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Components of Population Change: An Indirect Method for Estimating Births, Deaths and Net Migration for Age, Sex, Ethnic Group and sub-Regional Areas of Britain, 1991-2001

CCSR Working Paper 2008-03

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This paper details the method used in the Migration, Race and Population Dynamics project to estimate births, deaths and net migration over the period 1991-2001 for local authority districts of Britain, with sex detail and, for migration, age breakdown by single year. Estimates are needed because little demographic information is available for ethnic groups in Britain. The estimates produced not only provide demographic breakdown of population change for small areas, but are unique because they refer to the inter-censal decade and give net migration that includes emigration. They form part of a broader project investigating the demographic drivers of Britain's changing ethnic group geographies.

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Introduction

This paper details the method used in the Migration, Race and Population Dynamics project[1] to estimate births, deaths and net migration over the period 1991-2001 for local authority districts of Britain, with sex detail and, for migration, age breakdown by single year. The project aims to investigate the demographic drivers of Britain's changing ethnic group geographies and to engage with debates about population change, diversity and integration[2]. Estimates are needed because little demographic information is available for ethnic groups in Britain. For example, vital records of births and deaths do not state ethnicity and sub-national migration data by ethnic group is limited to the single year of each census. The estimates produced not only provide demographic breakdown of population change for small areas, but they are also unique in that they refer to the inter-censal decade and give net migration that includes emigration.

Contents:

1. Review of indirect methods to estimate migration

Demographic techniques for indirectly estimating migration are well established. They all rely on the demographic balancing equation which is shown in Box 1 (Voss *et al.* 2004, Rowland 2002, Edmonston and Michalowski 2004). Net migration is estimated as the difference between population change and natural increase over a particular time interval (Voss *et al.* 2004). When the start and end populations are known, as they are from censuses (and other population estimates) in the UK, population change is easily obtained.

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[1] Funded by the Leverhulme Trust, ID. 20050099, September 2006-September 2009.

[2] For further details including publications and resources, see www.ccsr.ac.uk/research/mrpd.

The challenge to estimate migration during the period is reduced to measuring natural change and deducting it from population change. To indirectly estimate the migration for a particular age group that was alive at the beginning of the period, there is no impact of births. For that reason the net impact of migration on a cohort aged, for example, 10 at the beginning of the decade, is just the population change during the decade plus the number of deaths that depleted that cohort during the decade.

Box 1: The demographic balancing equation

Population change = (births – deaths) + (in-migration – out-migration)
OR
Net migration = population change – natural change

Births do not add to a cohort already alive at the start of the period, for which :
Net migration to cohort age x at start of period = population aged (x+n) after n years – population aged x at the start of the period + deaths to the cohort during the period

There are two broad approaches to measuring natural change. The first is the vital statistics approach that uses numbers of births and deaths if they are known. Vital statistics are not available for ethnic groups in Britain so it is not possible to apply this method. The second approach is the survival method. This involves estimating the number of people (in each age, sex, ethnic sub-group) who survived over the defined period (1991 to 2001 in this case) to estimate deaths, and applying fertility rates to estimate births (Voss *et al.* 2004). Survival can be estimated using survival ratios from life tables and can be calculated from the starting population (forward survival) or the end point population (reverse survival). Survival methods have the disadvantage that they only provide statistics on net migration, with no details of inflows, outflows, origins or destinations. They have the advantage that they are applicable at all geographical scales and points in time.

1.1. Forward Survival

The forward survival method of indirectly estimating net migration uses survival ratios to calculate the population of each age that survived from the beginning of the time period of interest to the end point. Survivors are subtracted from the end of period population to give net migration. The formula for the forward survival method is given in Box 2. There are a number of sources of inaccuracy with the forward survival method. Forward survival doesn't estimate the migration of children born during the period, whether to residents or to in-migrants; child migration must be calculated separately. Migrants who die are not counted correctly. If net out-migration is occurring in an area, deaths in the area will be overestimated and net out-migration will be underestimated because people will be counted as dying when in fact they have first out-migrated. Conversely, if net in-migration is occurring in an area, deaths in the area will be underestimated and net in-migration will also be underestimated because not enough people will be assumed to in-migrate before they die. Finally, as there are no estimates of ethnic differential mortality in the UK, the implications of applying the same survival ratios to all ethnic groups must also be considered.

The advantage of this method is that it is comparable to Census measures of migration which also count migrants at the end of the migration interval and include only those who are alive at that time. It is also relatively straightforward to apply and the estimates using this method are appropriate for population projections.

Box 2: Formula for the forward survival method (adapted from Rowland 2002)

$$\text{Net } M'_{x+n\,e} = P^{n}_{x+n\,e} - S_e P^{0}_{xe}$$

Where:

Net $M'_{x+n\,e}$	is the estimated net migration for the end-of period population aged x+n in ethnic group e, obtained by forward survival
n	is the interval in years between the two dates
P^{0}_{xe}	is the initial population aged x in ethnic group e
$P^{n}_{x+n\,e}$	is the end-of period population aged x+n in ethnic group e
S_e	is the survival ratio from age x to age x+n for ethnic group e.

1.2. Reverse Survival

The reverse survival method uses the same concepts as forward survival but instead projects the population of an age group from the end of interval backwards in time to the beginning of the interval. The difference between this projected initial population and that of the measured population is net migration (see formula in Box 3). This method estimates migration at the start of the period before any mortality has occurred. It is therefore a more complete estimate of the volume of net migration than forward survival because migrants who died are included. This is particularly the case when the period of migration is long or mortality is high.

As with forward survival, child migration should be considered separately. The same concern of application of national survival ratios applies here. Reverse survival also has the disadvantage of not being comparable to vital statistics and census migration measures, or as appropriate for use in projections.

Box 3: Formula for the reverse survival method (adapted from Rowland 2002)

$$\text{Net } M'_{xe} = (P^{n}_{x+n\,e} / S_e) - P^{0}_{xe}$$

Where:

Net M''_{xn}	is the estimated net migration for the initial population aged x in ethnic group e, obtained by reverse survival

1.3. Adaptations to Forward and Reverse Survival Methods

One way to overcome some of the bias in the forward and reverse survival methods is to use the average survival method. This method adjusts for the mortality of migrants by averaging the net migration estimates produced from forward and reverse survival methods (Edmonston and Michalowski 2004).

Whether forward, reverse or average survival are used it is necessary to calculate the net migration of children born in the period in order to have a complete estimate of migration. This can be achieved using child-woman ratios (CWRs) to calculate birth cohorts before applying a method to estimate migration (Rowland 2002). CWRs are calculated by dividing the child population of a certain age or age group by the female population of a corresponding reproductive age or age group. Migration can then be estimated by applying a survival method to the birth cohorts. Alternatively, the CWR can then be multiplied by the net migration for the female age group and a multiplier that reflects the time of migration to give an estimate of child net migration. A multiplier to reflect time of migration is needed because the probability of a child migrating will depend upon the point during the time period at which it was born. For example, for a 10 year time interval, if it is assumed that the volume of migration is similar across time, children age under 5 at the second census would be born on average 2.5 years before the final time point and therefore only a quarter of their mother's migration would have occurred after that date. The time multiplier for this example would therefore be 0.25. Similarly, children age 5-9 at the second census were born on average 7.5 years before the census and three quarter's of their mother's migration would have occurred after this date meaning that a 0.75 multiplier is required (Box 4).

Gavalas and Simpson (2007) employed an alternative approach to estimating births and deaths for ethnic group populations, from which they calculated net migration. Births were estimated by taking the 2001 census population aged under 10 for each ethnic group, all of whom were born in the period 1991-2001, and scaling it to be consistent with the total number of births in that period (from ONS population estimates). Deaths were estimated by applying national mortality rates (1 – life table survival rate) to the population in 1991 at each age, and scaling the result to be consistent with the total number of deaths during 1991-2001. Net migration could then be estimated as the subtraction of natural change from total population change.

This method was found to estimate the net direction of migration correctly, but to under-estimate its size because infant migrants and deaths of migrants were not all counted as births and deaths correctly. Where net migration is inwards, this method slightly over-estimated births because some young children in 2001 were born elsewhere. Similarly deaths are under-estimated because some people who in-migrate during the period also die. This results in over-estimation of natural change and under-estimation of net in-migration.

Conversely, if there has been net out-migration there will be under-estimation of the size of that net out-migration.

Box 4: Estimation of child migration using child-woman ratios

For a 10 year time interval and 5 year age groups:

Net $_5M'_0$ = 0.25 x CWR x net migration of females aged 15-44
Net $_5M'_5$ = 0.75 x CWR x net migration of females aged 20-49

For a 10 year time interval and single years of age:

Net M'_0 = 0.05 x CWR x net migration of females aged 15-40
Net M'_1 = 0.15 x CWR x net migration of females aged 16-41
Net M'_2 = 0.25 x CWR x net migration of females aged 17-42
Net M'_3 = 0.35 x CWR x net migration of females aged 18-43
Net M'_4 = 0.45 x CWR x net migration of females aged 19-44
Net M'_5 = 0.55 x CWR x net migration of females aged 20-45
Net M'_6 = 0.65 x CWR x net migration of females aged 21-46
Net M'_7 = 0.75 x CWR x net migration of females aged 22-47
Net M'_8 = 0.85 x CWR x net migration of females aged 23-48
Net M'_9 = 0.95 x CWR x net migration of females aged 24-49

2. Method adopted for ethnic groups in the UK 1991-2001

The challenges for this research were in developing the methods described above for application to ethnic groups, small areas and the data available in the UK. As already noted, vital statistics are not available for ethnic groups in Britain so it was not possible to apply this method as in some other countries (e.g. in the USA, Voss *et al.* 2004). Therefore, an adaptation of the average survival approach was used in this research. The estimation involved six stages, as follows and detailed below, that take into account ethnic group and local variations.

1. Population change was calculated from 1991 and 2001 full population estimates.
2. The number of births into each age cohort aged between 0 and 9 at 2001 were estimated using child-woman ratios in 1991 and the number of children in 2001.
3. These births estimates were scaled so that when summed across ethnic groups they are consistent with official vital statistics data by district, age and sex for the relevant year. This scaling of births to each age cohort to official statistics allows accurate estimation of area child migration.
4. An initial estimation of the number of deaths was made using an average of the forward and reverse survival methods.

5. These deaths estimates were scaled so that when summed across ethnic groups they are consistent with total deaths from official vital statistics for each district for the period 1991-2001. The control on deaths incorporates differential area mortality into the estimates.
6. Final estimates of migration were generated with calculations based on the demographic balancing equation (Box 5).

Box 5: Method for estimating net migration

NM(x) = P01(x) - P91(x) + D(x).

x is age at 2001
P91(x) and P01(x) is population at mid-1991 and mid-2001 respectively
For x<10, P91(x) refers to B(x), births which will be aged x in mid-2001
e.g. P91(5)=B(5)=births mid-1995 to mid-1996.
D(x) is deaths to those who would have been aged x in 2001.

In full notation an ethnic group index is used, so the estimate of net migration is:

NM(x,e) = P01(x,e) - P91(x,e) + D(x,e).

2.1. Stage 1: Calculation of population change

Population change is the 1991 population of each district, sex, age and ethnic group combination subtracted from the corresponding 2001 population. The accuracy of the components of population change estimated relies upon an accurate and reliable time series of population. This research used population estimates produced by Sabater at CCSR, the specifications of which can be found in Sabater and Simpson (2007). These full population estimates give populations for districts of England, Wales and Scotland by sex, single year of age and ethnic group for mid-1991 and mid-2001. Each estimate is based on census data but includes allowances for non-response, alteration to the enumeration of students, timing adjustment between census day and mid-year, boundary changes, and changes to the ethnic group census categories.

Sabater provides population estimates for ten ethnic groups for 1991 and sixteen for 2001. For the purposes of comparison over time the data for each of the two time points have been aggregated to eight ethnic groups: White, Caribbean, African, Indian, Pakistani, Bangladeshi, Chinese and Other, with the 2001 Mixed groups being included in the residual Other category. There are a number of issues about the comparability of ethnic group categories over time but it has been found that the first seven of these groups were the most coherent and stable classification from 1991 to 2001 (Office for National Statistics 2006; Simpson and Akinwale 2007). The residual eighth category is used for completeness but is very diverse and of different composition in the two years. Sensitivity to alternative population estimates, including alternative allocation of ethnic groups, is reported later in this paper.

2.2. Stage 2: Estimate births

Estimation of births for each year of the decade involved the following steps which were applied to each sex, district and ethnic group. The method is summarised in Box 6.

1. *Calculate 1991-based births.* Child-Woman ratios for 1991 were calculated by dividing the group population aged 0 to 9 (in 1991) by the female population aged 20 to 49 (in 1991, which best approximates the population from which the children aged 0-9 have come). Child-Woman ratios were calculated in the same way for the 2001 population. The number of 'productive females' who may give birth during the decade 1991-2001 was calculated as the female population aged 10 to 39 in 1991. 1991-based births were calculated as the mean of the 1991 and 2001 CWRs multiplied by the number of productive females at the beginning of the decade. The average CWR is used to reflect changing fertility during the decade.
2. *Calculate 2001-based births.* This was taken as the population aged 0 to 9 in 2001, who are assumed to have been born in the district (and sex and ethnic group) in the previous decade. The number at each individual age under 10 in 2001 is the most direct estimate of those born in each year of the decade 1991-92 and so on.
3. *Calculate births over the decade.* The mean of 1991-based and 2001-based births is taken. This reduces the impact of the 2001-based estimates including child in-migrants. This averaging of the 1991 and 2001-based estimates is consistent with averaging the forward and reverse survival estimates of deaths.
4. *Allocate the decade's births to each birth cohort.* The births were allocated to each birth cohort in the same proportions as their cohort within the 2001 population aged 0 to 9.

Where a population group had no females aged 20-49 in 1991 or 2001, meaning CWRs could not be calculated in the way described above, the national CWR for the total population (calculated using the full population estimates) was substituted. Where a population group had no children aged 0 to 9 in 2001 the overall births for the decade were allocated evenly to each of the ten birth cohort years.

Where a population group had low numbers of children or women, the method also needs adjustment to avoid extreme high numbers of births resulting from very small female populations (age 20-49) in combination with larger populations of females aged 10-39. This occurred, for example, for the African and Bangladeshi groups in the districts of Eden, Ryedale and Alnwick. The solution applied to this problem was as follows: If the children or women's population was less than 3, the national ratio for their group was used. If the population of both children and women was 50 or higher, the local child/women ratio was used. If the minimum of child and women populations was at least 3 but below 50, the CWR combines the group's national and local ratios, giving weight to the local ratio to the extent that the minimum of child and women populations approaches 50. For example, if there were 10 children and 100 women in an ethnic group in a district, the local CWR of 0.1 is given the weight of 10/50 and the group's national ratio is given the weight 40/50. The nearer both the children and women's populations are to 50, the more weight is given to the local ratio.

Box 6: Method for estimating initial births

Total initial births: ([(CWR91 + CWR01)/2]*P91(females aged 10-39) + P01(aged 0-9))/2 where CWR = (aged 0-9) / (females aged 20-49) Proportion of total initial births born in year 1991-92=P01(aged 9)/P01(aged0-9); in year 1992-93=P01(aged 8)/P01(aged0-9), etc This gives an initial value, BI(x,e) for each x<10 and ethnic group e.

2.3. Stage 3: Scale births estimates to National Statistics estimates

In order that the estimated births for males and females in each district and each birth cohort of the decade were consistent with official statistics, an adjustment factor was applied to the initial births estimates (Box 7). The adjustment factor is the ratio of the registered (ONS/GROS) births in a cohort, for males and females separately, to the initial estimate of births, taken as the sum of the ethnic group estimates. The adjustment factor was then applied to each of the ethnic group births estimates. This ensures that in each District the ethnic group births sum to the number of registered births.

Box 7: Control of births to official statistics estimates

B(x,e) = BI(x,e) * B(x,.) / BI(x,.) Where B(x,.) is the number of registered birth in the district and B(x,e) is the final births estimate for each age and ethnic group

2.4. Stage 4: Estimate deaths

Deaths were calculated for each sex, year of age, district and ethnic group combination using the average survival method as shown in Box 8.

Box 8: Method for estimating initial deaths

Forward survival: DF(x,e) = P91(x,e) * (1-S(x-10))

If x≥10, S(x) is the ten-year life table survival ratio from age x, averaged from GAD England and Wales life tables 1991-2001. If x<10, S(x-10) is the survival from birth to age x

Reverse survival: DR(x,e) = P01(x,e) * ((1/S(x-10)) - 1)

Initial value of deaths: DI(x,e) = (DF(x,e) + DR(x,e))/2

2.5. Stage 5: Scale deaths to National Statistics estimates

In order that the estimated deaths for males and females in each district were consistent with official statistics, an adjustment factor was applied to the initial deaths estimates (Box 9). The adjustment factor is the ratio of the registered (ONS/GROS) deaths in the district over the decade, for males and females separately, to the initial estimate of deaths, taken as the sum of the ethnic group estimates. The adjustment factor was then applied to each of the ethnic group deaths estimates. The control ensures that areas with different mortality from the national are suitably adjusted, so that in each District the number of deaths for each ethnic group adds to the total number of registered deaths. It is a crude adjustment, in that all ages and all ethnic groups are adjusted by the same proportion.

Box 9: Control of deaths to official statistics estimates

D(x,e) = DI(x,e) * D(.,.) / (DI(.,.)

Where is D(.,.) is the number of registered deaths in the district over the decade
and D(x,e) is the final deaths estimate for each age and ethnic group

2.6. Stage 6: Estimate net migration

Net migration for each sex, age, district and ethnic group combination was calculated as the residual of population change minus natural change (Box 10).

Box 10: Estimating net migration

NM(x,e) = P01(x,e) - P91(x,e) + D(x,e)

x is age at 2001
D is deaths to those who would have been aged x in 2001
For x<10, B(x,e) is substituted for P91(x,e), where B(x,e) is Births which would be aged x in 2001

3. Outputs

The estimation procedure detailed above has, for each district of Great Britain over the period mid-1991 to mid-2001, produced estimates of:

- Births for males and females in each of 8 ethnic groups for each year of the decade;
- Deaths for males and females in each of 8 ethnic groups for each single year of age;
- Net migration for males and females in each of 8 ethnic groups for each single year of age.

The full dataset consists of 594,048 records (2 sexes * 8 ethnic groups * 91 age groups * 408 districts). This is held as an SPSS data file. All procedures for the estimation have been programmed in SPSS enabling them to be run with alternative populations and geographical areas. The estimates will be made available to the research community[3].

The estimates are summed for Great Britain in Table 1. Overall, natural change added just over 900 thousand to the population of Britain, while migration added just under 700 thousand. These are the same estimates as provided in national statistical agency datasets, since the project's population estimates, births and deaths have all been constrained to be consistent with statistical agency equivalents. Small differences may occur only because of inconsistencies between published vital statistics and those used in population estimates, due to late registrations for example.

The natural change and net migration summed for each ethnic group are new estimates from this project. They show that for Great Britain as a whole all populations gained from natural change, and all but the Caribbean group also gained from net migration. The African and Chinese groups have most recent migration which exceeds their natural growth. For all the other minority groups population growth is due mostly to natural growth and less so to continued international migration.

[3] Currently available on request and an on-line interface is being developed. For further details please see www.ccsr.ac.uk/research/mrpd.

Table 1: Components of population change for ethnic groups in Britain 1991-2001

Ethnic Group	Population 1991	Population 2001	Population Change 1991-2001	Births 1991 to 2001	Deaths 1991 to 2001	Natural Change 1991 to 2001	Net Migration 1991 to 2001
All Groups	*55,831,363*	*57,424,176*	*1,592,813*	*7,066,033*	*6,153,751*	*912,282*	*680,531*
White	52,441,709	52,709,827	268,119	6,136,459	6,018,735	117,724	150,395
Caribbean	570,751	573,990	3,239	86,952	30,003	56,949	-53,710
African	258,746	499,790	241,044	94,024	7,775	86,249	154,795
Indian	903,024	1,068,343	165,319	162,250	39,434	122,816	42,503
Pakistani	519,115	759,540	240,425	177,798	18,151	159,647	80,778
Bangladeshi	178,195	288,673	110,478	78,712	5,679	73,033	37,444
Chinese	184,788	249,666	64,879	27,143	7,242	19,901	44,978
Other	775,035	1,274,346	499,311	302,695	26,731	275,963	223,348

The table is an aggregate of the project estimates, across ages, males and females and all Districts in Britain. Net migration therefore refers to migration with areas outside Britain.

4. Quality of the estimates

Table 1 shows the same pattern of national population growth and the same balances between natural growth and net migration for each of the ethnic groups as Williamson found using a forward survival approach for England as a whole (Williamson, 2006, reproduced in Simpson, 2007). This replication of the broad pattern of change is reassuring.

However, the method used to produce net migration estimates makes a number of assumptions which, if incorrect, have implications for the quality of the results. These are investigated in this section to assess the sensitivity of the estimates to the method's assumptions. First, the accuracy of the 1991 and 2001 populations is assumed. However, the population estimates are known to be least reliable for ages 18-40 in both census years meaning that estimates of net migration are also less reliable for these ages. Second, births estimates are assumed to be correct. However, the controls using official vital statistics estimates make the same proportional adjustment to births in the same direction for all ethnic groups, which in effect assumes the same child migration for this adjustment. Thus the ethnic group differences in net migration rates (at ages 0-9 in 2001) will be identified but will tend to be under-estimated. Third, it is assumed that deaths to each age have been correctly estimated. There is no reason to expect a bias in the estimation procedure since research does not show a clear mortality differential between ethnic groups. However, the estimates of deaths are approximate and lead to approximate estimates of net migration in years for which there are most deaths i.e. older ages, particularly older than age 50. The next section will consider the robustness of births and deaths estimates in more detail. The following section will test the sensitivity of the net migration estimation to alterations in the populations and ethnic group allocations used.

4.1. Robustness of births and deaths estimates

Births: bias and adjustments

The births contain a bias that is related to the direction of net migration, not for the total but for ethnic groups whose net migration is different from the local average. The bias is greatest for the cohorts born in the earlier part of the 1991-2001 decade. The result is to dampen the volume of net migration, moving the estimate nearer to zero.

The births are estimated as an average from a 1991-based projection and a 2001-based back-projection. In the 1991-based projection, in-migration of child bearers will lead to an under-estimate of births, and vice versa. In the 2001-based projection, in-migration of children will lead to an over-estimate of births, and vice versa. Thus, if the direction of migration of children and child-bearers is the same, our averaging of the two estimates will keep the biases to a minimum.

However, the allocation of the births to individual years is entirely based on the 2001-based back-projection. If there is in-migration of children, all cohorts will be estimated too highly, but in particular those born earliest, which have had most years of addition from migration (and vice versa: out-migration leads to earlier cohorts being estimated particularly low). The total across ethnic groups is corrected for each cohort by the controls. However, the same factor is used for each group, so if migration is different in each group then migration will be biased.

Taking Birmingham as an example, the size of the bias is significant. The control of 8628 births 1991-92 adds 734 births to the initial estimate of 7894. The control implies that overall there has been an out-migration of young children after birth, and it adds them back in the same proportion to all groups. But since half the eight groups had in-migration rather than out-migration (African, Chinese, Pakistani, Bangladeshi), this adjustment gives too many extra births to these groups (who in fact should have some deducted) and too few to the other groups. The impact on the estimate of net migration is to under-estimate the volume of both net in-migration and net out-migration. Looking at the births and net migration estimates for each of the cohorts born 1991-2001, for White and Pakistani, the impact is clearly to bias the estimates for those born early in the 1990s.

We can gauge the extent of the bias by examining the adjustment factors used in the estimation procedure, to control the births to each cohort to official statistics. Table 2 provides descriptive statistics of the adjustment factors. An adjustment factor of 1 indicates an exact match between our estimates and the vital statistics control. Below 1 indicates overestimation; above 1 indicates underestimation. The mean adjustment across birth cohorts and districts is 0.99 indicating accuracy in our estimates. Deviation from the mean is low and quartiles lie in the acceptable range of 0.9 to 1.1. However, the minimum and maximum adjustment factors indicate that some birth cohorts and districts were substantially under- and over-estimated before control to the total number of registered births. The largest adjustment factors are in London, indicating initial under-estimation of births due to net out-migration. The smallest adjustment factors are in rural and other less urban areas, indicating initial over-estimation of births due to net in-migration.

Table 2: Descriptive statistics of births adjustment factor

N	Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum	Standard Deviation
8160	0.993	0.448	0.936	0.981	1.030	1.853	0.101

Deaths: bias and adjustments

Figures 1 and 2 show that the migration estimates are not affected by the different methods of using survival rates, except at ages 65+ and especially the oldest ages, when most deaths occur. Even then, the age pattern is not very sensitive to the alternative ways of implementing the survival rate method. At the oldest ages, reverse survival gives the lowest net migration estimate, followed by average and forward methods. At the oldest age, 90+, the controlled average produces a peak of net migration that is not evident in the other three methods.

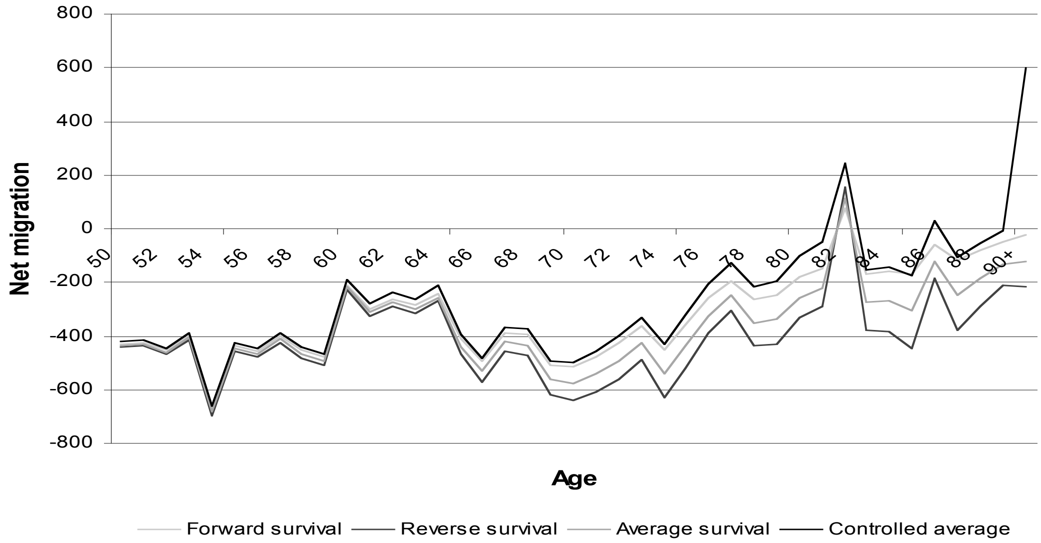
Table 3 presents descriptive statistics of the adjustment factors that were used to control deaths for each district to official statistics. The mean, deviation and inter-quartile range are acceptable, but some over-estimation of deaths leads to a downward adjustment on average by three per cent. The highest adjustment factors were for Manchester, North Lanarkshire, West Dunbartonshire, Inverclyde, and Glasgow City, and the lowest for rural areas.

Table 3: Descriptive statistics of deaths adjustment factor

N	Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum	Standard Deviation
816	0.970	0.723	0.890	0.955	1.041	1.442	0.108

Figure 1: Controlled average survival estimate of net migration of males in Birmingham 1991-2001, ages 0-90+

Figure 2: Divergence of the survival method estimates of net migration at ages over 50, for males in Birmingham 1991-2001



4.2. Sensitivity testing: alternative population estimates

As in the previous section, the approximation of births and deaths affects the accuracy of the net migration estimates at ages 0-9 and over 65 respectively. At ages 10-64 the migration estimates are more affected by the quality of the population estimates used. It is useful, therefore, to test the sensitivity of the estimates to alternative population estimates. The procedure to estimate components of change for every District-ethnic group combination was run using the following three alternative datasets for 1991 and 2001 populations, and the results are summarised in Table 4.

1. Proportional allocation of ethnic groups in 2001 to 1991 categories
2. Ethnic group differentials in the allocation of non-response in 2001
3. Census figures unadjusted in both 1991 and 2001

Proportional allocation of ethnic groups in 2001 to 1991 categories

The components of change estimates match seven of the 1991 Census ethnic group categories to whole 2001 categories leaving a residual, as specified above. Although analysis of the Longitudinal Study has found this allocation to produce the best fit, the allocation of whole categories is an approximation. For England and Wales as a whole, a better approximation is given by the proportions of people recorded in a category in 2001, who in 1991 were recorded in each of the categories available in 1991. These proportions can be used to allocate 2001 population using 2001 categories to 1991 categories not wholly but proportionately. The proportions are taken from Simpson and Akinwale (2007, Table 5, p196). For example, of those recorded in both censuses and in 2001 recorded as Indian, 93.7% were recorded as Indian in 1991, 1.5% as White, 0.1% as Black Caribbean, and so on adding in total to 100%. This alternative method of allocating the 2001 population to ethnic groups has the advantage of being based precisely on evidence of the degree of matching between the two censuses' category sets.

Table 4 shows for each ethnic group the impact of natural change and net migration in the decade as percentages of their 1991 population, taken from the main estimates in Table 1 and from the alternative allocation of ethnic groups in 2001 (and for other alternative estimates discussed below).

Apart from the residual Other category, the pattern of population dynamics is the same when using the alternative allocation of ethnic groups although the detailed numbers do change. This suggests that the eight group classification is reliable but that we should bear in mind potential errors for Great Britain as a whole: underestimation of natural change and overestimation of net out-migration for the Caribbean group; overestimation of net in-migration for the African group; and under-estimation of net in-migration for the Indian group.

The use of this alternative allocation of ethnic groups is not appropriate for use in our age-sex-sub-national population time series for at least three reasons:

a) The Longitudinal Study includes only those recorded at both censuses and matched in the Longitudinal Study. The 2001 population includes additionally those born or immigrating between 1991 and 2001, and those not responding to the census, who may well have a different pattern of responses to the questions, had they been included at both censuses.
b) The proportions are estimated for all people and may not be accurate in the same way at each age and sex. For example, the proportion of those in 2001 recorded as Caribbean who in 1991 were recorded as Other (including Mixed Caribbean/White) would not be the same for older as for younger people.
c) Similarly, the proportions may not hold for each area within Britain. For example, the proportion of those in 2001 recorded as Caribbean who in 1991 were recorded as Other (including Mixed Caribbean/White) would not be the same in each area, for example in Liverpool where the Caribbean population is relatively very long-standing with many mixed families. Similarly the proportion of Pakistani who were recorded in 1991 as Indian, is likely to differ between areas.

Ethnic group differentials in the allocation of non-response in 2001

The main estimates use ONS population estimates for England's ethnic group populations in 2001. The extra 0.25million persons added by ONS after further census validation are allocated differentially to Districts and to age-sex groups (predominantly to young adult men). However, ONS assumes equal allocation to each ethnic group proportional to their population within these categories of age and sex and area. The alternative of higher allocation to minority groups is taken from Sabater (2007) who tests the sensitivity of the ONS assumptions by allocating the extra non-response to ethnic groups in line with the ethnic differentials of imputed non-respondents already within the census output, and published by ONS for each District-sex-ethnic group combination.

Since this alternative allocation of non-response adds more non-response to the 2001 population for minorities and deducts some from the White population, one would expect a higher estimate of in-migration for minorities. Table 4 confirms this is so; the alternative allocation of non response has very little impact on the estimation of natural change and adds slightly to the estimated inward migration of minority groups. The numbers involved are too small to make a large difference nationally. In Districts where the allocation of extra non-response was more significant, primarily Manchester and Westminster (see Appendix table), the impact of allocating more of the extra population to minority groups is more noticeable. It increases the estimated in-migration of minority groups and the out-migration of the White population but does not affect the balance between natural change and net migration for each ethnic group. An extreme example in Manchester is the net in-migration of the African group, which is 38% of its 1991 population with the alternative allocation of non-response, compared to 29% in the main estimates.

Census figures unadjusted in both 1991 and 2001

Finally, an alternative estimation uses census figures for 1991 and 2001 without the adjustments that the main work has used to create full population estimates. The data from the census has simply been allocated to the same boundaries (2001 census districts) and smoothed to give single year of age in each census. This is the only one of the three alternatives which changes the total population; the previous two alternatives only distribute the ethnic group populations differently within each age-sex-District category.

Table 4 shows that the published unadjusted census figures produce higher estimates of both natural change and net in-migration for each ethnic group. Greater estimated population change is expected because the largest deficiency of the censuses is non-response in 1991. The published census figures imply greater increase in population during the decade than do the full population estimates, adding twice as much in-migration in net terms, 2.4% rather than 1.2%. The census figures give particularly higher natural change for the Other and

African groups, and particularly higher net migration for the African, Pakistani and Indian groups. The Caribbean group according to the raw census populations has experienced net in migration as opposed to net out migration using full population estimates. Natural change is greater with the raw census figures because they exclude disproportionately women of child-bearing age at 1991 (who were more likely to be non-respondents than younger women) with consequentially higher estimates of fertility (higher child-women ratios), but do not exclude to the same extent teenagers who will become of child-bearing age during the decade 1991-2001. Thus the number of births during 1991-2001 is greater with this alternative analysis using raw census data.

Although both natural change and in-migration are increased, the overall pattern of minority group population dynamics observed with the main set of estimates is not changed: greater net immigration than natural change for African and Chinese groups whose major immigration is most recent, but less net immigration than natural change for Caribbean, Indian, Pakistani and Bangladeshi groups.

Table 4: Sensitivity testing: impacts of natural change and net migration 1991-2001 for ethnic groups in Britain using full population estimates, alternative ethnic groups and alternative population estimates

	Full population estimates		Proportional allocation of ethnic groups in 2001 to 1991 categories		Ethnic group differentials in the allocation of non-response in 2001		Census figures unadjusted in both 1991 and 2001	
Ethnic group	**Natural Change as % of 1991 population**	**Net Migration as % of 1991 population**	**Natural Change as % of 1991 population**	**Net Migration as % of 1991 population**	**Natural Change as % of 1991 population**	**Net Migration as % of 1991 population**	**Natural Change as % of 1991 population**	**Net Migration as % of 1991 population**
White	0.2	0.3	0.4	0.6	0.2	0.2	0.3	0.9
Caribbean	10.0	-9.4	12.7	-5.2	10.0	-8.6	10.8	2.3
African	33.3	59.8	31.3	48.0	33.4	62.9	39.1	88.9
Indian	13.6	4.7	14.4	12.6	13.6	5.4	14.6	10.6
Pakistani	30.8	15.6	30.2	17.4	30.8	16.9	33.2	23.5
Bangladeshi	41.0	21.0	40.3	22.7	41.0	22.6	44.3	29.4
Chinese	10.8	24.3	11.2	23.0	10.8	25.8	12.2	43.2
Other	35.6	28.8	25.4	-1.7	35.6	28.8	40.0	47.4
All Groups	***1.6***	***1.2***	***1.6***	***1.2***	***1.6***	***1.2***	***1.7***	***2.4***

The table is an aggregate of the project estimates, across ages, males and females and all Districts in Britain. Net migration therefore refers to migration with areas outside Britain.

5. Conclusion

This paper has detailed the method used to estimate components of change and discussed the quality of the resulting estimates. We conclude that:

- An appropriate method has been devised that allows for separate estimates for each combination of ethnic group, sex and area.
- The method estimates births then uses average survival to calculate deaths, giving net migration as the residual.
- The estimates give births, deaths and net migration for the period mid-1991 to mid-2001 for 408 districts of GB, for sex, 8 ethnic groups and, for migration, single years of age. It could be applied to other geographical areas including smaller scales.
- There is no bias in the overall estimation of births and deaths as these are controlled to vital statistics; there is some bias towards under-estimating births for out-migrating groups, and vice versa over-estimating births for in-migrating groups. The impact of this bias is to under-estimate the volume of net migration among children.
- While alternative datasets might be used, and alternative detail of estimation formulae, sensitivity tests to alternative populations confirm the robustness of the main conclusions drawn from the estimates in this paper, which show the greater contribution of natural growth than new immigration for minority groups in the 1990s.
- The procedure provides a unique dataset that allows ethnic group population dynamics to be explored.

For further details about the project see website http://www.ccsr.ac.uk/research/mrpd/.

For a discussion of the early findings from this part of the project see Finney and Simpson (2008)

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Appendix: Population and population change, Westminster and Manchester, main estimates and alternative allocation of non-response

Main estimates										Contributions to population change 1991-2001, as % of 1991 population				
name	code	eth_8	Pop1991	Pop2001	PopChange	Births	Deaths	NaturalChange	NetMigration	PopChangepc	Birthspc	Deathspc	NaturalChangepc	NetMigrationpc
Westminster	00BK	White	140,915	148,919	8,004	13,576	15,036	-1,460	9,464	6	10	11	-1	7
Westminster	00BK	Caribbean	7,546	6,207	-1,339	1,130	348	782	-2,121	-18	15	5	10	-28
Westminster	00BK	African	6,326	7,447	1,121	1,651	122	1,530	-408	18	26	2	24	-6
Westminster	00BK	Indian	4,057	6,461	2,404	522	190	331	2,072	59	13	5	8	51
Westminster	00BK	Pakistani	1,355	2,101	746	258	55	203	543	55	19	4	15	40
Westminster	00BK	Bangladeshi	4,390	5,540	1,150	2,044	105	1,939	-790	26	47	2	44	-18
Westminster	00BK	Chinese	3,529	4,621	1,092	310	103	207	885	31	9	3	6	25
Westminster	00BK	Other	16,914	22,033	5,119	4,593	510	4,083	1,036	30	27	3	24	6
Westminster	00BK	Total	185,032	203,329	18,297	24,085	16,469	7,616	10,681	10	13	9	4	6
Manchester	00BN	White	368,953	342,347	-26,606	44,525	46,856	-2,331	-24,275	-7	12	13	-1	-7
Manchester	00BN	Caribbean	12,694	9,645	-3,050	1,497	898	599	-3,649	-24	12	7	5	-29
Manchester	00BN	African	4,854	7,272	2,418	1,245	211	1,034	1,383	50	26	4	21	29
Manchester	00BN	Indian	5,629	6,350	721	745	235	510	211	13	13	4	9	4
Manchester	00BN	Pakistani	17,821	24,819	6,999	5,638	664	4,974	2,024	39	32	4	28	11
Manchester	00BN	Bangladeshi	2,335	3,909	1,574	916	77	839	735	67	39	3	36	31
Manchester	00BN	Chinese	4,396	5,595	1,199	511	203	308	891	27	12	5	7	20
Manchester	00BN	Other	15,993	22,979	6,985	6,514	433	6,081	904	44	41	3	38	6
Manchester	00BN	Total	432,676	422,915	-9,761	61,592	49,577	12,015	-21,776	-2	14	11	3	-5

Alternative 2. Ethnic group differentials in the allocation of non-response in 2001										Contributions to population change 1991-2001, as % of 1991 population				
name	code	eth_8	Pop1991	Pop2001	PopChange	Births	Deaths	NaturalChange	NetMigration	PopChangepc	Birthspc	Deathspc	NaturalChangepc	NetMigrationpc
Westminster	00BK	White	140,915	147,671	6,756	13,511	15,020	-1,509	8,265	5	10	11	-1	6
Westminster	00BK	Caribbean	7,546	6,498	-1,049	1,145	355	790	-1,839	-14	15	5	10	-24
Westminster	00BK	African	6,326	7,917	1,591	1,693	125	1,567	23	25	27	2	25	0
Westminster	00BK	Indian	4,057	6,834	2,777	534	195	340	2,437	68	13	5	8	60
Westminster	00BK	Pakistani	1,355	2,204	850	263	56	206	643	63	19	4	15	47
Westminster	00BK	Bangladeshi	4,390	5,744	1,354	2,069	107	1,962	-609	31	47	2	45	-14
Westminster	00BK	Chinese	3,529	4,754	1,225	313	104	209	1,016	35	9	3	6	29
Westminster	00BK	Other	16,914	21,708	4,794	4,557	507	4,050	744	28	27	3	24	4
Westminster	00BK	Total	185,032	203,329	18,297	24,085	16,469	7,616	10,681	10	13	9	4	6
Manchester	00BN	White	368,953	339,942	-29,011	44,444	46,803	-2,359	-26,652	-8	12	13	-1	-7
Manchester	00BN	Caribbean	12,694	10,080	-2,615	1,509	919	590	-3,205	-21	12	7	5	-25
Manchester	00BN	African	4,854	7,744	2,890	1,267	218	1,049	1,841	60	26	4	22	38
Manchester	00BN	Indian	5,629	6,509	880	747	238	510	370	16	13	4	9	7
Manchester	00BN	Pakistani	17,821	25,081	7,260	5,648	669	4,979	2,282	41	32	4	28	13
Manchester	00BN	Bangladeshi	2,335	4,078	1,743	924	79	845	898	75	40	3	36	38
Manchester	00BN	Chinese	4,396	5,996	1,599	518	212	306	1,293	36	12	5	7	29
Manchester	00BN	Other	15,993	23,485	7,492	6,534	440	6,094	1,397	47	41	3	38	9
Manchester	00BN	Total	432,676	422,915	-9,761	61,592	49,577	12,015	-21,776	-2	14	11	3	-5