The use of a new indirect method to estimate ethnic-group fertility rates for subnational projections for England

Short title: Ethnic-group fertility rates

To project the ethnic-group populations of local authorities in England to 2051, estimates of ethnic-specific fertility rates were needed. In the absence of ethnic information on birth records, we developed indirect estimation methods that use a combination of vital statistics, the census (both microdata and aggregate tables), and survey data (Labour Force Survey). We estimated age-specific and total fertility rates successively for five broad ethnic groups encompassed by all datasets, and for eight ethnic groups encompassed by the 1991 and 2001 Censuses for England. We then used census data to disaggregate the estimates to the sixteen ethnic groups required for the subnational projections and the Hadwiger function to estimate single-year-of-age estimates. We estimated the uncertainty around the fertility estimates and used a logistic model to project rates to 2021, after which we assumed rates would remain constant.

Keywords: ethnic fertility; birth statistics; subnational estimates; ethnic projections; plausibility ranges

Introduction

The role of ethnicity in subnational population projections

In censuses and surveys, variables that can inform on ethnic background include the following: country of birth or family origin, country of citizenship or nationality, race, language, and religion. There is need to incorporate such information in demographic work for two broad reasons. The first is that such data are needed for planning purposes. Data on age and sex for members of ethnic subgroups are needed by local governments and other agencies in order to produce population estimates and projections for subnational areas (Haskey 2002; Simpson 2002a). Knowledge of ethnic-group numbers by age and locality can help in estimating demand for particular goods and services such as language support, design of housing, and food choices. If we can estimate recent trends and project future populations for ethnic groups, then debates about diversity and immigration levels can be better informed. The second reason is that establishing the heterogeneity of population subgroups improves the quality of aggregate data (Simpson 1997). If different groups of people have distinct age-sex structures and demographic propensities, which is the case for different ethnic groups (Penn 2000), details of these differences will lead to improved information about the population.

Methods for projecting ethnic populations

A range of methods exist for projecting populations (Wilson and Rees 2005; Booth 2006), the most common of which is the cohort-component method. In this method, age-specific fertility, mortality, and migration rates are applied to an area's base population to project the population in the future. Rees (2002) outlines the cohort-component method used for the official UK-wide national projections and shows how it can be extended to ethnic groups. For subnational projections, there is a need for robust estimates of ethnic-group fertility, mortality

and migration rates for local areas. In the UK, statistics on ethnic groups have been available from national surveys since the late 1970s and from the 1991 and 2001 Censuses. However, for population projections, the inclusion of age-specific fertility rates (ASFRs) by ethnic group poses a problem because ethnicity is not recorded when births are registered (Dubuc 2009; Williamson and Norman 2011).

In a number of countries, population projections are made for the different ethnic/racial groups that comprise the national population. The US Census Bureau (2008) makes projections by race and Statistics New Zealand (2008) differentiates between groups which are European or Other, Māori, Asian or Pacific in origin. For Australia Wilson (2009) projects regional populations by Indigenous (Aboriginal and Torres Strait Islander) and non-Indigenous status underpinned by census and vital events data. The practices of different European countries are reviewed by Coleman (2006). Ethnicity is defined by citizenship or country of birth, which means that the offspring of foreign-born individuals are usually treated as indigenous for projection purposes after one or two generations.

Classifications of ethnicity in the UK are based on self-reporting for census or social survey questionnaires (ONS 2003). The categories used are a compromise between the need to keep the question simple and the requirements of pressure groups, academics, and government practitioners for the ethnic detail needed for research and the formulation of policy. In the UK Census, ethnic-group classifications are based on two concepts: race and country of origin. To date, most estimates and projections (e.g. Rees and Butt 2004; Coleman and Scherbov 2005; Coleman 2006; Rees and Parsons 2006) use aggregated groups, which do not reveal the different demographic dynamics that might exist within subgroups. The 2001 Census revealed these groups to have relatively young age structures and potential for population growth, and thus demonstrated the limitations of mixed-group analyses.

Fertility variation by ethnic group and geographical area

Evidence has emerged that, cross-sectionally by age or in completed family size, fertility rates vary between ethnic groups in the UK (Thompson 1982; Coleman and Salt 1992; Rees and Phillips 1996; Simpson 1997; Sporton and White 2002; Robson and Berthoud 2006; Dubuc 2009; Coleman and Dubuc 2010; Dubuc and Haskey 2010). Compared with a white (largely British) reference group, women in ethnic groups originating from South Asian countries tend to have relatively high fertility. Among the South Asians, the Pakistani and Bangladeshi groups have higher fertility than the Indian group, whose fertility rates are gradually converging on the national level. The Chinese group has relatively low fertility. A more varied picture has emerged for Black African and Black Caribbean women.

Boyle (2003) has shown that the geography of fertility matters, and Boyle et al. (2007) and Tromans et al. (2008) have revealed cross-sectional and time-series patterns. Since there are distinct geographical distributions of ethnic groups (Rees and Butt 2004; Finney and Simpson 2009), we expected to find that variations in fertility by ethnic group would vary spatially.

A model for projecting ethnic-group populations for subnational areas in England

This paper reports on a method of estimating ASFRs by ethnic group for use in a projection model for local areas in England. The model provides population counts by age (0 to 100 and over) and sex (Rees et al. 2011). The projections start in 2001 and extend to 2051 in annual steps using England's 352 local authorities (LAs) (2001 Census boundary definitions). For the fertility component, the projection uses ASFRs applied to the population of women of child-bearing age to yield total fertility rates (TFRs). We describe the methods used to estimate fertility at local-authority level in England for the sixteen ethnic groups used in the 2001

Census. The method has also been applied using the ASFRs of ethnic groups in Wales, Scotland and Northern Ireland, but only at national level.

The rest of the paper is structured as follows. First, we report on the data sources, and then how we estimated fertility rates by ethnic group and five year age-groups at both national and local-authority level. We go on to report on how we estimated single-year-of-age fertility rates from the five-year grouped information. Since children can have a mother and a father of different ethnicities, we describe a method for estimating the ethnicity of the newborn. We quantify plausibility ranges of our estimates before going on to use past trends in ethnic fertility to inform our assumptions about future levels, which are entered into our projections. Finally we summarize and reflect on the method of producing the estimates of ethnic fertility for subnational areas in England and consider some possible enhancements for future work.

Data sources

We needed data on levels of ethnic-group fertility in England at *national* and *local-authority (LA)* level. Because vital registration in the UK does not record ethnicity (Dubuc 2009; Williamson and Norman 2011), proxy indicators must be used to make indirect estimates of fertility rate by ethnic group. The data sources used to estimate fertility by ethnic group, geography, and time points are set out in Table 1.

[Table 1 about here]

Vital statistics

The vital registration system provides counts of births for each calendar year from the 1980s by age of mother (aged less than 20, then five year groups up to age 40 and over) at national and local-authority level. This reliable source provides us with counts of births over time for subnational areas for all women (Tromans et al. 2008) but with no information on ethnicity.

Census

The census is the gold standard of data collection and it is used as the basis for mid-year estimates of subnational age-sex population counts (Jefferies and Fulton 2005). The 1991 Census was the first UK census that included a question asking people to self-report their ethnicity, and resulted in the 10 groups shown in Table 2. In the 2001 Census the number of categories was expanded to 16 groups and we adopted this level of detail in our projection model. To assess trends between 1991 and 2001, we used eight groupings common to both censuses (Simpson 2002b) and assumed that trends for these aggregate groups also applied to their component groups. The census area statistics adjusted to be mid-year estimates in 1991 (Sabater and Simpson 2009) and 2001 (ONS 2010) provided national and local populations by ethnic group. The census Samples of Anonymised Records (SARs) contain microdata on family relationships that can indicate fertility level by ethnic group, but the lack of geographical resolution and small numbers when crosstabulated with ethnic-group variables precluded using the SARs for subnational estimates of fertility. The SARs are an extract of original census returns and are equivalent to the US Public Use Microdata Sample (now part of the American Community Survey).

Labour Force Survey

The Labour Force Survey (LFS) has collected annual microdata on ethnicity since 1979 and can be used to estimate levels of fertility indirectly (Coleman and Dubuc 2010). The LFS has the advantage over the other sources in that it provides a run of data over a long period. The ethnic-group categorization in the LFS has changed substantially over time but the different categories can be allocated to broad groups. Even when successive LFS releases are pooled, this source provides reliable information at national level only.

Table 2 summarizes the ethnic-group categories derived from the censuses and LFS and shows how these correspond to the 16 ethnic groups used in the projection model.

[Table 2 about here]

Estimating fertility by ethnic group for England

The sources of population and sample data described above were used to calculate fertility rates at national level for England. The following methods were used: ratio and apportionment methods in which relationships between indicators are used to scale and distribute rates and counts; and constraints by which data from one source are controlled to sum to another, presumed more reliable, source (Shryock and Siegel 1976; Simpson 1998). We now describe the procedure adopted in broad steps.

First, we calculated ASFRs and TFRs for all women in a census year. Second, we estimated overall levels of fertility for the eight ethnic groups assumed common to 1991 and 2001, using the SARs. Third, we used information from the LFS to estimate differences in the age-profile of fertility by ethnic group. A table commissioned from the 2001 Census was used to disaggregate the fertility rates by broad ethnic group into the more selective 16 ethnic groups. To ensure that the outputs were as reliable as possible, all estimates were controlled to make the number of births across ethnic groups resulting from the application of the rates sum to the national total of births by each five-year age group.

The estimates of ethnic-group fertility reported below will refer to 2001, but equivalent computations have been carried out for 1991. All the ASFRs were for five-year age groups. The subsequent estimation of single-year-of-age rates is described later.

Age-specific fertility rates for England for all women

The first step was to calculate ASFRs for England in 2001 (Figure 1) using the counts of births by age of woman as numerators and the mid-year estimates as denominators. The TFR

resulting from these ASFRs was 1.63 children per woman (Tromans et al. 2008). Note that births to women aged less than 20 were grouped together as are births to women aged 40 and over. To calculate rates, these totals were divided by denominators of women aged 15-19 and aged 40-44 respectively obtained from the ONS mid-year estimates for 2001. Formally, this calculation can be expressed as:

$$f_x = 1000 \left({}^{B_x}/_{W_x} \right) \quad (1)$$

where f_x is the ASFR of women in age group x at time of maternity, B_x are the calendar year births to women in age-group x and W_x are women in age-group x at mid-year and 1000 is the conventional constant so that ASFRs refer to children per 1000 women. The total fertility rate was computed thus:

$$TFR = 5 \times \left({}^{\sum_{x=15-19}^{x=40-44} f_x}/_{1000} \right) \quad (2).$$

[Figure 1 about here]

Total fertility rates for England by ethnic group

Because birth registrations are not classified by ethnic group we estimated ethnic-specific fertility levels. The Sample of Anonymised Records is an extract of individual-level census records, but its microdata cannot be used to calculate five-year ASFRs. An alternative measure, Child-Woman Ratios (CWRs), can be used to represent family size since if fertility is high, CWRs will be high and *vice versa* (Newell 1988). This measure has been used to estimate fertility by ethnic group indirectly (Sporton and White 2002). Child-woman ratios are defined as follows:

$$CWR = \left(\sum_{x=0}^{x=y} \frac{P_x}{\sum_{x=15-19}^{x=40-44} W_x} \right) \quad (3).$$

The numerator P_x counts children within a desired age range (age 0 to age *y*) and the denominator W_x sums women at risk over the fertile age groups.

Using the SAR, a study population for England was extracted with the ethnic-group information re-coded into the eight groups common to the 1991 and 2001 Censuses (Table 2) of women of childbearing age (15-44), with a flag for a dependent infant aged 0-4 (determined using generation indicators, household member relationships, and age differences to exclude sibling or grandparent relationships). A national-level CWR which linked women by ethnic group to the presence of a dependent child was computed:

$$CWR_{e_8} = \left(\sum_{x=0}^{x=y} \frac{P_{xe_8}}{\sum_{x=15-19}^{x=40-44} W_{xe_8}} \right) \quad (4)$$

where a subscript e_8 refers to a member of the eight-group classification. The ratio of the ethnic-group CWR to the all-group CWR was applied to the TFR for all women:

$$TFR_{e_8} = TFR_{+} \times \left({}^{CWR_{e_8}}/_{CWR_{+}} \right) \quad (5)$$

where + refers to all ethnic groups combined. Table 3 shows the data underpinning the estimate and the resulting TFRs by ethnic group.

[Table 3 about here]

Age-specific fertility rates for England by ethnic group

Data from the LFS were obtained for each year from the 1980s. The detail of variables was harmonized to identify the following: consistent ethnic groups over time; the presence of a dependent child aged 0-4 in the family; and a study population of women of childbearing years who were not the sisters or grandmothers of a dependent child, if present, aggregated into five-year groups. It should be noted that in both the SAR-based and LFS-based estimates there is some uncertainty over whether a woman is the mother of a dependent child, and there may be gains and losses to the counts. There may be gains when a child is the woman's stepchild and losses when the father has custody of a child or a child dies.

Whilst the ethnic variables in the LFS vary considerably in definition in the 1980s, 1990s and 2000s, it is possible to align the definitions to those common to the 1991 and 2001

Censuses. However, to avoid small numbers, broader ethnic groups were adopted (Table 2). LFS files were pooled across three years so that, for example, estimates for 2001 related to surveys for 2002, 2003, and 2004. This centred child ages on 2001, but smoothing of change in adjacent years would have lost variation that might have been informative. National age-specific rates for 2001 were calculated by five-year age group of woman and ethnic group. The rates for 2001 are illustrated in Figure 2 by five broad ethnic groups revealing, for example, a relatively young age-profile and higher rates for the combined Pakistani and Bangladeshi group.

[Figure 2 about here]

Combining the vital statistics, census, and survey fertility estimates for England

We combined the information from each separate source to make estimates of ASFRs by the eight ethnic groups common to the 1991 and 2001 Censuses. The method, described below, is shown as a set of 6 steps with their associated equations in Table 4. Note that the numerical superscripts refer to the estimation sequence for the particular variable.

[Table 4 about here]

In *Step 1* initial ASFRs are estimated by scaling the rates by age for each ethnic group (Figure 2) by the VS-based all-women ASFRs and LFS-based all-women rates by age. The LFS-derived rates for the broader ethnic groups were applied to the ASFRs for more selective ethnic groups (Table 2) in equation (6). (Whilst the adjustments look large, the data were in different units). The rates for the combined Pakistani and Bangladeshi group were used for both of the separate groups. TFRs were calculated from these initial ASFRs by summation (equation 7). In Figure 3a rates for eight groups are graphed but only five curves are visible because at this stage we have estimates for combined groups only.

In *Step 2* the ASFRs from Step 1 were scaled to agree with the SAR-derived TFRs for each ethnic group in equation (8). Figure 3b shows ASFR curves that have the same shape but

are at different levels because the estimated TFRs differ, as with the previously combined Pakistani and Bangladeshi ASFRs. In *Step 3* the births by each ethnic group and age group of mother were calculated using equation (9).

In *Step 4* the first estimates of births by ethnic group and age were scaled to sum to the vital-statistics total for all women, using equation (10). In *Step 5* the ASFRs by ethnic group were re-calculated, using the births from step 4, employing equation (11). In *Step 6* Steps 2 to 5 were iterated until the fit of the datasets no longer improved (Figure 3c).

[Figure 3 about here]

In the processes defined above, relative to the national ASFR curve for all women, the LFS rates by age informed the shape of the curve by broad ethnic group and the SARs-based TFRs informed the overall levels of fertility by the ethnic groups common to 1991 and 2001. The total number of births which would result from applying the ASFRs to the 2001 mid-year ethnic-group populations were summed to agree with the number of births recorded in the vital statistics by each five-year age of women.

Disaggregating the age-specific fertility rates for England to the sixteen ethnic groups of the 2001 Census

The White group and Other group common to the 1991 and 2001 Censuses required further disaggregation into three and seven more selective 2001 Census groups, respectively. The required data do not exist in the standard 2001 Census tables but a Commissioned Table (CO534) classifies the household population in England by ethnic group and age of mother of children aged 0 on Census day.

A difficulty in relying on Table CO534 is that the Commissioned Table may suffer from numerator and denominator bias. The parent of a child born during the previous year may have filled out a census questionnaire, but it is known that newborns are often

undercounted in censuses (Werner 1984; Jefferies and Fulton 2005). Table CO534 records a total of 553,211 infants aged under one in the 2001 Census whereas the Vital Statistics for the 2000-01 mid-year to mid-year interval records 567,694 births in England. Also, any census can suffer from population under-enumeration (Norman et al. 2008) and differential non-response by ethnic group has been identified in the UK's censuses (Sabater and Simpson 2009). If infants and mothers are missed in the census, fertility rates will be affected.

Table 5 contains TFRs directly calculated using five-year ASFRs from Table CO534 and the census populations for the eight groups common to the 1991 and 2001 Censuses. The all-women TFR for 2001 is 1.59, lower than the national VS-derived TFR of 1.63, reflecting the undercount of infants in the census. Comparing the CO534-derived TFRs with the national level in 2001 indicates that the differentials in fertility between groups derived from this commissioned table are largely in line with the TFRs derived using the SARs (which is adjusted for census non-response).

[Table 5 about here]

The information in CO534 could be used to estimate fertility for the more selective division of ethnic groups, using the ratios in fertility between, for example, the White British, White Irish, and White Others and the broader White group to which they belonged and equivalently for the groups belonging to the Other category (Table 2). This presumes that any census non-response is the same for the more selective groups as a subset of the larger group. Table 6 sets out the computational equations.

[Table 6 about here]

In *Step 1* (equation 12) a TFR for the more selective group was calculated as the TFR for the broad group previously calculated, scaled by the ratio between the TFR for the more selective group and the broad group as evidenced by CO534. In *Step 2* (equation 13) the ASFRs for the broad ethnic groups calculated previously were scaled by the ratio between the

ASFRs for the more selective groups and the broad group as determined from CO534. TFRs were calculated as sums of the ASFR estimates (equation 14). In *Step 3* the ASFRs derived from Step 2 were scaled by the ratio between the TFRs for the more selective groups calculated in Step 1 and the TFRs derived from Step 2. In *Step 4* the number of births for each ethnic group was calculated, using the mid-year estimate of women as the population at risk. In *Step 5* the first estimate of births by ethnic group and age was scaled to sum to the total for the previous estimate of births for the broad group. In *Step 6* the ASFRs for the more selective ethnic groups were re-calculated using the births from Step 5. Finally, Steps 3 to 6 were iterated until the fit of the datasets no longer improved. The ASFRs for the groups which comprised the White and Other groups are illustrated in Figures 4a and 4b.

[Figure 4 about here]

The results of the estimations reported above are sets of five-year age-specific fertility rates for eight ethnic groups for 1991 and 2001 and for 16 ethnic groups for England in 2001. Next we describe how this national-level information was combined with local-authority level data to estimate five-year ASFRs by ethnic group for local areas.

Estimating fertility by ethnic group at local level

The England-level fertility rates are combined with local-level information to estimate five-year ASFRs for each local authority (LA) in England. Since they have small populations, data for the City of London and the Isles of Scilly have been combined with the City of Westminster and Penwith respectively. The procedure adopted for each LA was as follows. First, ASFRs and TFRs for all women in 2001 were calculated from vital statistics and mid-year populations. Next, overall levels of fertility by the eight ethnic groups common to 1991 and 2001 were estimated from local child-woman ratios, adjusted using information from the SARs and the national-level ASFR estimates by broad ethnic group to scale the local age

profiles of fertility. Finally, for the 2001 rates, we re-allocated the information for the eight ethnic groups to the 16 groups used in the 2001 Census outputs. As they had been at national level, these LA estimates of rates by ethnic group were controlled to make the number of births across ethnic groups sum to the local total of births by five-year age-groups. All the age-specific fertility rates were calculated for five year age-groups. The subsequent estimation of single-year-of-age rates will be described later.

Fertility rates for local areas for all women

We calculated ASFRs and TFRs for all women using counts of births by age of woman from the vital statistics as numerators and mid-year estimates as denominators. As with the national rates, births to women aged less than 20 were grouped together and divided by the total number of women aged 15-19. Births to women aged 40 and over were divided by the total number of women aged 40-44. Figure 5 illustrates the ASFRs in 2001 for Bradford, West Yorkshire alongside the national curve. This LA has a younger fertility profile than that shown for England as a whole and a TFR of 2.17. For 2001 in England, only Blackburn (2.19) and Newham (2.20) had higher total fertility rates than Bradford. The lowest TFRs were in the cities of Durham (1.14) and Cambridge (1.20).

[Figure 5 about here]

Total fertility rates for local areas by ethnic group

Child-Woman Ratios (CWRs) can be used to proxy family size by ethnic group. We used total counts of children aged 0-4 and women aged 15-44 from the mid-year estimates by ethnic group in CWRs to indicate local variations in family size. The reason for using counts of children aged 0-4 was to avoid small numbers by ethnic group at local-authority level. For the eight ethnic groups common to 1991 and 2001 and for each LA in England, the TFR for

all women in 2001 was scaled by the CWR for each ethnic group divided by the CWR for all women:

$$TFR^{i}_{e_8} = TFR^{i}_{+} \times \left({}^{CWR^{i}_{e_8}} / _{CWR^{i}_{+}} \right) \qquad (19)$$

where the superscript *i* refers to a local authority.

A drawback of this procedure is that the fertility of the White group tends to be under-estimated and the fertility of non-White groups to be over-estimated (Simpson 2002a). This is because, for example, if a child was reported at the 2001 Census as being of a 'Mixed' ethnicity, this may have been because the mother was 'White' and the father Black'. However, when calculating the CWRs, the children of 'Other' ethnicity (into which the Mixed would be allocated) were linked only with Other group mothers. The effect would have been to deflate the White CWR and inflate the Other CWR. Correction factors were needed to address this issue.

As noted previously, the individual-level data in the SARs give a realistic national-level CWR by directly linking women by ethnic group to the number of children they have had, and thus can be used to estimate ethnic-group-specific TFRs. The national CWR-based SARs and the area CWRs were used to provide ethnic-specific scaling factors through which the LA CWRs could be adjusted. The calculation proceeded as follows, for each LA:

$$TFR^{i}_{e_8} = TFR^{i}_{+} \times \left({}^{CWR^{SAR}_{e_8}} / _{CWR^{+}_{e_8}} \right) \times \left({}^{CWR^{i}_{e_8}} / _{CWR^{i}_{+}} \right) \qquad (20)$$

where $CWR^{+}_{e_8}$ is the child-woman ratio at national level derived from a population table by age and sex, and $CWR^{SAR}_{e_8}$ is a realistic child-woman ratio from SARs data. The CWRs for the eight ethnic groups in each LA, scaled as above, were used to scale the TFR for all women to give an estimated TFR for each ethnic group. To avoid small-number exaggerations, where numbers of children or women fell below a threshold (100 persons), the CWR was calculated

as the average of the national CWR for the ethnic group and the local all women-CWR (thereby still capturing both ethnic and local fertility influences). Table 7 contains the data used to calculate the TFRs before and after adjustment in Bradford for 2001. The White TFR was raised by the adjustment whilst the Pakistani, Bangladeshi, and Other ethnic-group TFRs were reduced. The Black-Caribbean and Indian TFRs were also raised by the adjustments. Since they had small numbers of children, the Black-African and Chinese TFRs were estimated using the average of the national CWR for the ethnic group and the local CWR for all women.

[Table 7 about here]

Combining the vital statistics, census, and survey data to estimate age-specific fertility rates at local level

For the projection model, age-specific fertility rates for each ethnic group were needed for each LA. These were estimated using the LA-specific TFRs and the national ASFRs calculated above. The series of steps in each procedure for each LA is describe below and listed in Table 8.

[Table 8 about here]

In *Step 1,* initial ASFRs by ethnic group for each LA were estimated by scaling the local authority's all-women ASFRs by the ratio of national ASFR by ethnic group to the national ASFR for all ethnic groups. First estimates of TFRs were sums of the initial ASFRs. In *Step 2* the ASFRs from Step 1 were scaled by each LA's CWR-derived TFR for each ethnic group. In *Step 3* births by each ethnic group were calculated by multiplying the five-year populations at risk by the second estimate of ASFRs. In *Step 4*, the first estimates of births by ethnic group and age were scaled to sum to the vital statistics totals. In *Step 5*, the ASFRs by ethnic groups were re-calculated using the births from Step 4. Steps 2 to 5 were iterated until the fit of the datasets was no longer improved. Figure 6 illustrates the age-

specific fertility rates in 2001 in Bradford for the ethnic groups common to 1991 and 2001 that result from application of the method defined in Table 8.

[Figure 6 about here]

Re-allocating the age-specific fertility rates for local areas to the sixteen ethnic groups of the 2001 Census

The White and Other groups common to the 1991 and 2001 Censuses were disaggregated into three and seven more selective 2001 Census groups respectively (Table 2), using the ratio of fertility measures for national selective ethnic groups to the broader ethnic groups of which they were members. Fewer steps were taken than with the national data since local TFRs cannot be derived from the England-level Commissioned Table. The steps are set out in Table 9.

[Table 9 about here]

In *Step 1* the ASFRs for the broad ethnic groups calculated above in each LA were scaled by the ratio of the national ASFRs for the more selective groups to the broad group. In *Step 2* the number of births for each ethnic group was calculated using the mid-year estimate for each LA for the selective groups. In *Step 3* the estimate of births by ethnic group and age was scaled to sum to the total for the previous estimate of births for the broad group. In *Step 4* the ASFRs for the more selective ethnic groups were re-calculated using the births from Step 3.

Estimating fertility rates by single year of age

All the rates estimated above at both England-level and local level were by five-year age-group. The literature reports various ways in which the estimates of five-year rates can be converted to rates by single year of age, by modelling age-specific fertility curves as mathematical functions (McNeil et al. 1977; Hoem et al. 1981; Chandola et al. 1999;

Schmertmann 2003; Peristera and Kostaki 2007). These methods often include the fitting of splines and the application of the Hadwiger function (Hadwiger 1940), which was used for smoothing ASFRs in London boroughs (Hay and Hollis 2005).

We used the Hadwiger function to compute robust estimates of fertility rates by single year of age. Details are given in Williamson and Norman (2011) and Norman et al. (2011). The age-specific fertility rates by single year of age and ethnic group for 2001 at both England-level and local-authority level comprised the inputs to the projection model. All the rates described above are period-age fertility rates and these were converted to the period-cohort rates required in the projection model by averaging rates for successive years.

Estimating mixed ethnicity births and applying a sex ratio

Since women may have partners of a different ethnicity from their own (Sporton and White 2002; Simpson 2002a), when the projection was run we included a step for generating the ethnicity of the newborn (Wilson 2009; Coleman 2010). We used Commissioned Table CO431 from the 2001 Census to estimate mixing probabilities, which cross-classify children under one in households by the ethnicity of their mother and the ethnicity assigned by their parent(s) on the census return.

In the projection model, after the age-specific fertility rates had been applied to the population at risk to estimate the births by ethnic group, a mixing matrix was applied to the births. The matrix contained the probabilities of the child's ethnicity conditional on the mother's ethnicity. Thus, transfers from one ethnic group to another could result. The main factors underpinning these transfers were partnerships between men and women of different ethnicities and decisions by parents about the ethnicity assigned to their offspring on the

census form. Parents and children may also have had different ethnicities when children were adopted.

Table 10 presents a matrix of the ethnic membership of infants by their mother's ethnicity. For White British women, 97 per cent of their children are assigned White British ethnicity. However, for White Irish mothers only 25 per cent of children are assigned White Irish ethnicity, with 64 per cent given White British ethnicity. Otherwise, the largest percentages are where the mother and child have the same ethnicity shown in the leading diagonal of the matrix. Within the broad groups, the Asians have the highest matches and the Mixed groups the lowest. While there will be compensating effects through differences between ethnic groups in fertility, mortality, and subnational and international migration, we expected this mixing process to lead to growth in all Mixed ethnic groups and in each 'Other' subcategory within the broad groups.

[Table 10 about here]

Within the projection model, the percentages in Table 10, in the form of probabilities, were used to assign ethnicity to the newborn. Mixing matrices for each of the nine Government Office Regions in England were applied to their constituent LAs.

Finally, a sex ratio of 105 males to 100 females was applied to separate the newborn into males and females. The same ratio was used for all ethnic groups.

Estimating plausibility ranges for fertility rates and birth counts

We have described the age-specific fertility rates and total fertility rates as estimates and should therefore reflect on their reliability. The aim was to use each data source for the advantage it had and to use triangulation and control to lessen the impact of potential error (Simpson 1998). Thus, it was essential that the counts of births which resulted from the application of estimated ASFRs by ethnic group returned the same counts of births by each

five year age-group at both England-level and local-authority level as recorded in the vital registration system. The Labour Force Survey sample was used to reveal differences in the shape of the fertility curve.

It was necessary to compromise between pooling years of data to achieve a sample size large enough to estimate differences between a detailed set of ethnic groups (but losing possible variations across years) and pooling fewer years but only for broad ethnic groups. We pooled three years of LFS samples with child age centred on census year, but we did not differentiate between the estimated ASFRs for Pakistani and Bangladeshi groups or the Black African and Black Caribbean groups although in fact there may have been age-specific differences. (For example, Coleman and Dubuc (2010), show variation between ASFRs for these groups for the whole of the UK and with LFS data pooled for 1996-2006). In both the LFS and Census Samples of Anonymised Records the presence of a dependent child overlaps years. Thus there was inevitably some smoothing of annual variation when, for example, overall levels of fertility were falling prior to 2001 but rising afterwards (Tromans et al. 2008), though the number of births by five-year age-group of women and the overall ASFR shape for each local authority specifically related to 2001.

When national-level fertility rates by ethnic group were calculated using the LFS, SARs, or the Commissioned Table, we could calculate statistical 95 per cent confidence intervals (CIs). This was also the case for the TFRs derived from LA child-woman ratios (all based on standard errors of rates and ratios after Fleiss 1973). When we used combined data sources at both national and subnational levels it was not possible to calculate statistical CIs, but we could use the lower and upper 95 per cent CIs from the calculations using the separate sources to estimate plausibility ranges within which the true values were most likely to lie. This was achieved by re-running the calculations reported in Tables 4-6 at national level and Tables 7-9 at local-authority level once with the 95 per cent lower CIs from all of the sources

(to indicate the lowest likely rates), and then re-running them again using all of the upper CIs (to indicate the highest likely rates). For these calculations, the resulting birth counts across ethnic groups were still constrained to the five-year counts at national level and LA level.

Table 11 presents the TFRs and birth counts with plausibility ranges for each of the 16 ethnic groups at national level. The birth counts estimated for 2001 sum to the VS total for that year, but the lower and upper plausibility ranges reported in the Table do not. The values listed for any ethnic group are the minimum and maximum values which resulted from the use of upper and lower CIs for the data sources. Since the constraints were always applied, it is the distribution of births between the ethnic groups that varies, with the lower CIs not necessarily resulting in the lowest birth counts for all groups. Different combinations of lower and upper CIs from the different sources lead to variations in the plausibility ranges but the rates and birth counts which resulted were within those reported here.

[Table 11 about here]

Extracting from the outputs of re-running the models, Table 12 shows equivalent data for Bradford, West Yorkshire as an example. The estimated TFRs are listed along with the plausibility range for the different TFRs which resulted from the concurrent application of 95 per cent lower and upper CIs derived from each of the different data sources at national level and of 95 per cent CIs for CWRs at local-authority level. As at national level, the estimated births in 2001 were constrained to sum to the vital registration totals by age, as had each version with the application of upper and lower confidence intervals. The birth counts tabulated in the plausibility range are the minimum and maximum values which result for each ethnic group. There is variation in the TFRs for groups, but the extent to which this leads to different numbers of births depends on the size of the populations. For example, both the Black African and Chinese groups have quite wide variation in the TFRs shown (the LA

CWRs have wide confidence intervals because the populations are relatively small for these groups in Bradford) but the variation in the number of births is plus or minus less than one birth for each group. The plausibility range is therefore narrow.

[Table 12 about here]

Establishing assumptions about future age-specific fertility rates

Essential to a population projection are plausible and justifiable assumptions about future levels of each demographic component. We used England-level annual time trends in fertility by age and ethnic group from 1991 to 2009 to inform assumptions about the direction of future fertility at local-authority level. Although the time frame of the projections model runs to 2051, we restricted our predictions to the year 2021, using constant rates thereafter.

As inputs to establish past trends we used five-year-age-group information from the following sources (i) an annual time-series of ASFRs for England (updating Tromans et al. 2008); (ii) an annual time-series of age-specific rates of the presence of a dependent child (Labour Force Survey); and (iii) our estimates of age-specific fertility rates for 1991 and 2001 for the ethnic groups used for both these census years.

First, the five-year ASFR estimates by ethnic groups common to 1991 and 2001 were scaled by growth (decline) rates in each age-group as indicated by the change from one year to the next from 1991 to 2009 in the national all-women rates:

$$f_{xe_{16}}^{1it+1} = f_{xe_{16}}^{it} \times \left({}^{f_{x+}^{+t+1}} / _{f_{x+}^{+t}} \right) \qquad (31)$$

where $f_{xe_{16}}^{1it+1}$ is the first estimate of ASFR for local authority *i* at time *t+1* for age group *x* and ethnic group e_{16}, f_{x+}^{+t+1} is the national ASFR at time *t+1* for women aged *x* for all ethnicities and f_{x+}^{+t} is the same variable for time *t*.

Second, the five-year ASFR estimates by ethnic groups common to 1991 and 2001 were scaled by growth (decline) rates in each age-group as indicated by the change from one year to the next in the rates for each broad ethnic group, using the LFS from 1991 to 2009:

$$f^{2it+1}_{xe_{16}} = f^{it}_{xe_{16}} \times \left({}^{p^{+t+1}_{x+}} / _{p^{+t}_{x+}} \right) \quad (32)$$

where p^{+t+1}_{x+} is the national rates at which women aged *x* at time *t+1* had a child aged 0-4 and p^{+t+1}_{x+} is the equivalent rate for time *t*. The changes for the larger groups in the LFS were applied to the 1991 and 2001 common groups they contained.

Third, an annual time-series of five-year rates by ethnic groups common to 1991 and 2001 was obtained by averaging the results of equations (31) and (32).

As examples, Figures 7a and 7b show ASFR trends for the White and the Bangladeshi ethnic groups between 1991 and 2009. This shows the fertility rates to be higher for Bangladeshi women in all age-groups except those aged 40 and over in which a rise in rates for the White group is shown. In both groups, fertility is falling steadily for women in their 20s. Large rises in fertility for White women in their 30s are not matched for Bangladeshi women.

What about the future? Coleman and Dubuc (2010) demonstrate the usefulness of fitting a logistic curve to time trends of TFRs by ethnic group. To model variations over time in fertility by age-group, we similarly fitted logistic curves to the 1991-2009 annual time-series, but to each age-specific rate for each ethnic group. This procedure determines whether trends towards postponement are experienced by all ethnic groups. We extended the time series by using the fitted curves to predict age-specific rates up to 2021. These modelled curves are illustrated in Figures 7c and 7d for the White and Bangladeshi ethnic groups, and show the trend in rates for each age-group. Figures 7e and 7f combine the estimates and modelled curves by applying the trends of the logistic curves from the 2009 jump-off point. The reduction of rates for women in their 20s over time is clearly shown, as are the rises in rates for White women in their 30s and 40s. For Bangladeshi women over the age of 30, a continuation of rates at similar levels over time is projected.

[Figure 7 about here]

The estimation of trends between 1991 and 2009 and curve fitting for the prediction of rates to 2021 were carried out for the eight ethnic groups common to the 1991 and 2001 Censuses. ASFRs for the more selective groups within the White and Other common groups were computed by applying growth (decline) rates for the broad group to the more selective groups they contained. We assumed that after 2021, ASFRs for each group would stay at the same level up to 2051, the final year of the projection model. When the projection was run, growth (decline) rates derived from our national time-series were applied to the local-authority level age-specific fertility rates by ethnic group. The relative level of fertility for local areas was therefore preserved but differences by ethnic group moved in proportion to national-level changes. The assumptions about age-specific fertility rate described here were used in our ethnic-population projections but were adjusted upwards or downwards depending on the scenario adopted (details are given in Rees et al. 2011). Table 13 shows fertility rates for England comparing examples of two time intervals with 2001as the base year.

[Table 13 about here]

Conclusions

For policy-related and practical applications, there is a need for age-sex population counts and projections by ethnic group and subnational area. We have developed a new population projection model that generates details for 16 ethnic groups by age, sex, and local-authority areas in England. A model of this nature requires inputs of ethnic-specific demographic rates of fertility, mortality, and migration. We have given details of the estimation of age-specific fertility rates. The estimation of the other components are discussed elsewhere (Rees et al. 2009; Boden and Rees 2010; Norman et al. 2010). Rees et al. (2011) provide a summary of the input estimations, a definition of the projection model, and an analysis of specimen projections.

The ethnic-specific fertility rates for local areas we have discussed require estimation because, whilst the vital registration system in the UK is a first-rate resource, ethnicity is not recorded. To compute our estimates we used a mix of individual-level and area data from vital statistics, censuses, and Labour Force Surveys as inputs. Our procedure was in the spirit of Citro (1998, p. 40) who defines this kind of estimation as, 'the use of statistical methods to produce "indirect estimates" for any area by combining data from several time periods or data sources to "borrow strength" and improve precision'. Through 'mixing and matching and squeezing methods appropriate to incomplete data of variable quality', Simpson (2002a: 55), explains that the "triangulation" of the inputs we used captured the different ethnic, geographic, and time dimension which each source provided. To best ensure the reliability of our estimates it was essential that the age-specific fertility rates by ethnic group in the population at risk returned a count of births consistent with the registered births for each five-year age-group in each geographical area. Nevertheless, the rates we produced were estimates and we presented plausibility ranges as a means of emphasizing uncertainty in the outputs. Owing to the constraints which control the births to those recorded in the Vital Statistics, it is the distribution of births between groups that varies. Using the lower and upper confidence intervals for indicators from different sources to obtain plausibility ranges is consistent with Smith et al.'s (2001) procedure for estimating 'prediction intervals' within which the actual values will lie.

To capture the changing shape of the age-specific fertility curve, we used evidence of past trends and modelled the age-group curves to inform future patterns by age. A population with a young ASFR curve will have a shorter generation length than a population with an older curve, so the shape of a curve influences the pace of any population change.

There is likely to be variation in fertility within ethnic groups dependent on the numbers reporting overseas or UK birth. There has been some work on this topic (Tromans et al. 2009)

but the contribution of recent immigrants to fertility rates is not fully clear. In terms of change over time in age-specific rates, we might also consider the pace of assimilation of recent immigrants and of the first and second generations of residents in this country who were born overseas. Birth registration provides data about the mother's country of birth so that differences in rates can be calculated for all women. Large-scale survey data might include variables that would make it possible to differentiate ethnicity by country of birth. A further source of the data needed to inform geographical time-series of ethnic fertility rates would be the Hospital Episode Statistics, but to date the reporting of ethnicity is incomplete (Klodawski 2003; Williamson and Norman 2011).

To fully inform a projection model, the ethnicity of both mother and child would be needed. We incorporated a mixing matrix to estimate the ethnicity of the newborn because this might differ from the mother's ethnicity. Since data on ethnicity is obtained through self-identification, we recognize that a person's ethnic group is not fixed over time (Simpson and Akinwale 2007). A refinement to the projection model might be to incorporate a mixing matrix at young adult age, when people move from being influenced by how their parents fill out a census questionnaire to record their own view on the form.

On March 27th 2011, the UK collected another Census. The best quality check we will have on both the fertility estimates and the projections for the initial decade is when detailed subnational age-sex counts of the 2011 Census are released. Compared with the incompatibility of ethnic groups between the 1991 and 2001 Censuses, there were few changes in the ethnic categories used in 2001 and 2011 (White and McLaren 2009). With 2011 Census data, analyses can be carried out of changes between 2001 and 2011 for the Other White group and the various Mixed ethnic groups, changes which we could only approximate for the period 1991 to 2001. An assessment of our input rates and the projection

model will require a complete decomposition of all demographic components over the 2001-11 decade to determine the relative contribution of each.

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Table 1 Data sources for the estimation of fertility by ethnic group in England

Source	Time point	Geography	Ethnicity	Notes
Vital Statistics	Annually from 1980s to date	National to Local Authority	None	A high-quality resource which informs national and subnational fertility trends but with no information on ethnicity. Any estimations will be controlled to sum to the total births in each area.
Census Area Statistics	1991	National to Local Authority	10 groups	1991 ethnic-group categories can be aligned with the 2001 categories by assuming that eight are equivalent over time (Simpson 2002b: 77).
	2001	National to Local Authority	16 groups	1991 data can be adjusted to 2001 areas (Norman et al. 2003). The Mid-Year Estimates used account for differential census non-response and other factors (Sabater and Simpson 2009).
Census Samples of Anonymised Records	1991	National	10 groups	A very large sample which can provide national-level information on family and household structures by ethnic group. Aligning 1991 and 2001 groups can show trends over time
	2001	National	16 groups	
Labour Force Survey	Annually from 1980s to date	National	A wide variety of different groups over time	A sample which can provide national-level information on family and household structures by ethnic group. Small numbers and changing ethnic information mean that information can be estimated reliably for broad groups only.

Table 2 Ethnic group classifications used in the 1991 and 2001 Censuses and Labour Force Survey, England

2001 Census [1]	Census 'common' [2]	1991 Census	Labour Force Survey [3]
White: British White: Irish White: Other-White	White	White	White
Black or Black British: Black Caribbean	Black Caribbean	Black Caribbean	Black
Black or Black British: Black African	Black African	Black African	
Asian or Asian British: Indian	Indian	Indian	Indian
Asian or Asian British: Pakistani	Pakistani	Pakistani	Pakistani and Bangladeshi
Asian or Asian British: Bangladeshi	Bangladeshi	Bangladeshi	
Chinese or Other Ethnic Group: Chinese	Chinese	Chinese	Chinese & Others
Mixed: White and Black Caribbean Mixed: White and Black African Mixed: White and Asian Mixed: Other Mixed	Other		
Black or Black British: Other Black		Black: Other	
Asian or Asian British: Other Asian		Other: Asian	
Chinese or Other Ethnic Group: Other Ethnic Group		Other: Other	

Notes:
1. The 2001 Census ethnic categorizations are the 16 groups for which the projections were carried out
2. The 8 ethnic categories which were assumed common to the 1991 and 2001 Censuses were used as the focus of the estimation process
3. The 5 broad ethnic groups from the Labour Force Survey were used to provide information on fertility variation by age and for trends over time
Source: Census and Labour Force Survey

Table 3 Estimates of total fertility rates by broad ethnic group based on the Sample of Anonymised Records, England 2001

Ethnic group [2]	Females aged 15-44	Dependants aged 0-4	Child-Woman Ratios	Total Fertility Rates	TFR 95% Confidence Interval [3]
White	196,012	131,877	0.67	1.62	(1.62 - 1.62)
Black Caribbean	2,877	1,868	0.65	1.56	(1.53 - 1.60)
Black African	2,425	1,610	0.66	1.60	(1.56 - 1.64)
Indian	4,880	3,698	0.76	1.82	(1.80 - 1.85)
Pakistani	3,515	3,008	0.86	2.06	(2.04 - 2.08)
Bangladeshi	1,337	1,219	0.91	2.20	(2.16 - 2.24)
Chinese	1,013	532	0.53	1.26	(1.19 - 1.33)
Other	5,131	3,164	0.62	1.48	(1.46 - 1.51)
Total	217,190	147,337	0.68	1.63 [1]	

Notes:
1. Based on Vital Statistics and mid-year estimates (Tromans et al. 2008)
2. The ethnic groups are those common to the 1991 and 2001 Censuses (Table 2)
3. Derived from standard errors around ratios (after Fleiss 1973)
Source: 2001 Census Sample of Anonymised Records

Table 4 Method for estimating national fertility rates for the 8 ethnic groups common to the 1991 and 2001 Censuses, England

Step	Equation	No.
Step 1	$f^{1}_{xe_8} = f_{x+} \times \left({}^{p_{xe_5}}/_{p_{x+}} \right), for\ e_8 \in e_5$	(6)
	$TFR^{1}_{e_8} = 5 \times \left(\frac{\sum_{x=15-19}^{x=40+} f^{1}_{xe_8}}{1000} \right)$	(7)
Step 2	$f^{2}_{xe_8} = f^{1}_{xe_8} \times \left({}^{TFR^{H}_{e_8}}/_{TFR^{1}_{e_8}} \right)$	(8)
Step 3	$B^{1}_{xe_8} = \left(\frac{f^{2}_{xe_8}}{1000} \right) \times W_{xe_8}$	(9)
Step 4	$B^{2}_{xe_8} = B^{1}_{xe_8} \times \left({}^{B_{x+}}/_{\sum_{e_8} B^{1}_{xe_8}} \right)$	(10)
Step 5	$f^{3}_{xe_8} = \frac{B^{2}_{xe_8}}{W_{xe_8}}$	(11)
Step 6	Steps 2 to 5 were iterated until the fit of the datasets was no longer improved	

	Definitions
$f^{1}_{xe_8}$	Estimate 1 of ASFR for age x and ethnic group e_8
f_{x+}	ASFR for age x for women in all ethnic groups (from VS)
p_{xe_5}	Rates of women aged x in ethnic group e_5 having a child (from the LFS)
p_{x+}	Rates of women aged x in all ethnic groups having a child (from the LFS)
e_8	Ethnic group in the 8-group classification (common to 1991 and 2001 censuses)
e_5	Ethnic group in the 5-group classification (used in the LFS)
$TFR^{1}_{e_8}$	Estimate 1 of TFR for ethnic group e_8
$TFR^{H}_{e_8}$	Estimate 1 of TFR for ethnic group e_8 from the Household SAR
$f^{2}_{xe_8}$	Estimate 2 of ASFR for age x and ethnic group e_8
W_{xe_8}	Women aged x in ethnic group e_8 (from mid-year population estimates and census)
$B^{1}_{xe_8}$	Estimate 1 of births to women aged x and in ethnic group e_8
$B^{2}_{xe_8}$	Estimate 2 of births to women aged x and in ethnic group e_8
B_{x+}	Births to women aged x in all ethnic groups
$f^{3}_{xe_8}$	Estimate 3 of ASFR for age x and ethnic group e_8

Table 5 Estimates of total fertility rates by broad ethnic group, England 2001

Ethnic group [2]	Total fertility rates		
	Census CO534	Adjusted	TFR 95% Confidence Interval [3]
White	1.58	1.62	(1.62 - 1.63)
Black Caribbean	1.42	1.46	(1.44 - 1.47)
Black African	1.87	1.92	(1.90 - 1.94)
Indian	1.86	1.91	(1.89 - 1.93)
Pakistani	2.06	2.12	(2.10 - 2.14)
Bangladeshi	2.15	2.21	(2.12 - 2.33)
Chinese	1.27	1.31	(1.29 - 1.33)
Other	1.59	1.64	(1.63 - 1.65)
Total	1.59	1.63 [1]	

Notes:
1. Based on Vital Statistics and mid-year estimates (Tromans et al. 2008)
2. The ethnic groups are those common to the 1991 and 2001 Censuses (Table 2)
3. Derived from standard errors around rates (after Fleiss 1973)

Source: 2001 Census Commissioned Table CO534

Table 6 Method for estimating national fertility rates for the 16 ethnic groups in the 2001 Census, England

Step	Equation	No.
Step 1	$TFR^{1}_{e_{16}} = TFR^{1}_{e_8} \times \left({}^{TFR^{CO534}_{e_{16}}} \big/ _{TFR^{CO534}_{e_8}} \right) \; for \; e_{16} \in e_8$	(12)
Step 2	$f^{1}_{xe_{16}} = f^{1}_{xe_8} \times \left({}^{f^{CO534}_{xe_{16}}} \big/ _{f^{CO534}_{xe_8}} \right)$	(13)
	$TFR^{2}_{e_{16}} = 5 \times \left(\frac{\sum_{x=15-19}^{x=40+} f^{1}_{xe_{16}}}{1000} \right) for \; e_{16} \in e_8$	(14)
Step 3	$f^{2}_{xe_{16}} = f^{1}_{xe_{16}} \times \left({}^{TFR^{2}_{e_{16}}} \big/ _{TFR^{1}_{e_{16}}} \right)$	(15)
Step 4	$B^{1}_{xe_{16}} = \left(\frac{f^{2}_{xe_{16}}}{1000} \right) \times W_{xe_{16}}$	(16)
Step 5	$B^{2}_{xe_{16}} = B^{1}_{xe_{16}} \times \left({}^{B^{1}_{xe_8}} \big/ _{\sum_{e_{16} \in e_8} B^{1}_{xe_{16}}} \right)$	(17)
Step 6	$f^{3}_{xe_{16}} = \frac{B^{2}_{xe_{16}}}{W_{xe_{16}}}$	(18)
Step 7	Steps 3 to 6 are iterated until the fit of the datasets is no longer improved	

Definitions (see also Table 4)	
e_{16}	Ethnic group in the 16 group classification used in the 2001 Census
$TFR^{1}_{e_{16}}$	Estimate 1 of TFR for ethnic group e_{16}
$TFR^{CO534}_{e_{16}}$	Estimate of TFR based on Commissioned Table CO534 for ethnic group e_{16}
$TFR^{CO534}_{e_8}$	Estimate based on Commissioned Table CO534 of TFR for ethnic group e_8
$f^{1}_{xe_{16}}$	Estimate 1 of ASFR for age x and ethnic group e_{16}
$f^{CO534}_{xe_{16}}$	Estimate based on Commissioned Table CO534 of ASFR for age x and ethnic group e_{16}
$f^{CO534}_{xe_8}$	Estimate based on Commissioned Table CO534 of ASFR for age x and ethnic group e_8
$TFR^{2}_{e_{16}}$	Estimate 2 of TFR for ethnic group e_{16}
$f^{2}_{xe_{16}}$	Estimate 2 of ASFR for age x and ethnic group e_{16}
$B^{1}_{xe_{16}}$	Estimate 1 of births to women aged age x and ethnic group e_{16}
$W_{xe_{16}}$	Women aged x in ethnic group e_{16} (from mid-year population estimates and census)
$B^{2}_{xe_{16}}$	Estimate 2 of births to women aged age x and ethnic group e_{16}
$f^{3}_{xe_{16}}$	Estimate 3 of ASFR for age x and ethnic group e_{16}

Table 7 Estimates of total fertility rates using child-woman ratios, Bradford, England 2001

Ethnic group [3]	Women (aged 15-44)	Children (aged 0-4)	CWR	TFRs	Scale factor	TFRs (scaled)
White	74,398	20,443	0.27	1.80	1.04	1.88
Black Caribbean	776	138	0.18	1.16	1.38	1.60
Black African	332	55 [2]	0.16	1.08	0.83	2.01
Indian	3,362	931	0.28	1.81	1.30	2.36
Pakistani	17,385	9,140	0.53	3.44	0.79	2.71
Bangladeshi	1,199	790	0.66	4.31	0.76	3.26
Chinese	319	42 [2]	0.13	0.87	1.48	1.81
Other	2,661	1,738	0.65	4.27	0.51	2.17
Total	100,433	33,276	0.33	2.17	1.00	2.17 [1]

Notes:
1. Based on Vital Statistics and mid-year estimates (Tromans et al. 2008)
2. Counts which fall below the threshold of 100 so the estimated TFRs (scaled) are based on an average of national ethnic-specific CWRs and the local all women CWRs
3. The ethnic groups are those common between the 1991 and 2001 Censuses (Table 2)

Source: Census and Vital Statistics data

Table 8 Method for estimating local fertility rates for the eight ethnic groups common to the 1991 and 2001 Censuses, England

Step	Equation	No.
Step 1	$f^{i1}_{xe_8} = f^{i}_{x+} \times \left({f^{EW}_{xe_8}}/{f^{EW}_{x+}} \right)$	(21)
	$TFR^{i1}_{e_8} = 5 \times \left(\frac{\sum_{x=15-19}^{x=40+} f^{i1}_{xe_8}}{1000} \right)$	(22)
Step 2	$f^{i2}_{xe_8} = f^{i1}_{xe_8} \times \left({TFR^{iCWR}_{e_8}}/{TFR^{i1}_{e_8}} \right)$	(23)
Step 3	$B^{i1}_{xe_8} = \left(\frac{f^{i2}_{xe_8}}{1000} \right) \times W^{i}_{xe_8}$	(24)
Step 4	$B^{i2}_{xe_8} = B^{i1}_{xe_8} \times \left({B^{i}_{x+}}/{\sum_{e_8} B^{i1}_{xe_8}} \right)$	(25)
Step 5	$f^{i3}_{xe_8} = \frac{B^{i2}_{xe_8}}{W^{i}_{xe_8}}$	(26)
Step 6	Steps 2 to 5 were iterated until the fit of the datasets was no longer improved	

Definitions (see also Tables 4 and 6)

$f^{i1}_{xe_8}$	Estimate 1 of ASFR for age x and ethnic group e_8 for local authority i
f^{i}_{x+}	ASFR for age x for women in all ethnic groups (from VS)
$f^{EW}_{xe_8}$	Estimate of ASFR for age x and ethnic group e_8 for England and Wales
f^{EW}_{x+}	Estimate of ASFR for age x and all ethnic groups for England and Wales
$TFR^{i1}_{e_8}$	Estimate 1 of TFR for ethnic group e_8 and local authority i
$f^{i2}_{xe_8}$	Estimate 2 of ASFR for age x and ethnic group e_8 for local authority i
$TFR^{iCWR}_{e_8}$	Estimate of Total Fertility Rate for ethnic group e_8 and local authority i (from CWRs computed using census age and ethnicity data)
$B^{i1}_{xe_8}$	Estimate 1 of births to women aged x and in ethnic group e_8 in local authority i
$W^{i}_{xe_8}$	Women aged x in ethnic group e_8 in local authority I (from mid-year population estimates and census)
$B^{i2}_{xe_8}$	Estimate 2 of births to women aged x and in ethnic group e_8 in local authority i
B^{i}_{x+}	Births to women aged x in all ethnic groups in local authority i
$f^{i3}_{xe_8}$	Estimate 3 of ASFR for age x and ethnic group e_8 in local authority i

Table 9 Method for estimating local fertility rates for the 16 ethnic groups in the 2001 Census, England

Step	Equation	No.
Step 1	$f^{i\mathbf{1}}_{xe_{\mathbf{16}}} = f^{i\mathbf{1}}_{xe_{\mathbf{8}}} \times \left(f^{EW}_{xe_{\mathbf{16}}} \Big/ f^{EW}_{xe_{\mathbf{8}}} \right)$	(27)
Step 2	$B^{i\mathbf{1}}_{xe_{\mathbf{16}}} = \left(\frac{f^{i1}_{xe_{16}}}{1000} \right) \times W^{i}_{xe_{16}}$	(28)
Step 3	$B^{i\mathbf{2}}_{xe_{\mathbf{16}}} = B^{i\mathbf{1}}_{xe_{\mathbf{16}}} \times \left(B^{i\mathbf{1}}_{xe_{\mathbf{8}}} \Big/ \sum_{e_{16} \in e_{8}} B^{i\mathbf{1}}_{xe_{16}} \right)$ for $e_{\mathbf{16}} = e_{\mathbf{8}}$	(29)
Step 4	$f^{i\mathbf{2}}_{xe_{\mathbf{16}}} = \frac{B^{i2}_{xe_{16}}}{W^{i}_{xe_{16}}}$	(30)

Definitions (see also Tables 4, 6 and 7)

$f^{i\mathbf{1}}_{xe_{\mathbf{16}}}$	Estimate 1 of ASFR for age x and ethnic group $e_{\mathbf{16}}$ for local authority i
$f^{i\mathbf{2}}_{xe_{\mathbf{16}}}$	Estimate 2 of ASFR for age x and ethnic group $e_{\mathbf{16}}$ for local authority i
$B^{i\mathbf{1}}_{xe_{\mathbf{16}}}$	Estimate 1 of births to women aged age x and ethnic group $e_{\mathbf{16}}$ for local authority i
$W^{i}_{xe_{\mathbf{16}}}$	Women aged x in ethnic group $e_{\mathbf{16}}$ for local authority i (from mid-year population estimates and census)
$B^{i\mathbf{2}}_{xe_{\mathbf{16}}}$	Estimate 2 of births to women aged age x and ethnic group $e_{\mathbf{16}}$ for local authority i
$f^{i\mathbf{3}}_{xe_{\mathbf{16}}}$	Estimate 3 of ASFR for age x and ethnic group $e_{\mathbf{16}}$ for local authority i

Table 10 Consistency of ethnic group of mother and child: probabilities (per cents) of ethnic group of child under one by ethnic group of mother, 2001 Census, England

Ethnic group of mother		White			Mixed				Asian				Black			Chinese or Other Group	
	Totals	WBR	WIR	WHO	WBC	WBA	WAS	OMI	IND	PAK	BAN	OAS	BLC	BLA	OBL	CHI	OTH
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
White																	
British (WBR)	83.4	96.8	64.3	49.7	21.0	23.5	40.2	33.5	2.6	2.9	3.8	7.8	3.5	2.7	7.8	5.9	12.8
Irish (WIR)	0.4	0.1	25.4	0.3	0.0	0.0	0.3	0.2	0.1	0.0	0.0	0.2	0.1	0.1	0.0	0.1	0.1
Other White (WHO)	2.2	0.4	4.4	40.1	2.2	4.9	3.0	6.1	0.3	0.2	0.2	1.7	0.6	0.6	1.9	0.8	3.1
Mixed																	
White & Black Caribbean (WBC)	1.5	1.1	1.7	1.5	48.1	3.5	2.7	3.4	0.2	0.1	0.2	0.6	15.2	0.3	7.0	0.4	0.7
White & Black African (WBA)	0.5	0.3	0.7	1.6	2.0	38.9	1.1	1.7	0.1	0.1	0.1	0.4	0.3	5.5	1.1	0.0	0.4
White & Asian (WAS)	1.2	0.6	1.5	2.3	0.9	0.9	39.1	4.0	7.4	1.9	1.7	7.1	0.5	0.2	0.4	5.8	18.5
Other Mixed (OMI)	0.9	0.3	0.9	2.2	12.1	11.6	5.9	41.2	0.8	0.3	0.6	3.9	2.1	0.8	11.1	16.1	14.4
Asian																	
Indian (IND)	2.1	0.0	0.1	0.2	0.5	0.3	1.1	0.8	83.2	1.6	1.2	4.6	0.2	0.4	0.3	0.4	0.7
Pakistani (PAK)	2.4	0.1	0.1	0.2	0.5	0.0	2.4	1.1	2.3	90.0	2.4	4.3	0.2	0.3	0.3	0.2	0.8
Bangladeshi (BAN)	0.9	0.0	0.0	0.2	0.1	0.3	0.9	0.4	0.4	0.6	87.3	1.5	0.0	0.2	0.0	0.0	0.3
Other Asian (OAS)	0.6	0.0	0.1	0.4	0.4	1.3	1.7	1.2	2.0	1.9	1.6	65.1	0.3	0.6	0.6	0.3	2.0
Black																	
Black Caribbean (BLC)	1.0	0.0	0.2	0.1	8.8	1.2	0.3	1.7	0.1	0.1	0.1	0.2	65.8	1.9	7.2	0.1	0.2
Black African (BLA)	1.7	0.0	0.2	0.6	0.7	10.7	0.2	1.1	0.2	0.1	0.1	0.6	4.0	80.8	6.5	0.2	0.8
Other Black (OBL)	0.4	0.0	0.1	0.2	2.6	2.4	0.2	1.7	0.0	0.0	0.1	0.4	7.2	5.6	55.4	0.1	0.5
Chinese or Other Group																	
Chinese (CHI)	0.4	0.0	0.1	0.1	0.0	0.0	0.3	0.7	0.1	0.1	0.1	0.1	0.1	0.0	0.0	68.3	1.1
Other Ethnic Group (OTH)	0.4	0.0	0.2	0.3	0.2	0.6	0.6	1.3	0.2	0.2	0.5	1.6	0.0	0.1	0.4	1.2	43.6

Key to % classes: > = 80%; 50 -< 80%; 25 -< 50%; 1- < 25%; < 1%

Notes: Percentages = 100 × (Children under one by child's and mother's ethnic group/Mothers by mother's ethnic group)

Source: 2001 Census Commissioned Table CO431

Table 11 Estimated national-level total fertility rates by ethnic group and the resulting birth counts, England 2001

Ethnic group	Total Fertility Rate		Birth count	
	2001 estimate	Plausibility range [2]	2001 estimate	Plausibility range [2]
White				
White: British	1.63	(1.63 - 1.63)	462,974	(462,124 - 463,774)
White: Irish	1.51	(1.49 - 1.53)	5,837	(5,826 - 5,847)
Other White	1.47	(1.45 - 1.49)	23,335	(23,292 - 23,376)
Mixed				
White & Black Caribbean	1.56	(1.53 - 1.59)	3,193	(3,144 - 3,243)
White & Black African	1.75	(1.72 - 1.78)	1,524	(1,500 - 1,547)
White & Asian	1.33	(1.30 - 1.35)	2,429	(2,391 - 2,466)
Other Mixed	1.38	(1.35 - 1.40)	2,337	(2,300 - 2,373)
Asian				
Indian	1.82	(1.80 - 1.85)	17,314	(17,170 - 17,462)
Pakistani	2.06	(2.04 - 2.08)	13,756	(13,718 - 13,806)
Bangladeshi	2.20	(2.16 - 2.24)	5,981	(5,962 - 6,008)
Other Asian	1.69	(1.66 - 1.72)	4,533	(4,463 - 4,603)
Black				
Black Caribbean	1.56	(1.53 - 1.60)	7,770	(7,664 - 7,894)
Black African	1.60	(1.56 - 1.64)	8,200	(8,061 - 8,355)
Other Black	1.31	(1.28 - 1.33)	1,646	(1,621 - 1,671)
Other				
Chinese	1.26	(1.19 - 1.33)	1,257	(1,188 - 1,325)
Other Ethnic	1.38	(1.35 - 1.40)	1,655	(1,564 - 1,745)
Total	1.63 [1]		563,742	

Notes:
1. Based on Vital Statistics and mid-year estimates (Tromans et al. 2008)
2. Plausibility ranges calculated combining the impact of lower and upper 95% confidence intervals from individual data sources (derived from standard errors around rates and ratios, after Fleiss 1973)

Source: Census, Vital Statistics and Labour Force Survey data

Table 12 Estimated sub-national total fertility rates by ethnic group and the resulting birth counts, Bradford, England 2001

Ethnic group	Total Fertility Rate		Birth count	
	2001 estimate	Plausibility range [2]	2001 estimate	Plausibility range [2]
White				
White: British	1.92	(1.91 - 1.93)	4,561	(4,491 - 4,636)
White: Irish	1.79	(1.74 - 1.84)	33	(32 - 34)
Other White	1.75	(1.73 - 1.79)	93	(92 - 95)
Mixed				
White & Black Caribbean	2.33	(2.27 - 2.39)	41	(40 - 42)
White & Black African	2.62	(2.60 - 2.64)	9	(9 - 9)
White & Asian	2.00	(1.95 - 2.05)	42	(41 - 43)
Other Mixed	2.07	(2.05 - 2.09)	14	(14 - 14)
Asian				
Indian	2.36	(2.32 - 2.40)	265	(261 - 269)
Pakistani	2.71	(2.69 - 2.75)	1,805	(1,777 - 1,835)
Bangladeshi	3.26	(3.22 - 3.32)	161	(159 - 164)
Other Asian	2.54	(2.50 - 2.58)	61	(60 - 62)
Black				
Black Caribbean	1.60	(1.56 - 1.64)	37	(36 - 38)
Black African	2.01	(1.98 - 2.03)	27	(27 - 27)
Other Black	1.97	(1.95 - 1.99)	6	(6 - 6)
Other				
Chinese	1.81	(1.79 - 1.83)	20	(20 - 20)
Other Ethnic	2.06	(2.02 - 2.13)	31	(31 - 32)
Total	2.17 [1]		7,206	

Notes:

1. Based on Vital Statistics and mid-year estimates (Tromans et al. 2008)
2. Plausibility ranges calculated by combining the impact of lower and upper 95% confidence intervals from individual data sources (derived from standard errors around rates and ratios after Fleiss 1973)

Source: Census, Vital Statistics, and Labour Force Survey

Table 13 Comparison of estimated total fertility rates by ethnic group for different time intervals, England

Ethnic group	Total fertility rates		
	2001	2006-11	2015-21
White			
White: British	1.63	1.90	1.88
White: Irish	1.51	1.75	1.73
Other White	1.47	1.71	1.69
Mixed			
White & Black Caribbean	1.56	1.82	1.76
White & Black African	1.75	2.05	1.97
White & Asian	1.33	1.56	1.51
Other Mixed	1.38	1.62	1.56
Asian			
Indian	1.82	2.10	2.00
Pakistani	2.06	2.32	2.17
Bangladeshi	2.20	2.47	2.34
Other Asian	1.69	1.98	1.91
Black			
Black Caribbean	1.56	1.78	1.67
Black African	1.60	1.82	1.74
Other Black	1.31	1.54	1.48
Other			
Chinese	1.26	1.47	1.34
Other Ethnic	1.38	1.61	1.55
Totals	1.63 [1]	1.92	1.93

Notes:
1. Based on Vital Statistics and mid-year estimates (Tromans et al. 2008)
Source: Census, Vital Statistics, and Labour Force Survey

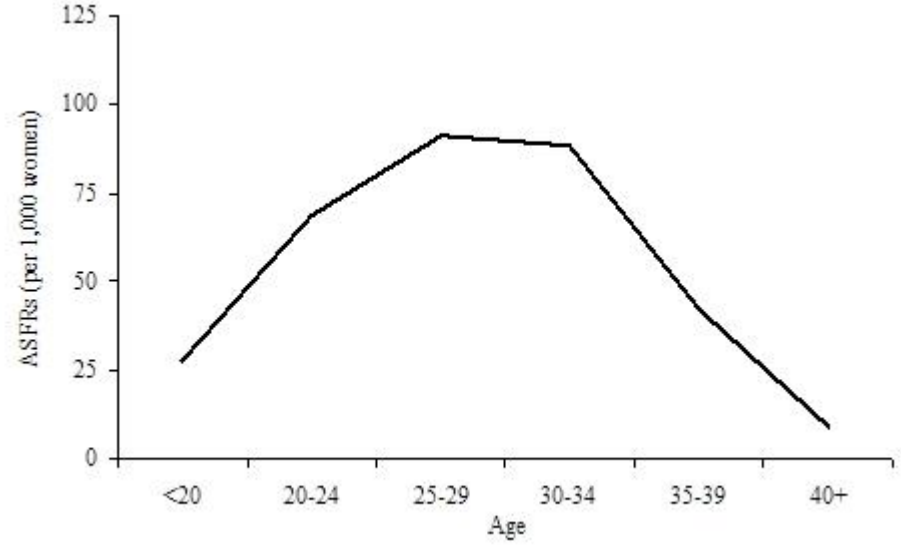


Figure 1 Age-specific fertility rates, England 2001

Source: Vital Statistics and mid-year estimates (Tromans et al. 2008)

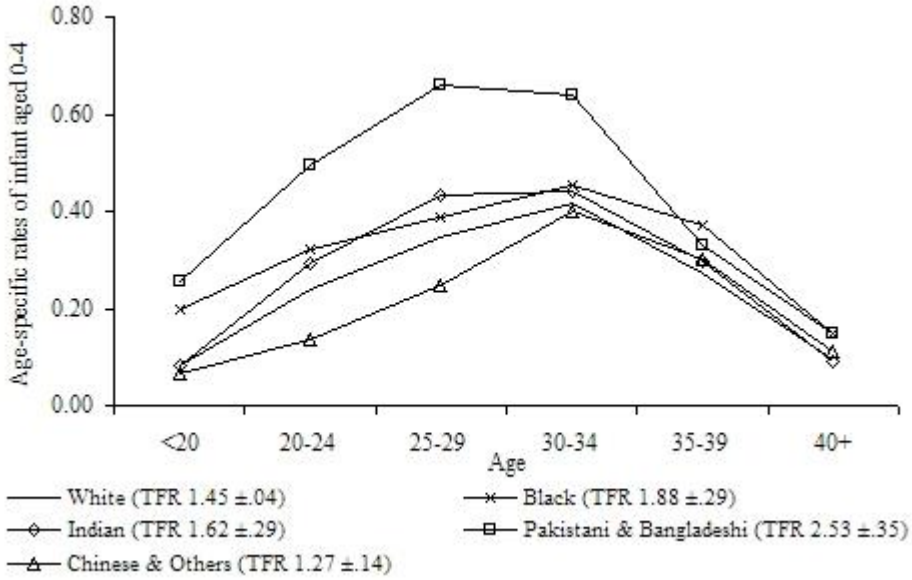
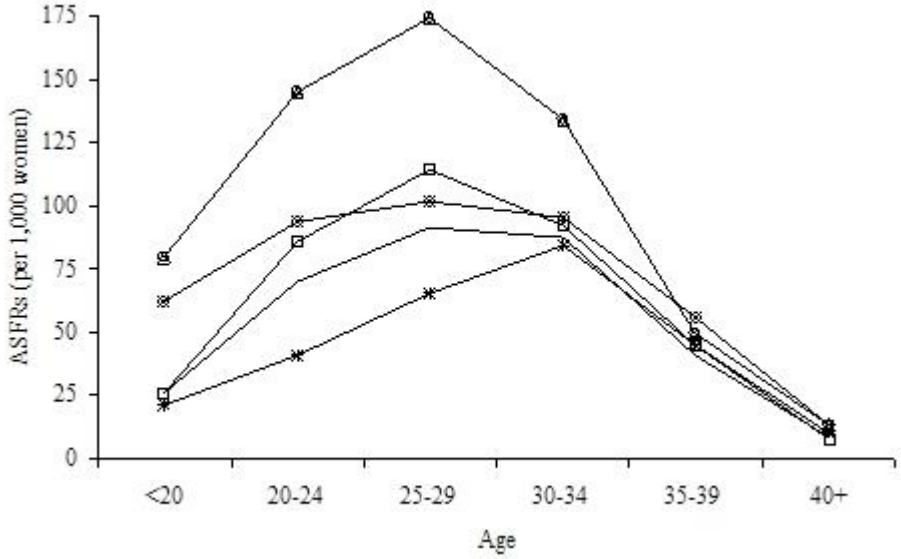


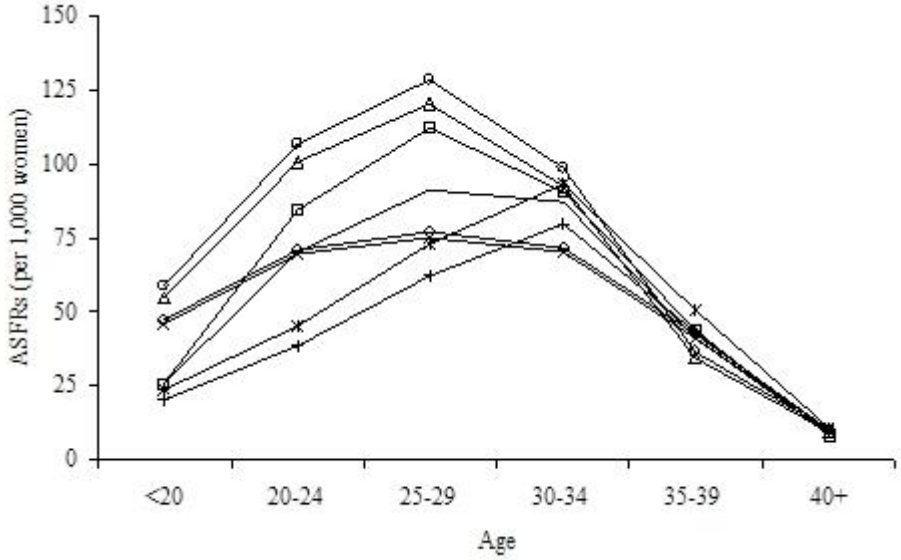
Figure 2 Estimated age-specific rates of having a child aged 0-4 by ethnic group, England, 2001

Notes:
Total Fertility Rates (TFRs) reported in the legend have ± to indicate the TFR confidence interval derived from standard errors of the five-year rates (after Fleiss 1973)
Source: Labour Force Survey

3a Application of age-specific rates of having a child aged 0-4 to the age-specific fertility rates for all women



3b Controlling the estimates of age-specific fertility rates to estimate total fertility rates by ethnic group



3c Final estimates of national-level age-specific fertility rates by ethnic group

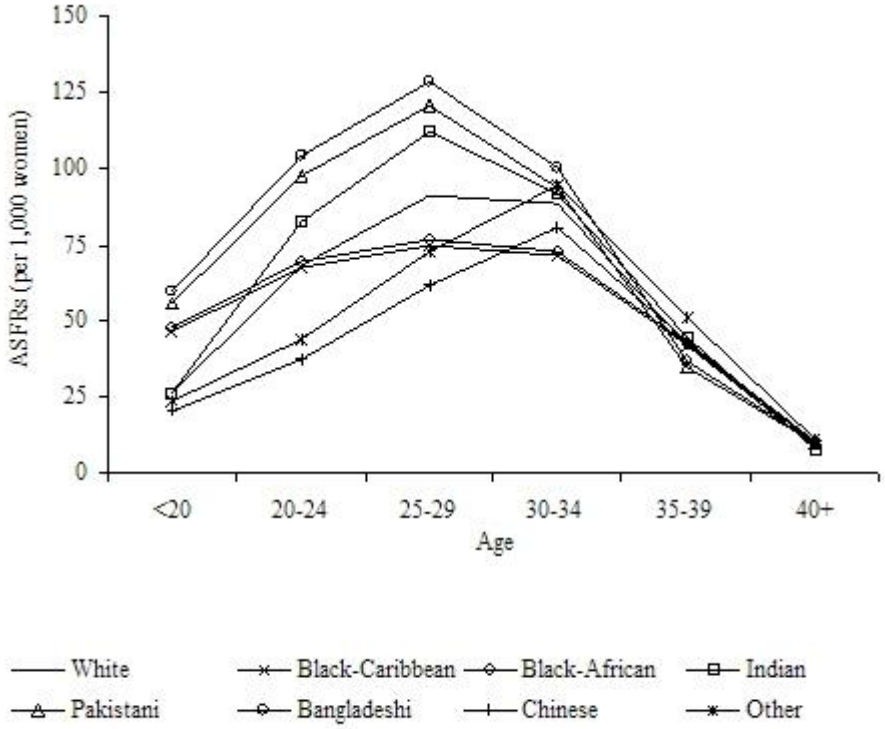
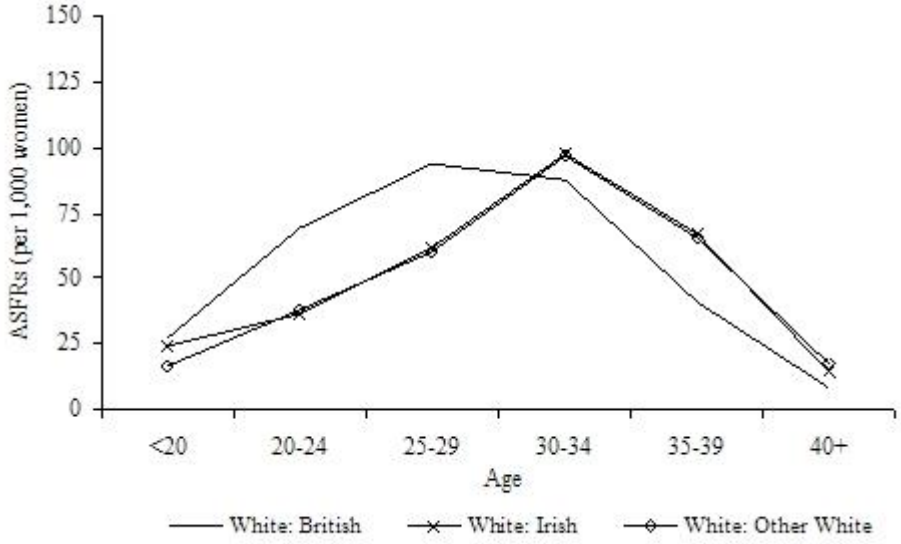


Figure 3 Estimation of age-specific fertility rates by ethnic group, England 2001

Source: Census, Vital Statistics, mid-year estimates, and Labour Force Survey

4a Estimates of age-specific fertility rates of 'White' ethnic group subdivided into three groups



4b Estimates of age-specific fertility rates of 'Other' ethnic group subdivided into seven groups

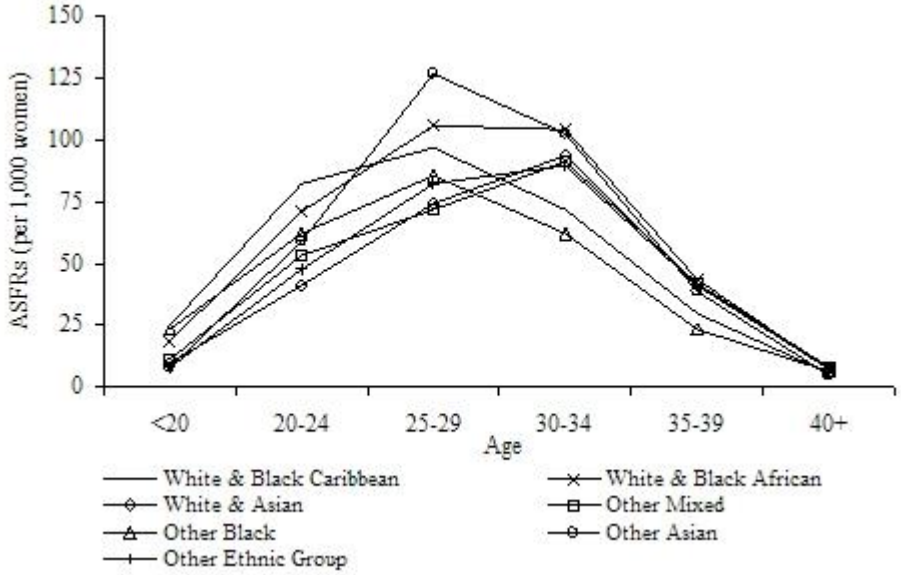


Figure 4 Estimated age-specific fertility rates of more selective ethnic groups, England 2001

Source: Census, Vital Statistics, mid-year estimates, and Labour Force Survey

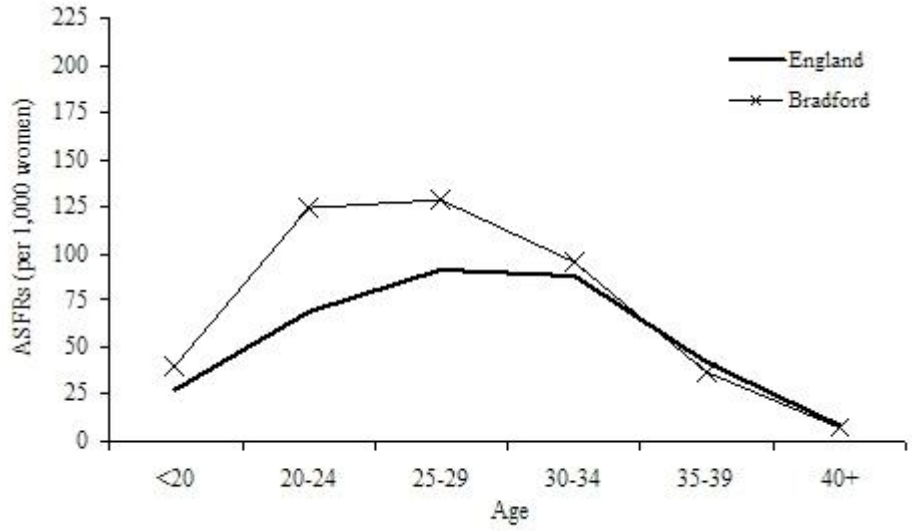


Figure 5 Age-specific fertility rates for all women, Bradford, England 2001

Source: Vital statistics and mid-year estimates

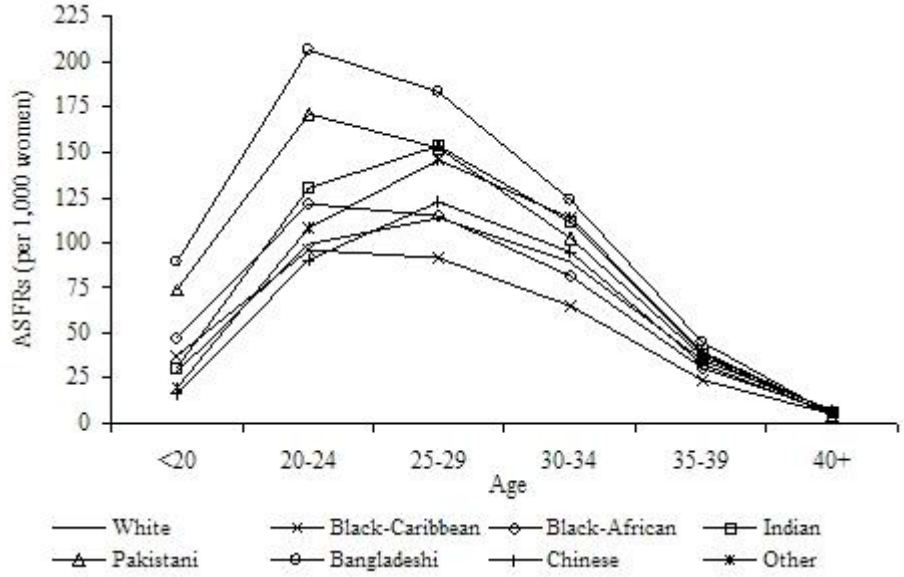
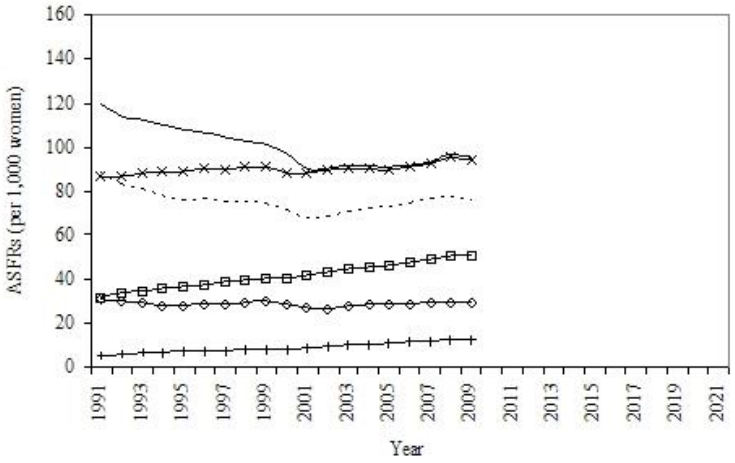


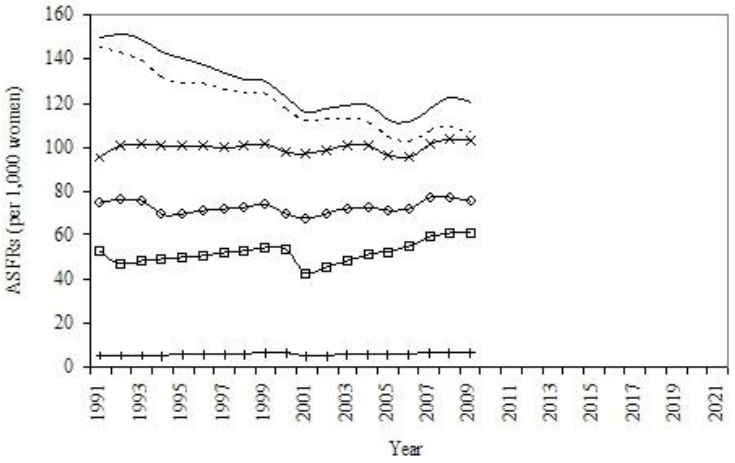
Figure 6 Estimated age-specific fertility rates by ethnic group, Bradford, England 2001

Source: Census, Vital Statistics, mid-year estimates, and Labour Force Survey

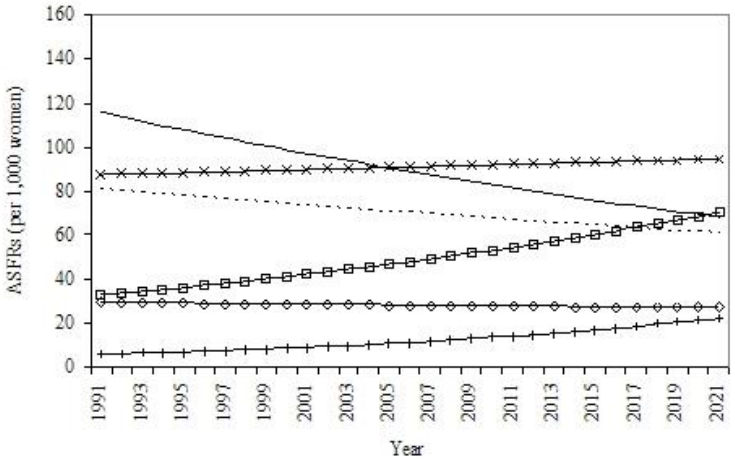
7a Estimated trends,
White ethnic group, England 1991-2009



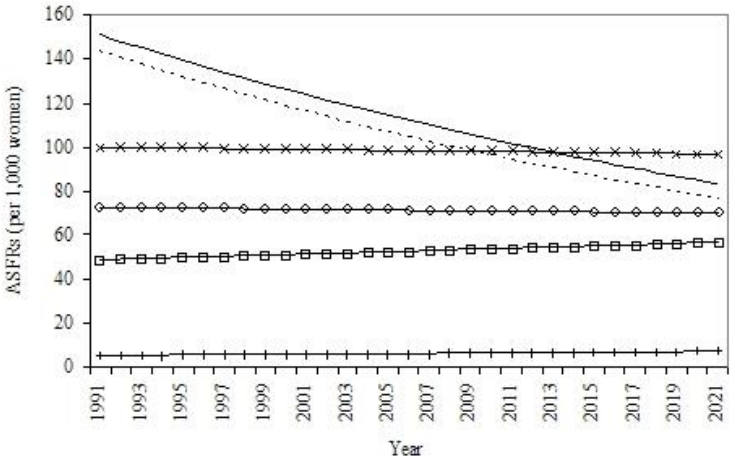
7b Estimated trends,
Bangladeshi ethnic group, England 1991-2009



7c Modelled logistic curves,
White ethnic group, England 1991-2021



7d Modelled logistic,
Bangladeshi ethnic group, England 1991-2021



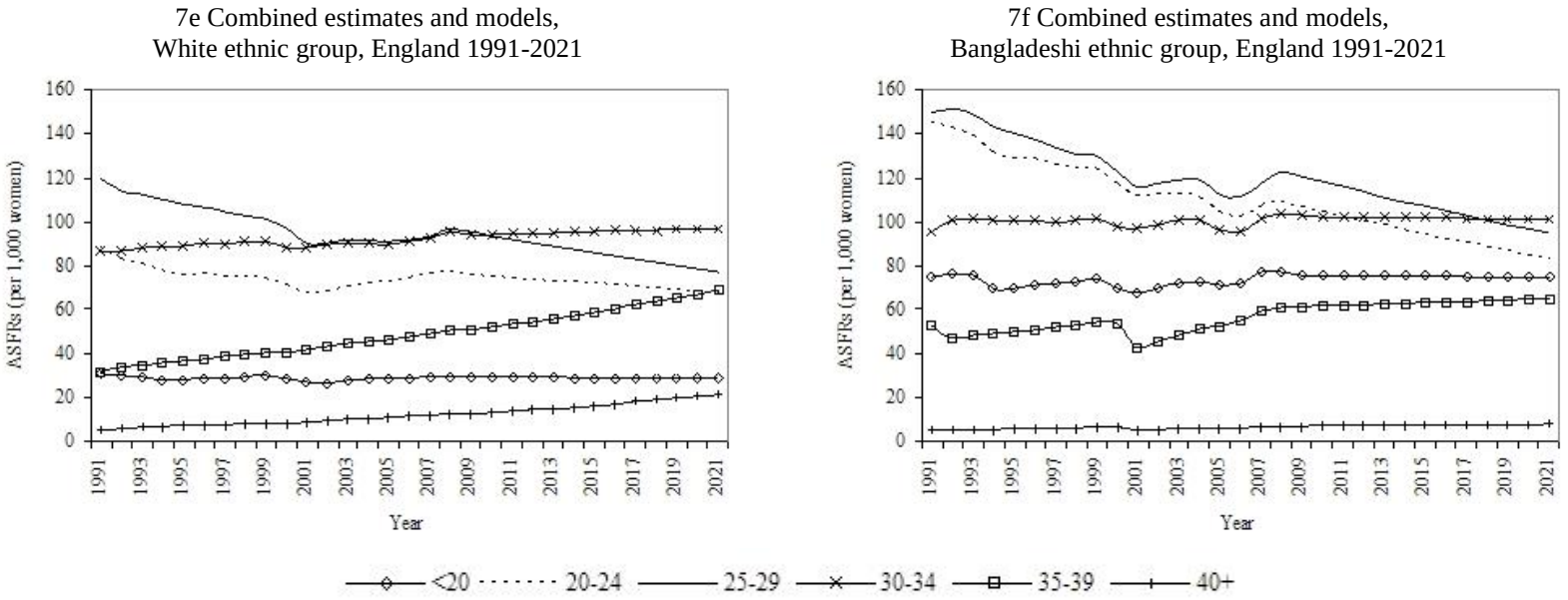


Figure 7 Modelling of age-specific fertility rates by ethnic groups common to 1991 and 2001, to inform future trajectories, England 1991-2021

Source: Census, Vital Statistics, mid-year estimates, and Labour Force Survey