	1.31	1.42
MSOA	1.23	1.24	1.25	1.31	1.33	1.35
OA	1.14	1.15	1.16	1.19	1.20	1.20

**Table 3.** The MRR values, with associated Low and High CIs at each scale, for each ethnic group, at each scale and date.

Borough Scale	2001			2011		
	LowCI	MRR	HighCI	LowCI	MRR	HighCI
Bangladeshi	3.48	4.99	7.85	2.81	3.80	5.57
Pakistani	2.45	3.17	4.40	2.35	3.01	4.10
Black Other	2.38	3.07	4.20	1.97	2.41	3.08
Black Caribbean	2.14	2.67	3.52	1.93	2.34	2.98
Black African	2.07	2.55	3.02	1.71	2.01	2.47
Indian	1.91	2.29	2.89	1.88	2.26	2.82
Other	1.83	2.18	2.71	1.68	1.95	2.34
Asian Other	1.80	2.13	2.64	1.55	1.76	2.07
Chinese	1.51	1.71	1.99	1.40	1.55	1.76
Mixed	1.33	1.44	1.60	1.27	1.36	1.49
White	1.18	1.24	1.31	1.24	1.31	1.42

MSOA Scale	2001			2011		
	LowCI	MRR	HighCI	LowCI	MRR	HighCI
Bangladeshi	<u>2.24</u>	2.36	2.51	<b>1.98</b>	<b>2.06</b>	<b>2.17</b>
Black Other	2.01	2.09	2.18	<b>1.82</b>	<b>1.87</b>	<b>1.93</b>
Pakistani	2.00	2.08	2.17	<b>1.86</b>	<b>1.92</b>	<b>1.99</b>
Black African	<u>1.87</u>	1.93	1.99	1.91	1.97	2.04
Black Caribbean	1.80	1.85	1.91	1.74	1.79	1.84
Indian	1.76	1.81	1.87	1.72	1.76	1.81
Asian Other	1.69	1.74	1.79	<b>1.49</b>	<b>1.52</b>	<b>1.55</b>
Chinese	<u>1.60</u>	1.65	1.71	1.57	1.61	1.66
Other	<u>1.52</u>	1.56	1.60	<b>1.40</b>	<b>1.42</b>	<b>1.47</b>
Mixed	<u>1.27</u>	1.28	1.30	<b>1.24</b>	<b>1.26</b>	<b>1.27</b>
White	1.23	1.24	1.25	1.31	1.33	1.35

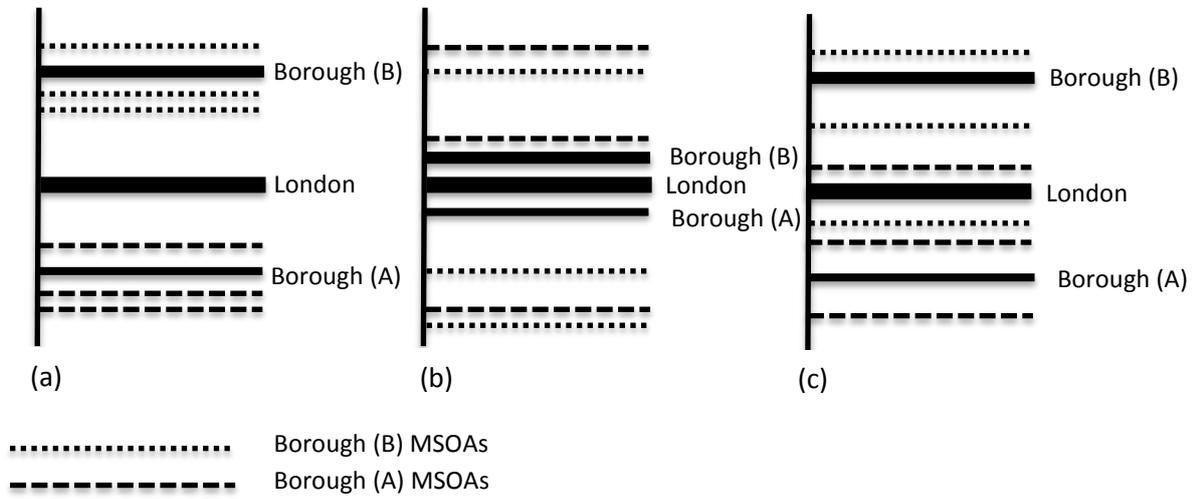
  

OA Scale	2001			2011		
	LowCI	MRR	HighCI	LowCI	MRR	HighCI
Bangladeshi	<u>5.88</u>	6.09	6.33	<b>3.49</b>	<b>3.57</b>	<b>3.65</b>
Pakistani	3.27	3.35	3.43	<b>2.37</b>	<b>2.41</b>	<b>2.45</b>
Chinese	<u>3.14</u>	3.21	3.28	<b>2.15</b>	<b>2.18</b>	<b>2.20</b>
Black Other	<u>2.87</u>	2.94	3.01	<b>1.94</b>	<b>1.96</b>	<b>1.98</b>
Asian Other	2.35	2.39	2.42	<b>1.67</b>	<b>1.68</b>	<b>1.69</b>
Other	<u>2.29</u>	2.32	2.36	<b>1.71</b>	<b>1.72</b>	<b>1.73</b>
Black African	<u>2.04</u>	2.06	2.08	<b>1.91</b>	<b>1.93</b>	<b>1.95</b>
Indian	<u>1.88</u>	1.90	1.92	<b>1.77</b>	<b>1.78</b>	<b>1.80</b>
Black Caribbean	<u>1.69</u>	1.71	1.72	1.70	1.71	1.73
Mixed	<u>1.64</u>	1.65	1.66	<b>1.51</b>	<b>1.51</b>	<b>1.53</b>
White	1.14	1.15	1.16	<i>1.19</i>	<i>1.20</i>	<i>1.20</i>

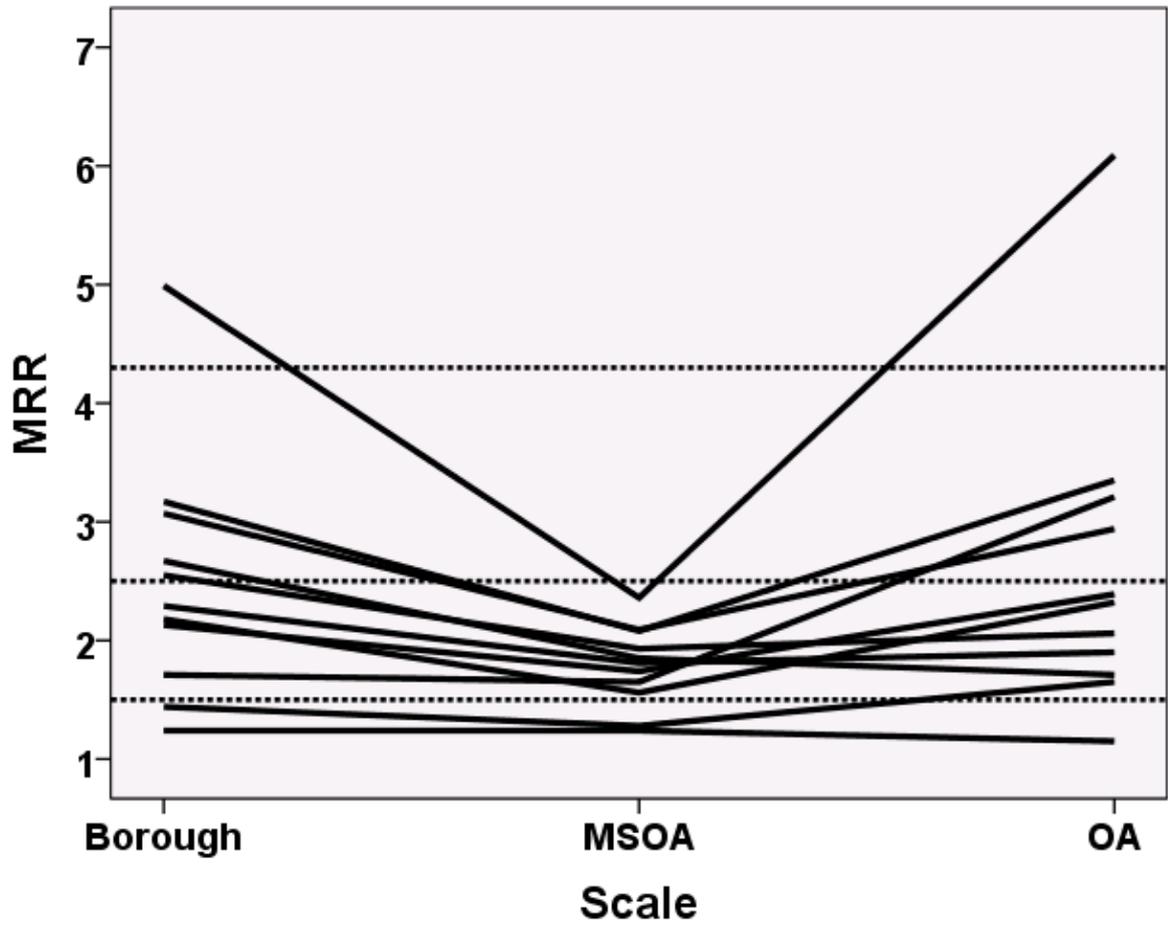
In the left-hand columns, for each of the spatial scales MRR values that are significantly different from those immediately below them in the table are underlined. In the right-hand columns those MRR values significantly smaller than the comparable ones in the left-hand columns are in bold, whereas those significantly larger are in italics.

**Table 4.** The correlations between distributions for 2001 and 2011  
for each ethnic group sorted at each scale

Borough		MSOA		OA	
Group	Corr	Group	Corr	Group	Corr
Black Caribbean	0.93	White	0.96	White	0.98
Black Other	0.92	Black Caribbean	0.94	Black Caribbean	0.80
White	0.91	Indian	0.92	Indian	0.71
Mixed	0.90	Black African	0.92	Black African	0.68
Pakistani	0.89	Black Other	0.91	Chinese	0.52
Asian Other	0.88	Pakistani	0.89	Pakistani	0.51
Indian	0.88	Chinese	0.89	Bangladeshi	0.50
Other	0.83	Bangladeshi	0.87	Mixed	0.41
Chinese	0.83	Mixed	0.84	Black Other	0.38
Black African	0.83	Asian Other	0.83	Asian Other	0.36
Bangladeshi	0.76	Other	0.66	Other	0.21



**Figure 1.** The modelling structure illustrated



**Figure 2.** The MMR values for each ethnic group at each scale, 2001. (The divisions on Cohen's scale are shown as dashed lines.)