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Scale and zonation effects on internal migration indicators in the United Kingdom

Stephane Chatagnier [ORCID] | John Stillwell [ORCID]

School of Geography, University of Leeds, Leeds, UK

Correspondence
John Stillwell, School of Geography, University of Leeds, Leeds, UK.
Email: j.c.h.stillwell@leeds.ac.uk

Abstract

Consistent data from the last two population censuses in the United Kingdom are utilised in this paper to compare migration intensity and impact between two 1-year periods and to identify the scale and zonation effects on the selected migration indicators. The picture of change that emerges is one of declining migration intensities and a diminution in the distribution of migrants from urban to rural areas, with the exception of students and young workers whose net migration losses from rural areas are increasing and whose migration effectiveness is increasing. Scale effects are more apparent for migration intensity than effectiveness, the two components of the aggregate net migration rate, whereas zonation effects are relatively unimportant across scale for intensity but become more significant as zones become larger for effectiveness.

KEYWORDS
impact, intensity, internal migration, scale, United Kingdom, zonation

1 | INTRODUCTION

Quantitative studies of internal migration tend to rely on the use of indicators to measure, in summary form, the propensities, patterns and trends in population mobility in one or more time periods. The identification of indicators that represent the various domains of internal migration and that can be used to compare migration behaviour in different countries around the world has been pioneered by Bell et al. (2002). In most previous national studies, migration data availability or access restrictions dictate that analysis is undertaken at a limited range of spatial scales (often only one) and little attention is paid to the possibility that scale and zonation effects, collectively known as the modifiable areal unit problem (Openshaw, 1983), may exist, let alone how they may vary over time.

One of the twin aims of this paper is to investigate the MAUP effects on internal migration in the United Kingdom (UK), using age-specific flow data published at the local authority district (LAD)

scale from the last two population censuses and a methodology that involves the progressive aggregation of the initial data into increasingly larger spatial units. In particular, we examine how one migration impact indicator, the aggregate net migration rate, together with its components, the crude migration intensity and the migration effectiveness index, vary according to spatial scale and the different zonal configurations that are created by the aggregation of basic spatial units (LADs). Whilst the literature on internal migration in the UK is extensive, our review indicates that little attempt has been made to use the Special Migration Statistics (SMS) from the 2001 and 2011 Censuses to inform our understanding of changes in internal migration between the two time periods, 2000–01 and 2010–11. This paper therefore aims also to fill this gap and contribute to the discussion on how migration propensities are changing in different parts of the world (Champion et al., 2017) and what trends are emerging in the UK in particular, complementing analysis by Lomax et al. (2014) and Champion and Shuttleworth (Champion & Shuttleworth, 2016a, 2016b).

The paper continues in the next section with a short contextual review of recent work on internal migration in the UK and an introduction to the methodology and software used to perform the scale and zonation analysis. This is followed by a discussion of the data and of the means employed to adjust the data to achieve a more consistent set of flow estimates for the two periods in question. Thereafter, crude migration rates are used to demonstrate how migration intensities have fallen over the intervening period, net migration rates are mapped to show the inter-LAD changing spatial patterns of redistribution of people in broad age groups, and intra-LAD migration rates reveal their own unique patterns of change. Variation in scale and zonation effects on the aggregate net migration rate and its components are then explored and the relationship between the crude migration intensity and the migration effectiveness index is revealed for different age groups. Some conclusions are presented in the final section of the paper.

2 | REVIEW

There is a long history of studies of migration in the UK at different spatial scales which starts with Ravenstein (1885) and is exemplified by early post-war contributions from Newton and Jeffery (1951) and Rowntree (1957) through to more recent studies by Champion (2005), Fielding (2012) and Lomax and Stillwell (2017). Recent interest in changing levels of national mobility in the UK was stimulated by Cooke's (2011) time-series analysis in the USA based on data from the US Census Bureau's Current Population Survey (CPS), showing a declining rate of internal migration caused initially by the great recession but also due to increasing secular rootedness. Champion and Shuttleworth (2016a) have subsequently used longitudinal data from the last five censuses in England and Wales to suggest that whilst short-distance (intra-district) moves are in long-term decline, this trend is less evident in longer-distance (inter-LAD or inter-region) migration propensities, once fluctuations due to economic cycles are accounted for. Evidence from annual time-series data for England and Wales since the 1970s reported by Champion and Shuttleworth (2016b) also suggests no long-term decline in the overall intensity, a conclusion supported by Lomax and Stillwell (2017) using an estimated time series of patient reregistration data for moves between LADs in the UK in the 2000s. Champion et al. (2017) contains a number of case studies of migration trends in different countries, showing a diversity of experience across the more developed world.

When analysing migration propensities and patterns and investigating migration trends over time, many researchers (e.g., Bates & Bracken, 1982; Dennett & Stillwell, 2010; Raymer et al., 2007) have used migration data for different age groups since age is proxy for life-course stages and although age itself is not a determinant of migratory decisions, individuals or households in particular age groups are influenced by certain social, cultural and economic drivers associated with being at specific stage within the life course which determine whether a person will migrate or not (Stillwell, 2008).

Rogers and Castro (1981) produced the seminal work on age variations, providing models of migration age schedules with indicators and parameters enabling comparisons to be made between countries and regions. Age data were used in the policy sensitive MIGMOD model of internal migration created for the Office of the Deputy Prime Minister (ODPM) in the UK (Champion et al., 2002; Fotheringham et al., 2004). De Jong and Graefe (2008) and Geist and McManus (2008) have also emphasised the relationship between age and migration intensity and demonstrated the links between life course and migration behaviour including employment status, family status, housing preference and retirement, all of which are related to age since there are patterns where specific age groups are more likely to be influenced by the same factors. A classic example is those in the student age groups who choose to leave home to extend their education, a key life-course event encouraging long-distance migration (Duke-Williams, 2009; Faggian et al., 2006).

Scale is of major importance when it comes to identifying spatial patterns of internal migration and changes taking place therein. Whilst standard regions may be appropriate for monitoring long-distance moves such as those between the north and the south (Lomax & Stillwell, 2017), smaller spatial units such as LADs are more suitable for capturing patterns of counterurbanisation (Champion, 1989, 2005), the predominant feature of sub-national migration in the UK over the last 50 years, although Stillwell et al. (2000) aggregated LADs into more meaningful functional regions to examine this phenomenon. Lomax and Stillwell (2017) suggest that this movement down the urban hierarchy from large cities to smaller cities, towns and rural areas has waned in the 2000s with a decrease in moves from metropolitan to non-metropolitan areas. Since the majority of migration takes place within LADs and typically occurs over shorter distances as residential mobility, a system of spatial units based on wards or output areas is more appropriate for understanding processes such as suburbanisation or reurbanisation. Whilst there are examples in the literature of analysis at ward level focused on ethnic migration at a national level (Simon, 2010) and for particular regions (Stillwell, 2010), the census data for migration at this scale remain underexploited and patient reregistration data are partial and inaccessible. It has become common practice to use individual or micro data to model residential mobility using spatial microsimulation or agent-based modelling techniques (e.g., Jordan et al., 2012) at small area scales in contrast to the gravity or spatial interaction models traditionally used to model internal migration over longer distances (e.g., Flowerdew & Lovett, 1989). Explanations of the different macro and micro approaches to migration modelling can be found in Stillwell and Congdon (1991) and Champion et al. (1998).

Previous studies of internal migration in the UK, whether descriptive or model-based, have utilised a particular spatial scale and methodology that best fits their purpose, thereby ignoring how scale might affect the measurement of area-based indicators and the relationships between variables. The MAUP was first identified by Gehlke and Biehl (1934), almost 50 years before Openshaw (1983) distinguished two components of the MAUP as the scale effect, the difference in results due to what size of units are being used, and the zonation

effect measuring the difference that occurs depending on how the area is divided, even when the same scale (number of zones) is being used. In attempting to make comparisons of internal migration indicators in different countries, the IMAGE (Internal Migration Around the GlobE) project (https://imageproject.com.au/) was challenged with the need to address the MAUP because of the differing spatial systems used for the collection of migration data in different countries. Bell, Charles-Edwards, Kupiszewska, et al. (2015) report the results gained from constructing an inventory and show national differences in the type of data collected on internal migration, the sources used to derive migration data, the ways they measure migration, the time intervals adopted, the periodicity of the collection processes, the scope of the questions, and the spatial frameworks employed.

The IMAGE project built on earlier work (Bell et al., 2002) identifying the lack of research comparing various dimensions of migration in different countries using a basket of indicators. Consequently, an IMAGE data repository was constructed containing origin–destination internal migration flows from different countries around the world, together with associated data on populations at risk and zone boundaries. A methodology was required to facilitate comparison and the IMAGE Studio was therefore developed to aggregate data on all-age migration flows, populations and boundaries for basic spatial units (BSUs) to different scales and zonations as specified by the user, and to compute migration indicators for systems of aggregated spatial regions (ASRs). Details of the structure and operation of the IMAGE Studio software are available in Stillwell et al. (2014). Essentially, there is an *Aggregation* subsystem within the Studio that requires the user to specify (i) a scale increment with which to aggregate BSUs on an iterative basis and (ii) the number of zone configurations required at each scale. Implementing the aggregation process involves choosing a spatial algorithm that is fed automatically with normalised data from the *Data Preparation* subsystem of the IMAGE Studio to produce zone centroid coordinates, inter-zonal distances, zone contiguities, inter-zonal flow matrices and zone populations for each set of zones referred to as aggregated spatial regions (ASRs) which can then be used to compute global migration indicators and their summary statistics at each spatial scale. Two algorithms are available for aggregating initial BSUs to larger ASRs based on the automated Initial Random Aggregation (IRA) procedure first introduced by Openshaw (1977). The initial IRA algorithm provides a high degree of randomisation to ensure that the resulting aggregations are different during the iterations (Stillwell et al., 2018). The IRA-wave aggregation algorithm is a hybrid version of the former algorithm with strong influences from the mechanics of the Breadth First Search (BFS) algorithm. If N ASRs are required, the first step of the IRA-wave algorithm is to select N BSUs randomly from the initial set of BSUs and assign each one to an empty region (ASR). Using an iterative process until all the BSUs have been allocated to the N ASRs, the algorithm identifies the BSUs contiguous with each ASR, targeting only the BSUs without an assigned ASR and adds them to each ASR respectively.

The relationship between aggregate crude migration intensities (ACMIs) and zone scale was used to estimate ACMIs for total mobility in countries where these data were unavailable (following the equation for Courgeau's k) and to produce league tables (Bell, Charles-Edwards, Ueffing, et al., 2015), demonstrating significant variations between countries with high rates of migration such as New Zealand, USA, Australia and Canada, and countries with low rates such as India, North Korea, Egypt and Venezuela. Whilst Rees et al. (2017) have used the IMAGE Studio to configure geographic zones and implement new measures to compare migration data across large samples of different countries, by examining the relative contributions of migration intensity and effectiveness to cross-national variations, the software was used by Stillwell et al. (2016) to compare distances of internal migration and distance decay parameters across different countries at a national scale. In terms of age group variations at national level, Bernard et al. (2014) have used techniques in association with the IMAGE Studio to investigate internal migration intensity, age profile and spatial impact and how they vary between countries around the world.

In summary, the IMAGE project was the first attempt at a global comparison of indicators of intensity, impact and distance for all-age migration flows, and the IMAGE Studio was the software created to provide data at a series of spatial scales with which to enable comparison in a consistent way. In this paper, the IMAGE Studio has been used with age group data for the whole of the UK to examine variations in aggregate net migration rates, crude migration intensities and migration effectiveness indices using data sets for two consecutive census periods as explained in the following section.

3 | DATA

The most comprehensive understanding of the migration behaviour of the UK population is attained once every 10 years through the census of population, which asks respondents where they lived 1 year prior to the census date. By comparing respondent locations, the migration flow information can be extracted and used to build a picture of change over time, both in terms of migration intensities (e.g., Champion & Shuttleworth, 2016a) and spatial patterns of residential relocation (e.g., Lomax et al., 2014). Whilst NHS patient reregistration data provides a more frequent time series than the decadal census, the latter provides data on flows within the UK as a whole and reliable estimates of movements within LADs as well as between these spatial units. After merging the 2011 data for the City of London and Westminster, North Cornwall and the Isles of Scilly, Mid Bedfordshire and South Bedfordshire, and North Shropshire and South Shropshire, a set of 404 LADs with consistent boundaries provided the BSUs for subsequent aggregation and analysis.

Since age is a critical internal migration selectivity factor, the data used in this paper has been sourced via the UK Data Service Census Support platform (https://census.ukdataservice.ac.uk/) and includes age-specific migration flows from *2001 Census Special Migration Statistics (SMS) Level 1* Table 1: Age by sex (24 age groups including single year groups for ages 0 and 15, 2-year groups for ages 1 to 19, 5-year groups between 20 and 89 followed by 90+) and 2011 Census SMS Merged LA/LA [Origin and destination of migrants by

Migration type	2000–01			2010–11		
	Flow	Share (%)	Rate (%)	Flow	Share (%)	Rate (%)
Inter-LAD	2,660,240	40.07	4.51	2,794,882	40.50	4.42
Intra-LAD	3,978,318	59.93	6.75	4,106,665	59.50	6.50
All migration	6,638,559	100.00	11.27	6,901,547	100.00	10.92

TABLE 1 All-age migration in the UK, 2000–01 and 2010–11

Note: Source: Estimates based on data from 2001 and 2011 Censuses.
Abbreviation: LAD, local authority district.

age (grouped—mid) by sex (including those aged under 1)]—MM01BUK_all—Safeguarded (23 age groups, 5-year groups between 20 and 89 followed by 90+ group). To achieve consistency, the data for these ages have been aggregated to 11 groups (0–4, 5–9, 10–14, 15–19, 20–24, 25–34, 35–44, 45–59, 60–64, 65–74 and 75+) and summarised further in four life-course groups labelled: families (0–14 and 25–44); students and young workers (15–24); mature workers (45–59); and retired and elderly (60+). Corresponding age-specific end-of-period populations were chosen as appropriate populations at risk for computing migration intensities since these estimates are reliable and the use of mid-period estimates would be likely to make very little difference to the relative intensities. The respective population counts have been obtained from the relevant tables of the 2001 and 2011 Censuses.

Consistency problems arise, however, when migration counts are not comparable between censuses. From one census to the next, there are often alterations to census questions and coverage, to the adjustment procedures or to the way in which outputs are provided, as exemplified by the data on migration by age. In this case, a further problem relates to the way in which some respondents reported their place of residence 1 year ago in the two censuses. In the 2001 Census, a migration was recorded using the response given by the household reference person to a question asking: 'What was your usual address one year ago?' One possible response was 'no usual address', intended to identify only 'a child born after 29 April 2000', who would not have been in existence on that date (ONS, 2014). However, this question caused substantial confusion amongst respondents, with many ticking the 'no usual address' response for themselves or for other members of their household who were not aged under one at the time of the census.

As a result of this confusion, 467,036 individuals were identified as having 'no usual address one year ago' in the 2001 Census return (ONS, 2001). Of these, an estimated 463,605 (99.27%) were aged 1 year or over at the time of the 2001 Census, so should have been included with some origin stated, either within or outside the UK. This confusion and the resulting over-count of people meant that the 'no usual address' (NUA) response was removed for the 2011 Census (ONS, 2012a). The NUA problem with the 2001 Census has been recognised and discussed previously by Champion (2005) and Lomax (2013), but to date no definitive solution has been offered for allocating the NUA migrants identified in the 2001 SMS tables to origin areas to provide an adjusted set of intra- and inter-district flows for 2000–01.

The methodology adopted estimates the origins of those people who should not have been identified as having NUA in the 2001 Census returns so as to compile complete sets of migration flows for the UK for 11 age groups which are comparable to equivalent data for 2010–11. The matrix of flows for each age group contains all migrants who reported an origin and a destination in the 2001 Census. Two kinds of migrant (M) can be distinguished, i.e., migrants with an origin (i) and destination (j) in the same district (intra-district flows), M_{ij}, i = j; and migrants with an origin in a different district of the UK than the destination (inter-district flows), M_{ij}, i ≠ j. In addition, two additional types of migrant can be identified: migrants with an origin outside of the UK (RoW) and a destination district j in the UK (immigrant flows), M_{RoWj}; and migrants with NUA year ago and a destination district j in the UK (NUA flows), M_{NUAj}. The NUA migrants therefore need to be apportioned between the other three migrant types (intra-LAD, inter-LAD and inflow from RoW) for each LAD in order to generate an adjusted estimate the internal migration. The adjustment for each M_{ij} flow, for example, is as follows:

$$\text{New } M_{ij} = M_{ij}\left(D_j + \frac{M_{NUAj}}{D_j}\right) \quad (1)$$

where New M_{ij} represents the adjusted cell value in the origin–destination matrix and D_j is the total inflow. A similar adjustment is made to the original intra-district and immigration flows and the adjusted data for 2000–01 provide a more consistent set of migration matrices for comparison with those with flows during 2010–11.

4 | LEVELS AND PATTERNS OF INTERNAL MIGRATION AT LOCAL AUTHORITY SCALE

On census night 2011, the population of the UK was estimated to be 63.2 million. It had increased by 7% between the 2001 and 2011 Census dates (ONS, 2012b), partly due to the changing level of fertility but largely due to the increase in the number of immigrants from abroad that reached unprecedented levels during the 2000s (Bijak et al., 2016). Total internal migration in the UK, that is all changes of usual place of residence within the year prior to the census, also increased from 6.64 to 6.9 million between the two census 1-year periods but the migration rate decreased by nearly 0.35%, from 11.3% in 2000–01 to 10.9% in 2010–11. The all-age statistics shown in Table 1 suggest that around 6 out of 10 internal migrants relocated

to usual residences within LADs in both periods whilst the other four moved between LADs and therefore tended to migrate over longer distances. It is apparent that the intra-LAD migration rate declined between the two 1-year periods, a finding in line with the longer-term fall in shorter-distance migration identified by Champion and Shuttleworth (2016b) using data from the ONS Longitudinal Study for England and Wales. The rate of inter-LAD migration, involving movement over longer distances, also experienced a marginal fall. This migration rate has tended to fluctuate over the last 50 years, influenced rather more than intra-LAD migration by changes in national economic conditions (Champion & Shuttleworth, 2016a).

The spatial patterns of inter-LAD migration can be effectively summarised using the net migration (in-migration minus out-migration) for each LAD expressed as a percentage of its population. The all-age net rates for 2010–11 are mapped in Figure 1a to exemplify some of the distinctive features of the spatial pattern of migration exchanges. Graduated symbols (with rates of net gain in blue and of net loss in red) are preferred to choropleth shading since they offer a clearer indication of variations in net migration rates and illustrate the tendency for urban/metropolitan/conurbation districts to have experienced net migration losses in 2010–11 whereas the more rural

districts have gained population through net migration. This pattern reflects the process of counterurbanisation reported widely in the literature (e.g., Champion, 2005; Lomax & Stillwell, 2017). Consequently, the highest rates of net migration gain are in rural areas such as Ceredigion, Bournemouth and Lincoln, each with an average rate of 2.2%, compared to densely population urban boroughs in London such as Newham, Ealing and Harrow whose rates of loss are around 1.5%. LADs with high rates of net migration gain are also found along the coast of southern England in western Wales and in East Anglia. In Northern Ireland, the spatial pattern is rather different with most rural LADs showing migration losses.

Changes in net migration rates between 2000 and 01 and 2010–11 are shown in Figure 1b using a district categorisation that shows the basic distinction between areas gaining and losing but also gives an indication of the path of change from one period to the next. The pattern of change is quite complicated. In the south, several coastal areas of England and Wales gained population through internal migration at increasing rates in contrast to much of the South East, especially the Greater London area, which has experienced net migration losses but at a reduced rate in many cases. Increasing rates of net gain were also apparent in certain LADs in the Midlands, for example, Melton,
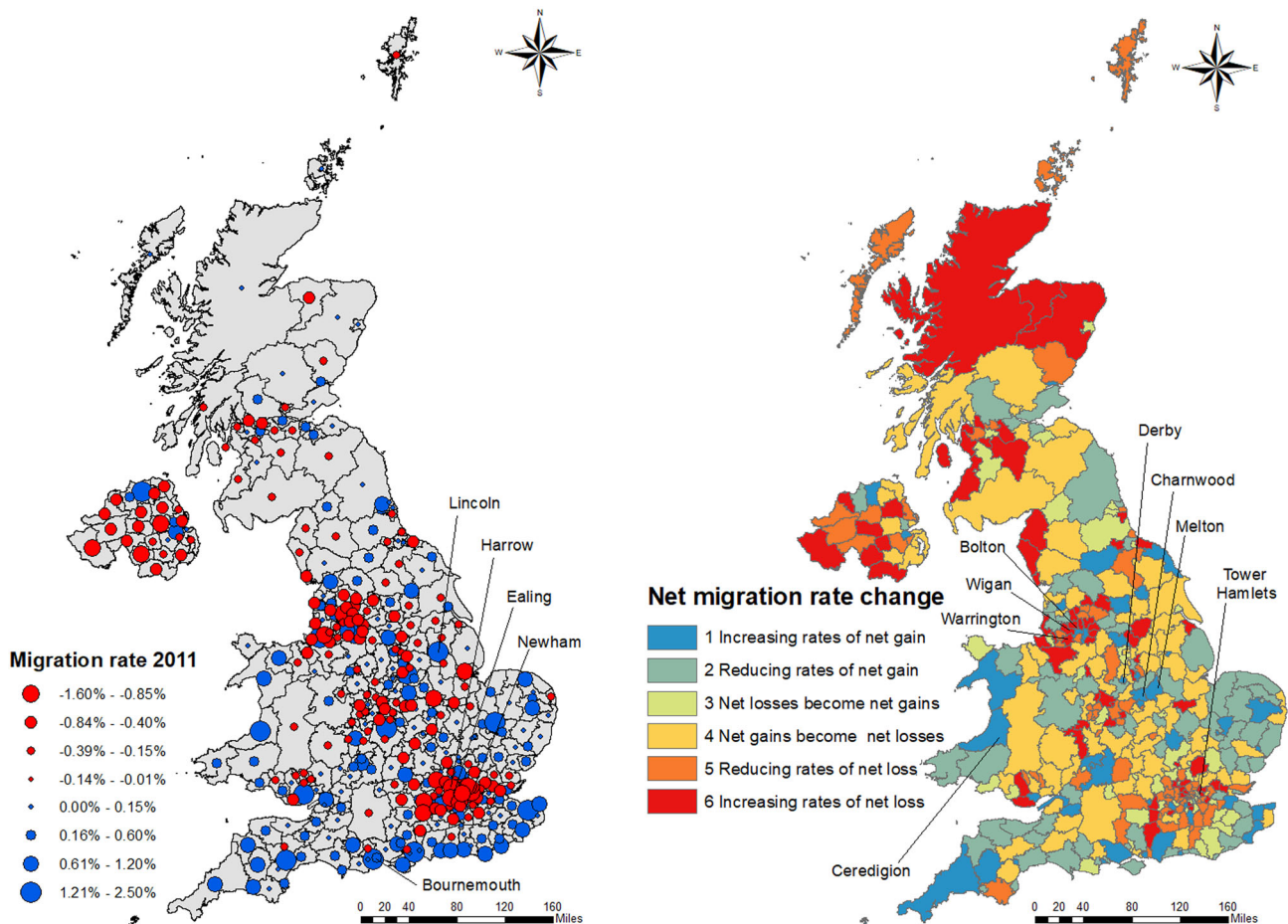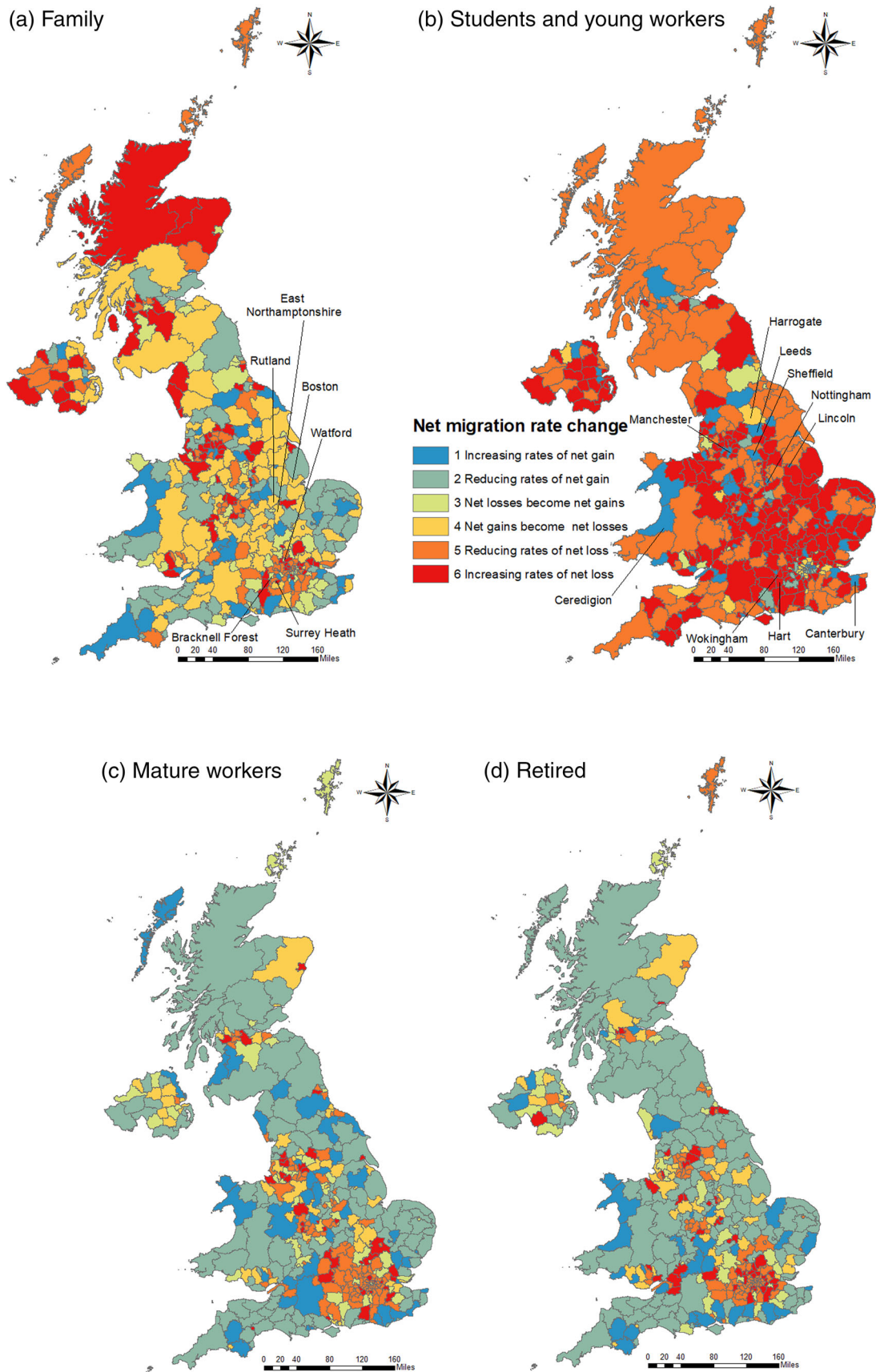

FIGURE 1 Inter-local authority district (LAD) net migration rates

FIGURE 2 Net migration rate change, 2000–01 to 2010–11 for broad age groups

Charnwood and Derby. Some more peripheral areas experienced increasing net losses especially in northern Scotland, in Northern Ireland and in the North West of England (e.g., Wigan, Warrington and Bolton). However, large migration gain rate changes are also found in the Tower Hamlets (up by 1.97%) and Ceredigion (up by 1.38%).

When looking at the data for broad age groups (Figure 2), the primary observation is that changes taking place in net migration patterns across LADs for students and young workers are very different from the patterns for the other groups. Students and young workers depart from LADs across the UK and travel to destinations with higher education institutions or large cities with employment opportunities. So, amidst the sea of increased migration losses, there are urban islands of increased migration gains, including Leeds, Nottingham, Sheffield and Manchester. The pattern of change for the family age group (Figure 2a) is, to a large extent, the reverse of that of students and young workers (Figure 2b). Net gains increased most in LADs like Watford (13%), Surrey Heath (10%) and Bracknell Forest (9.8%) whereas net losses declined most in places like East Northamptonshire, Rutland and Boston. In the case of students and young workers, gains have increased mostly in Ceredigion (18.4%), Lincoln (13.3%) and in Canterbury (12%). Increasing migration rate losses for this age group were highest in Harrogate, Wokingham and Hart with an average loss of 15.7%. An urban–rural divide is more apparent in the patterns of net migration rate change for the two other age groups (Figure 2c,d) with a significant number of urban areas tending to lose migrants at a decreasing rate in both cases and corresponding reductions in rates of net gain in many rural LADs.

Table 2 contains a summary of inter-district and intra-district migration flows and rates within the UK for both periods for the four broad age groups, illustrating that the increases in all-age migration occurring at both scales (Table 1) were largely as a result of substantial increases in the number of students and younger workers moving home over longer and shorter distances respectively, although their corresponding migration rates declined at both scales. Lower migration rates were also apparent for the family and retired groups with the latter experiencing the largest percentage variation in intra-district mobility between the periods of all the age groups at both scales. The rates for mature workers, on the other hand, changed the least and actually increased at the within-district scale.

The highest intra-LAD migration rates can be found in southern LADs such as Oxford, Brighton and Hove and Southampton with rates of over 11% respectively in 2010–11 (Figure 3a). Some of the lowest intra-LAD migration rates are found in Northern Ireland where Castlereagh, Moyle and Magherafelt are towards the bottom of this list, with 2.5%, 3.1% and 3.3% increases in migration rates respectively. Central England also contains low rates, with South Bucks at 2.5% and Oadby and Wigston at 2.7%, for example. Figure 3b highlights which of these LADs experience the most changes between both censuses. The map indicates that Northern Ireland and north east of England had high negative changes of intra-LAD migration rates, whereas the Greater London area and the south east of Wales saw intra-LAD migration rates increase. Bournemouth, Norwich and Cardiff are the leading LADs with high positive changes with 1.4%, 1.4% and 1.3% of migration rates respectively. Coleraine, Orkney Islands and Blackburn with Darwen have high negative changes with a reduction of −2.77%, −2.19% and −2.13%, respectively. The map suggests that a north–south division exists for intra-LAD migration change, with northern LADs tending to have declining rates of intra-district migration and residential mobility increasing in the majority of southern LADs, particularly in Greater London.

TABLE 2 Total intra-LAD migration by broad age group, 2000–01 and 2010–11

Time period	Family	Students and young workers	Mature workers	Retired
	Inter-district flows			
2000–01	1,476,136	754,366	240,013	186,629
2010–11	1,462,010	867,363	268,966	196,543
Difference	−14,126	112,997	28,953	9,914
	Inter-district rates			
2000–01	5.43	9.41	2.35	1.68
2010–11	5.19	9.09	2.35	1.49
Difference	−0.24	−0.31	0.00	−0.19
	Intra-district flows			
2000–01	2,384,415	916,985	357,943	322,405
2010–11	2,364,540	1,045,375	404,582	292,168
Difference	−19,875	128,390	46,639	−30,237
	Intra-district rates			
2000–01	8.09	11.13	3.11	2.52
2010–11	7.88	10.69	3.15	1.97
Difference	−0.21	−0.45	0.04	−0.55

Note: Source: Estimates based on data from 2001 and 2011 Censuses.
Abbreviation: LAD, local authority district.

(a) Rates in 2010-11
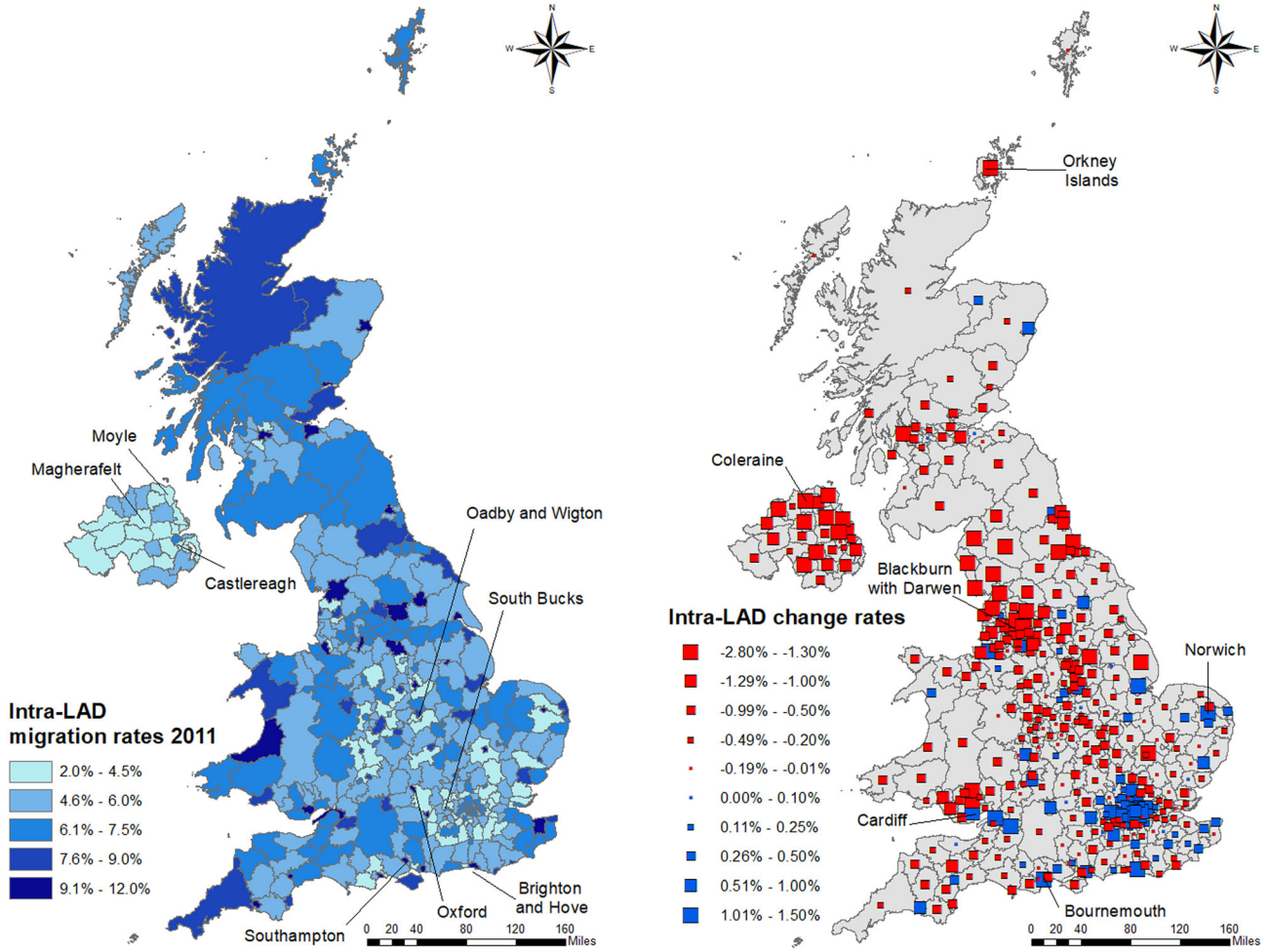

(b) Change in rates, 2000-01 to 2010-11

FIGURE 3 Intra-local authority district (LAD) migration rates

5 | VARIATIONS IN AGGREGATE NET MIGRATION AND ITS COMPONENTS

Whilst the explanation of patterns such as these has been the focus of many deterministic studies, including the MIGMOD model

mentioned earlier, our focus in this paper is to ascertain how stable are indicators of internal migration at different spatial scales. Across any system of sub-national regions, the overall impact of net migration on the pattern of settlement is most effectively captured by the aggregate net migration rate (ANMR), defined as half the sum of the
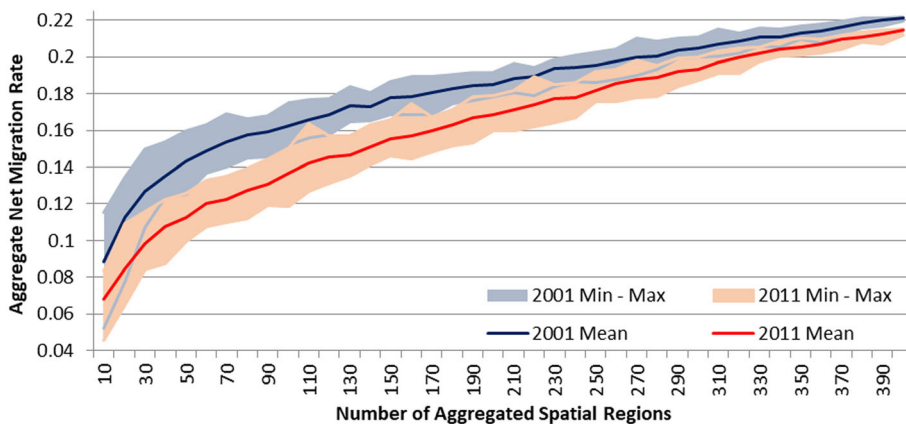

FIGURE 4 Aggregate net migration rate by scale, 2000–01 and 2010–11

absolute net changes aggregated across all regions divided by the population at risk (Bell et al., 2002). The IMAGE Studio has been used to investigate the effects of scale and zonation on the ANMR by aggregating LADs (BSUs) using the IRA wave algorithm in scale steps of 10 from 10 to 400 ASRs with 50 different configurations computed at each scale. Figure 4 illustrates the means of the ANMR estimates for 2000–01 and 2010–11 at each scale, signifying the scale effect, whilst the shaded areas are the range of values around the mean in each case representing the zonation effect. As expected, the ANMR falls progressively as the number of ASRs reduces (from right to left on the graph), with increasingly fewer migrants moving between ASRs over longer distances and with increasingly less impact on redistribution. The difference between the mean ANMR in the two periods increases as the ASRs increase in size suggesting that scale has a marginally greater impact in the most recent period, although the zonation effect, which gets larger as ASRs increase, is similar in both periods.

In fact the ANMR is the product of two component indicators, the crude migration intensity (CMI) defined as the **proportion of the population who changed their place of usual residence over a defined time interval, and the migration effectiveness index (MEI)**, measured as the sum of the absolute values of net migration for each zone, divided by the sum of the gross inflows and outflows for each zone (Stillwell et al., 2000). Migration intensity is determined by various explanatory factors including household financial decisions and

individual life course plans as well as macro-economic or housing market conditions whilst migration effectiveness provides the degree of (a)symmetry or (dis)equilibrium in the network of inter-regional migration flows (Bell & Muhidin, 2009). The scale and zonation effects of both these components on all-age migration in the UK are shown in Figure 5, illustrating the importance of CMI in determining the scale effect in both periods but displaying relatively a minor zonation effect across the range of scales. In contrast, the MEI schedules show much greater scale stability but an increasing zonation effect as the number of ASRs gets smaller.

6 | AGE VARIATIONS IN MIGRATION INTENSITY AND IMPACT

In this section, we ask whether scale matters as far as migration intensity and effectiveness are concerned when age-specific migration streams are considered and what variations from the all-age scale and zonation profiles can be observed. The two graphs in Figure 6 are plots of the mean CMI value against the number of ASRs for each of the 11 age groups in 2000–01 and 2010–11. The schedules commence on the right-hand side with rates at the BSU scale. Thus, the 20–24 year olds have the highest rates, whereas the lowest rates are for the 65–74 year olds. The CMIs for each age group decline from
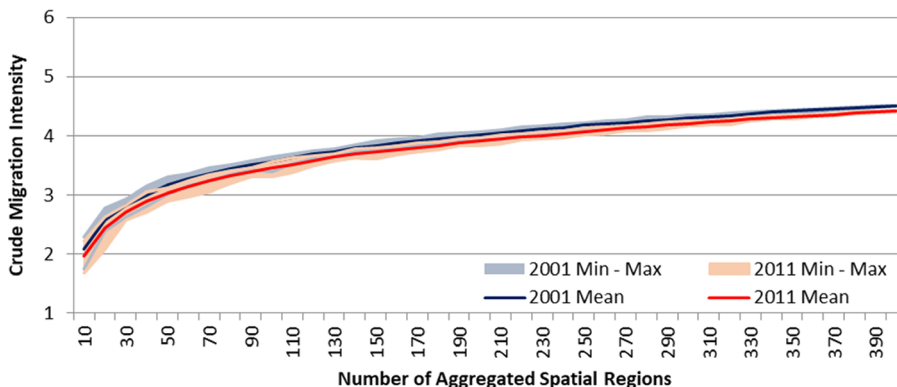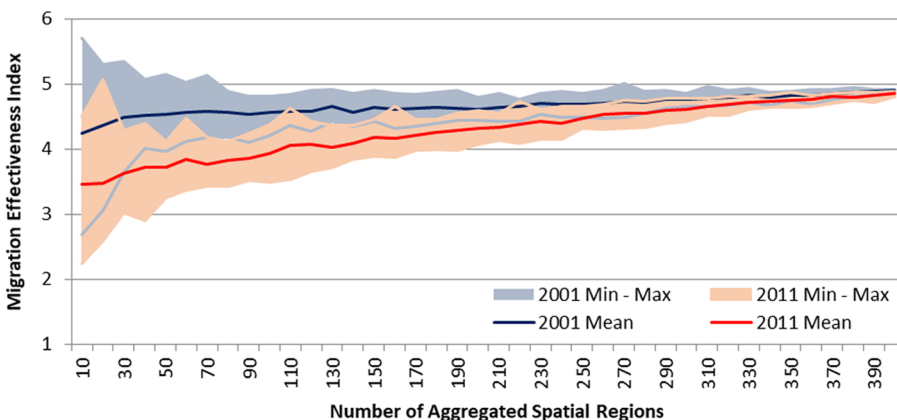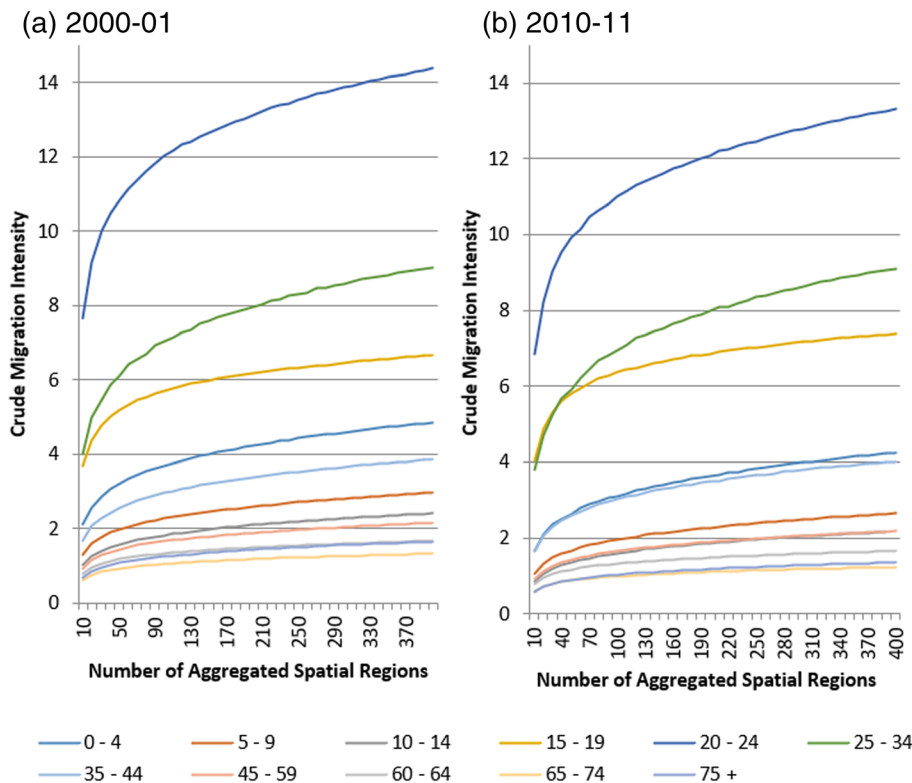

FIGURE 5   Components of aggregate net migration rate by scale, 2000–01 and 2010–11

FIGURE 6 Crude migration intensity by scale for age groups, 2000–01 and 2010–11

right to left as the number of ASRs gets smaller. The schedules are non-linear but have a regular shape relative to one another. The graphs suggest that three age groups stand out as having a comparatively large scale effect and high CMI values; these are the 15–19, 20–24 and the 25–34 year olds. Although the CMI values for the 20–24 age group decrease between the two time periods, the scale effect remains strong. The CMI values for the 15–19 age group show an increase between 2000 and 01 and 2010–11 whilst the CMI for the 0–4 year olds drops. Lower CMI values are associated with the older age groups and appear to remain less dependent although the percentage drop in CMI between scales of 400 and 10 is 53.12% for age group 65–74 in 2010–11 compared to 48.42% for age group 20–24.
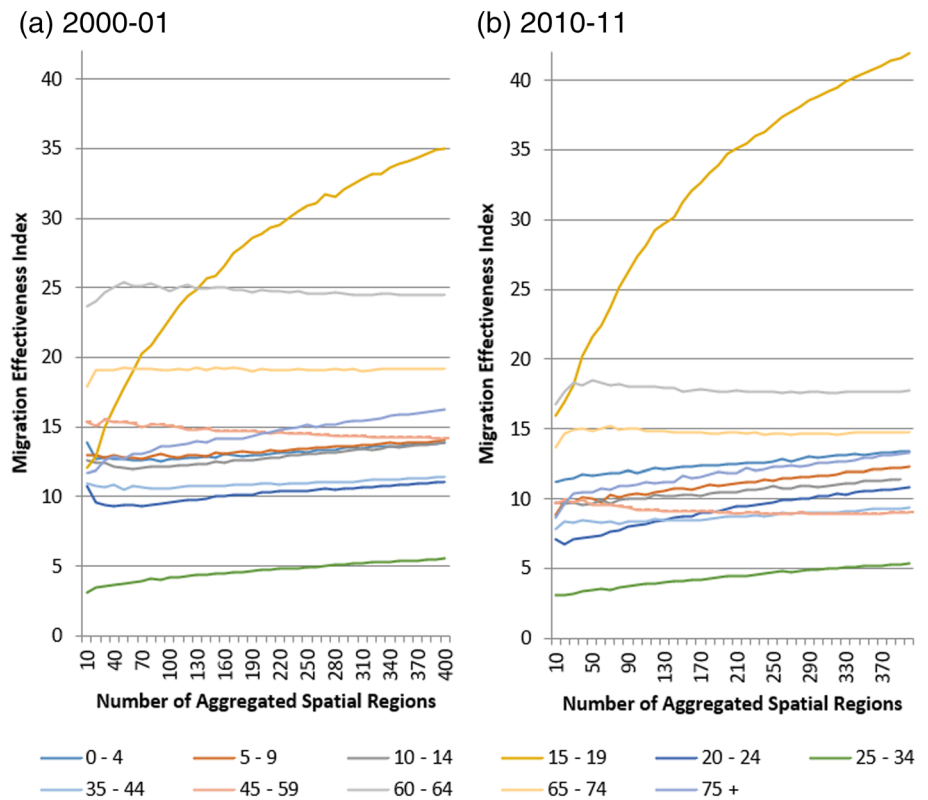
Whereas the CMI schedules shown in Figure 4 are as expected, the age-specific MEI schedules illustrated in graphs in Figure 7 showing how the MEI values change according to scale (number of ASRs) indicate a totally different ranking. In general, the MEI schedules are linear and much more scale independent, with the 60–64 year olds having the highest level of MEI and 0–4 year olds the lowest. In other words, internal migration is much more important in redistributing the elderly than it is for the children and their parental age groups. In fact, as the number of ASRs gets smaller, the mean MEI values appear to increase for those in the 60–64 and 65–74 age groups as well as those aged 45–59, that is until the number of ASRs gets below 50. The anomaly amongst the age groups appears to be those aged 15–19 whose mean MEI is much higher at BSU level but whose value reduces significantly as the number of ASRs gets smaller and the size of the zones gets larger. Moreover, the scale effect for this age group

increases from 2000 to 01 to 2010–11. This age group contains the students who migrate to their places of higher or further education and those spatial pattern of net migration is almost the reverse of that of other age groups as suggested in Figure 2. Both graphs in Figure 7 indicate that scale is therefore only an important consideration for 15–19 year olds; the impact of migration measured by the MEI for this highly mobile group reduces by more than half when the number of ASRs falls from 400 to 50 and the scale effect is greater in 2010–11.

The graphs in Figures 6 and 7 have illustrated the scale effect but have excluded any visualisation of the zonation effect. These graphs become too muddled when the range values are included so, in order to compare between age groups effectively, a measure of total zonation effect has been computed for each age group as the summation of the maximum value minus the minimum value (the range) for each indicator at each scale divided by the mean standardises for variation in the indicator between age groups. The results of the total zonation effects are shown in Table 3 with the strongest for the CMI observed for the 25–34 age group in both periods. Total zonation effects are much greater for the MEI with the highest values for the 15–19 and 25–34 year olds and the lowest for the 45–74 year olds.

In order to evaluate how the CMI and MEI vary in relation to one another in explaining the all-age ANMR across a sample of countries, Rees et al. (2017) developed an Index of Net Migration Impact (INMI) based on the assumptions that (i) the variation in intensity by scale can be captured by fitting regression lines to the logged values of CMI and computing the ratio between the CMI slope for one country and the average slope for all countries; and (ii) there is no variation in

FIGURE 7 Migration effectiveness by scale for age groups, 2000–01 and 2010–11

(a) 2000-01

(b) 2010-11

Legend: 0 - 4, 5 - 9, 10 - 14, 15 - 19, 20 - 24, 25 - 34, 35 - 44, 45 - 59, 60 - 64, 65 - 74, 75 +

TABLE 3 Total zonation effect for CMI and MEI by age group, 2000–01 and 2010–11

	Crude migration intensity		Migration effectiveness index	
Age groups	2000–01	2010–11	2000–01	2010–11
0–4	1.88	2.52	5.03	6.96
5–9	1.76	2.08	4.86	6.50
10–14	1.68	2.01	5.26	6.19
15–19	1.23	1.24	7.53	7.00
20–24	1.80	1.81	4.42	5.84
25–34	2.42	2.88	8.04	8.41
35–44	1.94	2.22	5.25	6.55
45–59	1.66	1.70	4.43	4.33
60–64	1.56	1.49	4.59	4.34
65–74	1.44	1.68	4.48	4.48
75 +	2.18	1.67	6.23	7.44

Abbreviations: CMI, crude migration intensity; LAD, local authority district; MEI, migration effectiveness index.

effectiveness by scale so the ratio between the mean value of MEI for a country and that for all countries can be computed. The INMI for one country is then computed as the product of these two measures of relative intensity and impact. When applying this method to the age-specific CMIs for the UK, the log transformation of the data generates negative values for some of the older age groups when the number of regions gets smaller. This is not ideal and CMI values have not been logged in our version of the INMI which is defined as follows:

$$
\begin{aligned}
\text{INMI for age group } x = &\ (\text{CMI slope for an age group } x / \text{Average CMI} \\
&\ \text{slope for all age groups}) \\
&\ *(\text{Mean MEI for an age group } x / \text{Average MEI for all age groups})
\end{aligned}
$$

(2)

The INMI is the product of two ratios, distinguishing the relative contributions of migration intensity and migration effectiveness for each age group which, following Rees et al. (2017), can be visualised
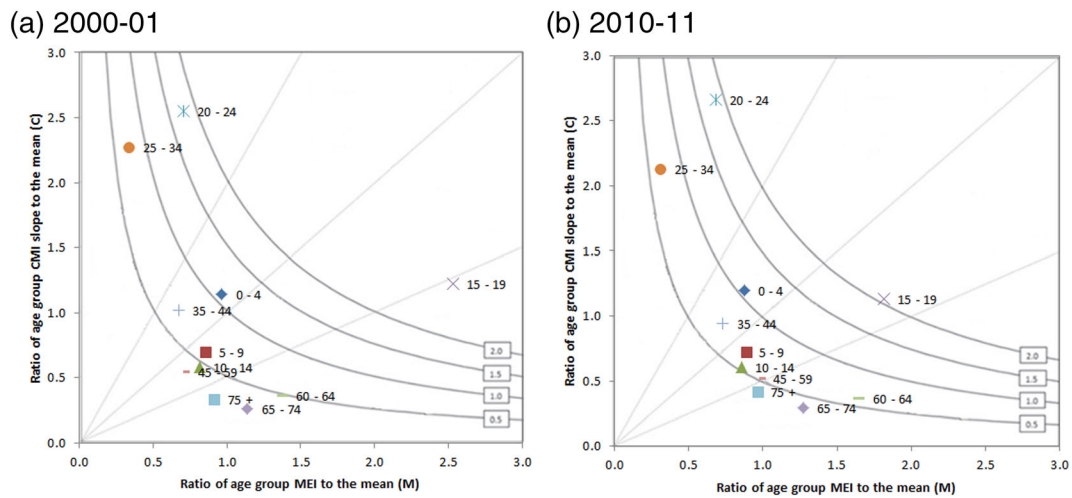
FIGURE 8 Index of net migration impact by age group, 2000–01 and 2010–11

on scatterplots for each period. The surface of the plots in Figure 8 represents the INMI for each age group, and the contour lines (0.5, 1.0, 1.5 and 2.0) link points of equal migration impact. All INMI values above 1.0 demonstrate an above average effect of migration in redistributing population and INMI values below 1.0 show an effect below average. The radial lines help divide the plot to show the relative contributions of the CMI and the MEI, with the principal diagonal dividing the plot at a point where the two indicators demonstrate an equal effect on the population redistribution. The top graph (Figure 8a) shows the INMI for the 11 age groups in 2000–01. It can be observed that the 15–19 year olds exhibit the highest net migration impact, driven by above average MEI and CMI slope relative to the average. This age group has a higher MEI ratio than CMI slope ratio, and the MEI ratio has become more significant over the decade; whereas the 20–24 and 25–34 age groups have the highest CMI but a relatively low MEI, these values remained roughly the same across both time periods. The majority of the age groups remain in centre of the graph with a balance of CMI and MEI for 2000–01 and 2010–11. The older migrant populations have higher MEI ratios and lower CMI slope ratios in both time periods.

7 | CONCLUSIONS

This paper is the first to report the differences between migration propensities and patterns evident from the census-based estimates of internal migration published by the ONS in the SMS for 2000–01 (adjusted to include those reported with no usual address in 2001) and for 2010–11. It has also demonstrated the extent of the MAUP effects on indicators of migration intensity and impact and how they vary by age. The data indicate that the overall propensity to migrate in the UK has declined, a trend that is apparent for both inter-LAD and intra-LAD migration rates and for each of the broad age groups apart from mature workers moving shorter-distances within LADs. The general decline in mobility in the UK confirms what others have

suggested based on longitudinal and administrative data and may be due to a variety of factors including housing availability, changing occupational structures, the impact of technology on working arrangements and the desire for people to feel more rooted in their communities (Champion et al., 2017).

It is evident that patterns of all-age net migration continue to reflect the relatively longstanding process of counterurbanisation but the intensity of urban losses and rural gains has diminished between the two census periods, predominantly due to changes in family mobility. A significant proportion of rural LADs experienced a switch from net gain to net loss in the broad family age group, whereas the changes for mature workers and the more elderly involved reducing net gains in rural areas and lower rates of net loss in urban areas. However, in the case of students and younger workers, net migration losses intensified across many LADs in England and Northern Ireland and gains increased in towns and cities with large higher education institutions, reflecting the expansion of this sector of education during the early 2000s in particular.

It is the student and young worker age group (15–19) which has experienced the most dramatic impact on population re-distribution with the MEI being much higher than for other age groups and whose scale effect is an anomaly. Unlike other age groups for which the scale effect of migration effectiveness is constant or scale independent, migration effectiveness for this age group reduces significantly as the number of zones becomes fewer. The two other age groups with relatively high migration effectiveness are the 60–64 and 65–74 years olds but the MEI of both these age groups show scale independence and the overall impact of their mobility if less because of their relatively low intensity.

Our analyses suggest that scale effects are more apparent for the CMI component of ANMR with schedules for all age groups that follow a common trajectory with mean rates declining at an increasing rate as the scale becomes coarser and the zones get larger. However, the zonation effects associated with the CMI are relatively small and do not appear to fluctuate substantially with scale. In general terms,

intensity is more important that effectiveness in explaining the impact of all-age migration over scale measured by the ANMR and of those aged 20–24 and 25–34 in particular, as measured by the INMI. The increasing zonation effect associated with the MEI indicator and therefore the ANMR suggest that as the number of zones used for analysis in the system declines, the boundary configuration of the zones becomes increasingly important in terms of accurate measurement of the true rate of inter-zonal migration. Researchers choosing to analyse migration at one particular scale need to be aware of this issue, although it becomes less important as the number of zones increases. The IMAGE studio might prove useful in providing an optimum set of zones for analysis of certain indices.

One of our priorities was to undertake a 'national' analysis of internal migration within the whole of the UK and consequently the census provided the most appropriate source of data although we are aware that using two single-year time periods 10 years apart has its limitations, particularly since the second period came fairly soon after the global recession when mobility levels might have been lower than average. Further work based on annual data on patient registrations might usefully be undertaken to provide corroborating evidence of our results though this would require substantial effort to acquire and estimate flows for Scotland and Northern Ireland and integrate them with data for England and Wales. As well as the limitation set by the time periods, it is also necessary to acknowledge that the age groups for which data are available and the broad age groups used for summarising patterns are not altogether appropriate for representing the migration behaviour of individuals or families influenced by the same explanatory factors.

The IMAGE Studio has been used previously to assist in the comparison of internal migration in different countries around the world. This is the first paper that reports results of analysing migration within one country disaggregated by age. Our experience of using the software has generally been positive though, for those seeking to undertake similar work, perhaps for a different country, it is worth giving prior consideration to the system of BSUs and to the variables used for disaggregation, not least because of the amount of time taken to prepare and process the data. Age is a good variable to use because of the relative ease of interpretation of the behaviour of different groups and their likely motivation. The Studio[1] requires a matrix of migration flows between BSUs, a vector of populations at risk and a set of digital boundaries of the BSUs labelled to correspond with the origin/destination zones of the flows in the migration matrix. Data for individual age groups have to be input in turn and the time taken for processing is dependent on the number of indicators for which the user wants to compute scale and zonation effects and on the number of scales and configurations at each scale for which indicators and summary statistics are required. In selecting an appropriate system of interest, users need to strike a balance between what data are available and what data can be effectively processed; there is no point in having a very large number of BSUs if this means that there are a large number of zero cells in the migration matrix. A small number of zones, on other hand, puts restrictions on the number of aggregations that can be performed at any one scale so experience

suggests that a system of between 100 and 500 BSUs of migration origin and destination is optimal.

Finally, our analysis in this paper has been confined to an examination of the scale and zonation effects on just the ANMR, CMI and the AEI using inter-LAD age group data but further research using other indicators (such as distance or zone connectivity) and migration flows disaggregated by other variables (such as occupation, gender or ethnicity) might prove useful. The use of data between wards rather than LADs is another possible avenue of investigation but transition to this scale of BSUs for the UK as a whole would involve using huge and very sparsely populated matrices because of the distance decay effect associated with migration; it might be more appropriate to conduct analysis of one particular region, such as Greater London (Chatagnier, 2020). Moreover, the availability of migration flow matrices from the 2021 Census will provide the opportunity in due course to extend the comparison reported in the paper across another decade although caution will be required because the corona virus pandemic is likely to have had a significant influence of internal migration behaviour in the UK in 2020–21.

CONFLICT OF INTEREST STATEMENT

DATA AVAILABILITY STATEMENT

All the raw 2001 and 2011 Census data used in this paper are available from the UK Data Service Census Support online (https://census.ukdataservice.ac.uk/).

ORCID

Stephane Chatagnier https://orcid.org/0000-0001-9834-1775
John Stillwell https://orcid.org/0000-0002-8803-2001

ENDNOTE

[1] The IMAGE Studio software and manual are available at https://github.com/IMAGE-Project. Further details of applications can be found in Stillwell et al. (2014, 2018).

REFERENCES

Bates, J., & Bracken, I. (1982). Estimation of migration profiles in England and Wales. *Environment and Planning a, 14*(7), 889–900. https://doi.org/10.1068/a140889

Bell, M., Blake, M., Boyle, P., Duke-Williams, O., Rees, P., Stillwell, J., & Hugo, G. (2002). Cross-national comparison of internal migration: Issues and measures. *Journal of the Royal Statistical Society: Series A (Statistics in Society), 165*, 435–464. https://doi.org/10.1111/1467-985X.00247

Bell, M., Charles-Edwards, E., Kupiszewska, D., Kupiszewski, M., Stillwell, J., & Zhu, Y. (2015). Internal migration data around the world: Assessing contemporary practice. *Population, Space and Place, 21*, 1–17. https://doi.org/10.1002/psp.1848

Bell, M., Charles-Edwards, E., Ueffing, P., Stillwell, J., Kupiszewski, M., & Kupiszewska, D. (2015). Internal migration and development: Comparing migration intensities around the world. *Population and Development Review, 41*, 33–58. https://doi.org/10.1111/j.1728-4457.2015.00025.x

Bell, M., & Muhidin, S. (2009). Cross-national comparisons of internal migration. Research Paper, United Nations Development Programme. http://hdr.undp.org/en/content/cross-national-comparisons-internal-migration

Bernard, A., Bell, M., & Charles-Edwards, E. (2014). Improved measures for the cross-national comparison of age profiles of internal migration. *Population Studies*, *68*(2), 179–195. https://doi.org/10.1080/00324728.2014.890243

Bijak, J., Disney, G., Lubman, S., & Wisniowski, A. (2016). International migration and asylum seekers. In T. Champion & J. Falkingham (Eds.), *Population change in the United Kingdom* (pp. 47–64). London: Rowan and Littlefield.

Champion, A. (Ed.) (1989). *Counterurbanisation: The changing pace and nature of population deconcentration*. New York: Routledge.

Champion, A. (2005). The counterurbanisation cascade in England and Wales since 1991: The evidence of a new migration dataset. *Belgeo*, *1-2*, 85–101.

Champion, A., Bramley, G., Fotheringham, A. S., Macgill, J., & Rees, P. H. (2002). A migration modelling system to support government decision-making. In J. Stillwell & S. Geertman (Eds.), *Planning support systems in practice* (pp. 257–278). Berlin: Springer Verlag.

Champion, A., Cooke, T., & Shuttleworth, I. (Eds.) (2017). *Internal migration in the developed world: Are we becoming more mobile?* Abingdon: Routledge. ISBN:9780367245269. https://doi.org/10.4324/9781315589282

Champion, A., Fotheringham, A. S., Rees, P., Boyle, P., & Stillwell, J. (1998). The determinants of migration flows in England: A review of existing data and evidence. Report for the Department of the Environment, Transport and the Regions, University of Newcastle upon Tyne. http://www.geog.leeds.ac.uk/publications/DeterminantsOfMigration/report.pdf

Champion, T., & Shuttleworth, I. (2016a). Are people changing address less? An analysis of migration within England and Wales, 1971–2011, by distance of move. *Population, Space and Place*, *23*, e2026. https://doi.org/10.1002/psp.2026

Champion, T., & Shuttleworth, I. (2016b). Is longer-distance migration slowing? An analysis of the annual record for England and Wales. *Population, Space and Place*, *23*, e2024. https://doi.org/10.1002/psp.2024

Chatagnier, S. (2020). Internal migration in the United Kingdom: The effects of scale and zonation on migration indicators, PhD Thesis, University of Leeds. Available at: http://etheses.whiterose.ac.uk/27808/.

Cooke, T. (2011). It is just not the economy: Declining migration and the rise of secular rootedness. *Population, Space and Place*, *17*(3), 193–203. https://doi.org/10.1002/psp.670

De Jong, G. F., & Graefe, D. R. (2008). Family life course transitions and the economic consequences of internal migration. *Population, Space and Place*, *14*(4), 267–282. https://doi.org/10.1002/psp.506

Dennett, A., & Stillwell, J. (2010). Age sex migration patterns at the start of the new millennium. In J. Stillwell, O. W. Duke-Williams, & A. Dennett (Eds.), *Technologies for migration and commuting analysis: Spatial interaction data applications* (pp. 153–174). Hershey: IGI Global. https://doi.org/10.4018/978-1-61520-755-8.ch008

Duke-Williams, O. (2009). The geographies of student migration in the UK. *Environment and Planning a*, *41*(8), 1826–1848. https://doi.org/10.1068/a4198

Faggian, A., McCann, P., & Sheppard, S. (2006). An analysis of ethnic differences in UK graduate migration behaviour. *Annals of Regional Science*, *40*, 461–471. https://doi.org/10.1007/s00168-006-0061-y

Fielding, A. (2012). *Migration in Britain: Paradoxes of the present. Prospects for the future*. Cheltenham: Edward Elgar Publishing Ltd. ISBN:978-1-78100-419-7. https://doi.org/10.4337/9781781004203

Flowerdew, R., & Lovett, A. (1989). Fitting constrained Poisson regression models to inter-urban migration flows. *Geographical Analysis*, *20*, 297–307. https://doi.org/10.1111/j.1538-4632.1988.tb00184.x

Fotheringham, A., Rees, P., Champion, T., Kalogirou, S., & Tremayne, A. R. (2004). The development of a migration model for England and Wales: Overview and modelling out-migration. *Environment and Planning a*, *36*(9), 1633–1672. https://doi.org/10.1068/a36136

Gehlke, E., & Biehl, K. (1934). Certain effects of grouping upon the size of the correlation coefficient in census tract material. *Journal of the American Statistical Association*, *29*(185A), 169–170. https://doi.org/10.1080/01621459.1934.10506247

Geist, C., & McManus, P. A. (2008). Geographical mobility over the life course: Motivations and implications. *Population, Space and Place*, *14*(4), 283–303. https://doi.org/10.1002/psp.508

Jordan, R., Birkin, M., & Evans, A. (2012). Agent-based modelling of residential mobility, housing choice and regeneration. In A. J. Heppenstall, A. T. Crooks, L. See, & M. Batty (Eds.), *Agent-based models of geographical systems* (pp. 511–524). Dordrecht: Springer. https://doi.org/10.1007/978-90-481-8927-4_25

Lomax, N. (2013). Internal and cross-border migration in the United Kingdom: harmonising, estimating and analysing a decade of flow data. Unpublished PhD Thesis, University of Leeds, Leeds. http://etheses.whiterose.ac.uk/5839/

Lomax, N., & Stillwell, J. (2017). United Kingdom: temporal change in internal migration. In A. Champion, T. J. Cooke, & I. Shuttleworth (Eds.), *Internal migration in the developed world: Are we becoming less mobile?* (pp. 120–146). London: Routledge. https://doi.org/10.4324/9781315589282-6

Lomax, N., Stillwell, J., Norman, P., & Rees, P. (2014). Internal migration in the United Kingdom: Analysis of an estimated inter-district time series, 2001-2011. *Applied Spatial Analysis and Policy*, *7*(1), 25–45. https://doi.org/10.1007/s12061-013-9098-3

Newton, M. O., & Jeffery, J. R. (1951). Internal migration: some aspects of population movements within England and Wales, SMPS No 5, HMSO, London.

ONS. (2001). Census: Special migration statistics (United Kingdom) [computer file]. UK Data Service Census Support. Downloaded from: http://cids.census.ac.uk/.

ONS. (2012a). 2011–2001 Census in England and Wales Questionnaire Comparability. [online]. Available from: http://www.ons.gov.uk/ons/guide-method/census/2011/census-data/2011-census-user-guide/comparability-over-time/2011-2001-census-questionnaire-comparability.pdf.

ONS. (2012b). 2011 Census: Population Estimates for the United Kingdom, March 2011 Estimates of the usually resident population of the UK and its constituent countries, by age and sex. Statistical Bulletin, ONS. Available at: http://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/2011censuspopulationestimatesfortheunitedkingdom/2012-12-17

ONS. (2014). 2011 Census Analysis: Internal and International Migration of Older Residents (aged 65 and over) in England and Wales in the Year Prior to the 2011 Census [online]. Available from: http://www.ons.gov.uk/ons/dcp171776_377047.pdf.

Openshaw, S. (1977). Algorithm 3: A procedure to generate pseudo-random aggregations of N spatial units into M spatial units, where M is less than N. *Environment and Planning a*, *9*, 1423–1428. https://doi.org/10.1068/a091423

Openshaw, S. (1983). *The modifiable areal unit problem*. Norwich: Geo Books. ISBN 0860941345. OCLC 12052482

Ravenstein, E. (1885). The laws of migration. *Journal of the Statistical Society*, *46*, 167–235.

Raymer, J., Abel, G., & Smith, P. (2007). Combining census and registration data to estimate detailed elderly migration flows in England and Wales. *Journal of the Royal Statistical Society Series a-Statistics in Society*, *170*(4), 891–908. https://doi.org/10.1111/j.1467-985X.2007.00490.x

Rees, P., Bell, M., Kupiszewski, M., Kupiszewska, D., Ueffing, P., Bernard, A., Charles-Edwards, E., & Stillwell, J. (2017). The impact of internal migration on population redistribution: An international comparison. *Population, Space and Place*, 23, e2036. https://doi.org/10.1002/psp.2036

Rogers, A., & Castro, L. (1981). *Model migration schedules*. Laxenburg: International Institute for Applied Systems Analysis. ISBN:3-7045-0022-4. http://pure.iiasa.ac.at/id/eprint/1543/1/RR-81-030.pdf

Rowntree, J. A. (1957) Internal migration: A study of the frequency of movement of migrants. SMPS No 11, HMSO, London.

Simon, A. (2010). Do ethnic groups migrate towards areas of high concentration of their own group within England and Wales. In J. Stillwell & M. van Ham (Eds.), *Ethnicity and integration understanding population trends and processes volume 3* (pp. 133–151). Heidelberg: Springer.

Stillwell, J. (2008). Inter-regional migration modelling: a review and assessment. In J. Poot, B. Waldorf, & L. van Wissen (Eds.), *Migration and human capital* (pp. 29–48). Cheltenham: Edward Elgar.

Stillwell, J. (2010). Ethnic concentration and net migration in London. *Environment and Planning a*, 42, 1439–1456. https://doi.org/10.1068/a438

Stillwell, J., Bell, M., Blake, M., Duke-Williams, O., & Rees, P. (2000). A comparison of net migration flows and migration effectiveness in Australia and Britain, 1976-96. Part 1, Total migration patterns. *Journal of Population Research*, 17(1), 17–41. https://doi.org/10.1007/BF03029446

Stillwell, J., Bell, M., Ueffing, P., Daras, K., Charles-Edwards, E., Kupiszewski, M., & Kupiszewska, D. (2016). Internal migration around the world: Comparing distance travelled and its frictional effect. *Environment and Planning A: Economy and Space*, 48(8), 1657–1675. https://doi.org/10.1177/0308518X16643963

Stillwell, J., & Congdon, P. (Eds.) (1991). *Migration models, macro and micro approaches*. London: Belhaven Press. ISBN:1-85293-148-5.

Stillwell, J., Daras, K., & Bell, M. (2018). Spatial aggregation methods for investigating the MAUP effects in migration analysis. *Applied Spatial Analysis and Policy*, 11(4), 693–711. https://doi.org/10.1007/s12061-018-9274-6

Stillwell, J., Daras, K., Bell, M., & Lomax, N. (2014). The IMAGE studio: A tool for internal migration analysis and modelling. *Applied Spatial Analysis and Policy*, 7(1), 5–23. https://doi.org/10.1007/s12061-014-9104-4