CITY INTELLIGENCE

GLA Trend-based Projection Methodology

2019-based demographic projections

November 2020

Introduction

The GLA Demography Team produce a range of annually updated population projections at local authority, ward and MSOA level for the 33 London boroughs. Each round of projections includes a number of variants designed to meet various user requirements, but in general the variants form two groups:

- Trend projections – those based purely on trends in fertility, mortality and migration;
- Housing-led projections – those which incorporate a forecast housing development trajectory.

This *Update* is concerned with the development of the GLA trend projection model and the production of the 2019-based trend-based population projections at local authority level. The release includes outputs for all local authorities in England and Wales as well as national outputs for Northern Ireland and Scotland. Model outputs and a document presenting the results are available on the London Datastore[1].

In addition to providing a detailed overview of the GLA trend population projection methodology, this *Update* describes the assumptions which feed the 2019-based projection variants, and the data modelling processes used to create model inputs.

[1] https://data.london.gov.uk/demography/population-and-household-projections/

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Notes

For clarity this *Update* refers to periods from one mid-year point to the next by reference to the end year. Therefore, the year mid-2001 to mid-2002 is referenced as mid-2002. Similarly, a longer period such as that between mid-2001 and mid-2014 is referenced as mid-2002 to mid-2014.

The unit of geography is local authority district in England and Wales and nation for Northern Ireland and Scotland. Where this *Update* refers to 'local authority' readers should assume this also includes national data for Northern Ireland and Scotland.

Development of the GLA cohort component model

The GLA's models and assumptions continue to evolve as new data are released. As such, each new round of projections supersedes earlier rounds.

The primary differences between this round and the last are:

- Changes to the input population estimates and components backseries (GLA adjustments to official ONS mid-year estimates and components of change);
- The incorporation of an additional year of official population estimates data;
- The incorporation of age-specific mortality and fertility curves from the ONS 2018-based Subnational Population Projections (SNPP) replacing those from the 2016 SNPP;
- The use of the 2018-based ONS Household model as replacement for the 2016-based ONS Household model (updates the communal establishment population only)[2];
- Updates to model inputs so that the model runs on 2020 local authority boundaries for England and Wales;
- International outmigration is applied as a constant flow in the model loop, rather than applying an outmigration rate to calculate migration flows dynamically;
- Migration assumptions are varied according to different periods within the projection, as opposed to a single set of assumptions applying to the entire projection.

[2] See the section on the household model below

Overview of methodology

These projections are produced using a cohort component projection model. Projections are run forward from the starting point of an adjusted ONS Mid-Year Estimate for 2019[3].

Each subsequent year's population is generated by the same process, taking the previous year's projected population as the start point.

The cycle of events that takes an initial local authority population and generates a projection of the subsequent year's population is described below and illustrated in the flowchart (Figure 1).

1. The cycle begins with the initial local authority populations by single-year-of-age (0 to 90+) and sex. For the first year, this is the base population, for subsequent years this is the projected population at the end of the previous cycle.

2. The starting population is aged-on and births are calculated by applying age-specific fertility rates to the aged-on female population (aged 15-49).

3. Mortality rates are applied to the aged-on population and the births to calculated deaths which are subtracted from the aged-on population to give the survived population.

4. Numbers of out-migrants from the UK are subtracted from the survived population.

5. Numbers of in-migrants from overseas are added to the survived population.

6. A domestic migration matrix is calculated by applying age and sex specific out-migration probabilities to the survived population. The matrix includes flows (by age and sex) between all local authorities in England and Wales as well as Northern Ireland and Scotland. Local authority-level gross in and out migration flows are calculated by summing the inflows and outflows for each authority.

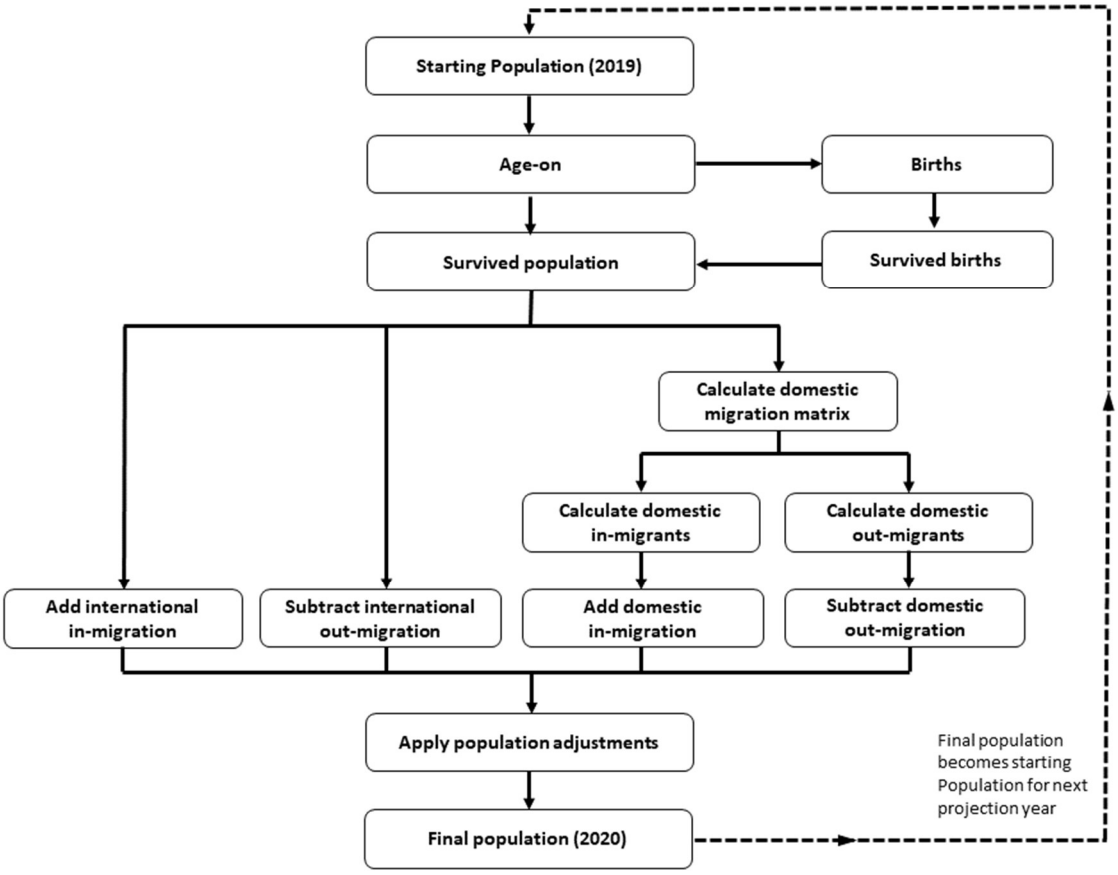
7. Additional population adjustments are applied to the post-migration adjusted population (e.g. deaths from COVID-19). Note that this step is optional and that in most years no adjustment is made.

8. The final population for the projection year is fed back into step 1 as the initial population for the next projection year.

The model outputs estimated and projected population by single year of age and sex from 2011 to 2050. Additional reporting outputs are also produced, including births, deaths and gross migration flows.

[3] See section on base population below

Figure: Flow chart of the projection cycle



Source: GLA Demography, 2020

Projection variants and phases

The 2019-based projections are broken into three projection periods each with differing migration assumptions specific to the period and the projection variant. This is distinct from previous rounds of projections where a single set of assumptions was applied to the entire projection period. This approach has been taken so that the projections can account for both the short-term impacts associated with the COVID-19 pandemic and desire for variants which address the longer-term uncertainty about population change.

The three projection periods are:

- 2020-2022 – Covid period
- 2023-2028 – Transition period
- 2029-2050 – Long-term period

Covid period projection

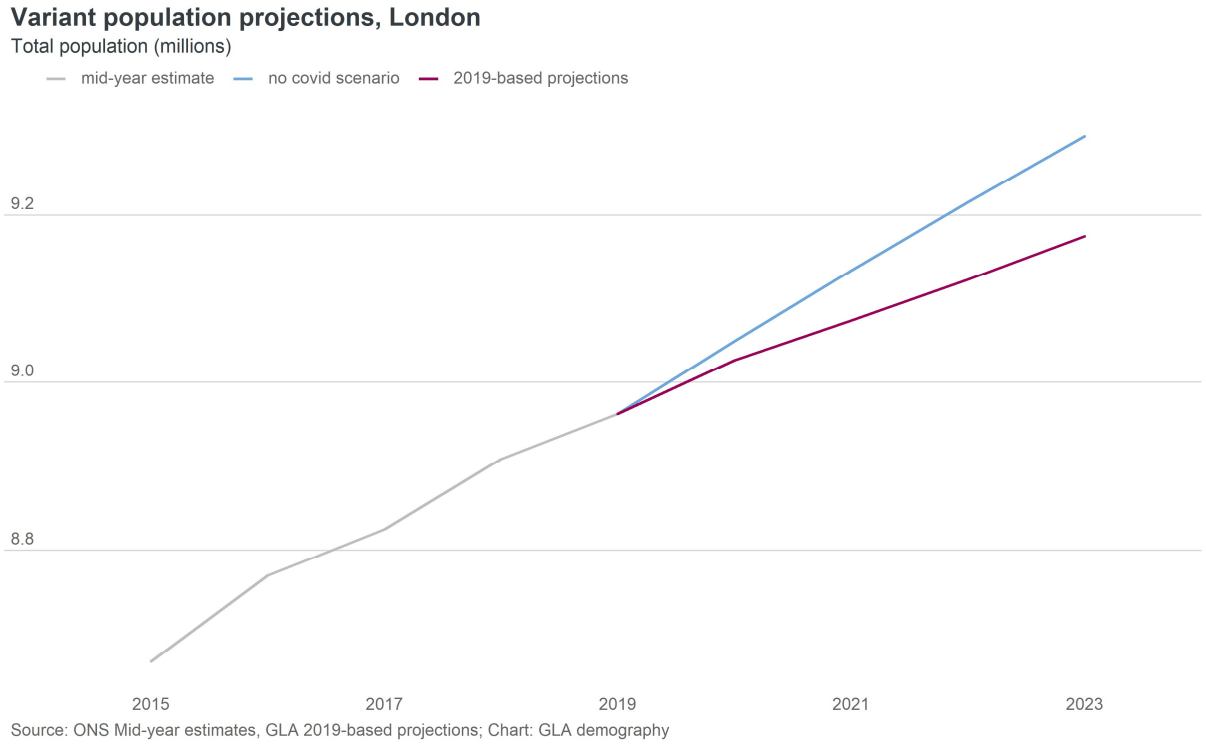
The *covid period* is defined as the projection years 2020 to 2022 inclusive. This is the period in which the impacts of the COVID-19 pandemic are most directly and acutely felt both in terms of mortality from the virus and the impacts on migration and movement. The direct effect of the pandemic began in March 2020 – the first UK Covid fatality was recorded on 2nd March and national lockdown began on 17th March. Therefore, in the first projection year (2020) Covid impacts are limited to the last 4 months of the year (projections run mid-year to mid-year). In the following two years (2021 and 2022) the impacts of the pandemic are assumed to be less direct than those in 2020.

All projection variants use common assumptions for the initial period and only to diverge when differing assumptions are applied from 2023 onward.

The chart shows past mid-year estimate population for London and two projected populations for the period 2020-2022. The *'no covid'* variant is presented to give an indication of the impacts of the adjustments made to the 2019-based projections to account for the immediate impacts of the pandemic.

The *no Covid* variant uses an unadjusted 10-year average of international and domestic migration. No deaths from COVID-19 are included in this projection. The difference between the two is 92,700 persons in 2022. Growth in the *no-Covid* variant is 253,500 over the three years (an average of 84,500 per year) while under the covid adjustment projection growth is 160,800 (an average of 53,600 per year).

Figure: Projected London population to 2022: impact of assumptions applied in Initial Period



Covid mortality

At least 55,000 thousand people in the UK lost their lives to COVID-19 in the year to mid-2020[4], of which at least 8,000 were in London. Official data provide the age and sex breakdown of covid deaths at the national level and total counts of deaths at local authority level. For the purposes of modelling these data have been combined to produce single-year-of-age by sex counts for all local authorities in England and Wales and nationally in Northern Ireland and Scotland. Details of this process can be found in Appendix B.

For the years to 2021 and 2022 assumptions about the level of COVID-19 mortality are necessary. Covid deaths for 2021 have been modelled at 50% of 2020 level (27,578 UK deaths) following the same age-sex and geographic distribution as was seen in 2020 (4,211 London deaths). The modelling does not explicitly assume any additional deaths from COVID-19 in 2022.

Non-Covid mortality

Mortality rates based on trending forward the last five years mortality rates are used to calculate non-covid deaths in 2020. Subsequent years mortality rates are calculated by applying the rate of national change to the LA-level rates for 2020.

It is anticipated that this approach may slightly over-estimate the number of deaths in the covid period as some of the deaths which are accounted for by applying mortality rates will not occur because the individual will have died from COVID-19. However, the impact of this on the projections is assessed to be relatively small and will not affect their overall robustness. Similarly, it is anticipated that mortality rates may be higher than expected in the years immediately following the covid period as the longer-term impacts of the pandemic on underlying health as well as the impacts of missed screenings during lockdown are felt. Again,

[4] ONS weekly deaths by LA for England & Wales; weekly national deaths NISRA for Northern Ireland and NRS for Scotland. Up to and including week 27 (ending 3rd July).

these impacts are not well enough understood at this time to warrant adjustment to the projection methodology.

International migration

International migration in 2020 is assumed to be 70% of the five-year migration flow average for both inflows and outflows. Migration was unaffected in the first eight months of the year (July to February) but in the final four months was severely impacted. The working assumption that flows were 10% of the five-year average in these four months gives an overall level of 70% migration for the year.

In the each of the following two years (2021 & 2022) international flows are assumed to be 50% of the five-year average. This reflects the expectation that international migration will be significantly impacted in the immediate future as a result of COVID-19 but also in response to Brexit uncertainty and wider economic concerns.

The table shows the level of migration for London used in the *covid period* modelling. For context, the ten-year averages for London are: 95,000 international net; 204,000 international in; 109,000 international out.

Table: Covid period international migration: London

	2020	2021 & 2022
International In	144,600	103,300
International Out	72,600	51,900
International Net	72,000	51,400

Table: Covid period international migration: UK

	2020	2021 & 2022
International In	411,200	293,700
International Out	224,100	160,000
International Net	187,100	133,600

Note: UK total includes London

Domestic migration

The baseline assumption is that the structure of domestic migration will not change significantly. London will remain an attractor, particularly to those in their 20s while families and older individuals will continue to out-migrate.

The balance of domestic migration for London is negative, meaning more people leave than arrive (this is offset by international in-migration to the capital). Under conditions where the overall level of residential mobility is low, the population of London will therefore tend to rise more rapidly. The assumptions about domestic migration during the covid period must take this into account.

Domestic migration levels are assumed to be 70% of the recent five-year average over all three years of the covid period.

As with international migration, domestic migration was unaffected in the first eight months of 2020 and can be assumed to follow recent trends. In the final four months mobility was severely restricted and, as with international migration, a level of 70% of the five-year average for the year is used.

In the following two years (2021 & 2022) the impacts on migration are somewhat smaller – we are assuming that any restrictions applied over this period will act as less of a direct constraint on migration than did the initial Lockdown in 2020.

Analysis of migration patterns in previous recessions shows that mobility in such periods has been supressed as individuals' ability to make moves is hampered by their financial situation and wider fears associated with economic uncertainty. In the current circumstance this tendency towards reduced migration is balanced against the increase in home working and the impacts may that have on individuals' needs/desires to reside in London. Our assumptions about domestic migration for the years 2021 and 2022 attempt to balance these opposing forces. Migration for these years is therefore held at 70% of the five-year average.

Transition period

The period 2022-2028 is the *transition period*. During this five-year period migration rates and flows change incrementally providing a smooth transition between the levels during the *covid period* and the final levels used in the *long-term period*.

Long-term period and variant assumptions

The long-term period begins in 2029 and continues to the end of the projection in 2050. A range of different projection variants were modelled, primarily to reflect uncertainty in future migration patterns. Of these, four have been chosen as the principal GLA 2019-based projections, these are:

- *Central upper*
- *Central lower*
- *High population*
- *Low population*

Each variant projection results from a combination of assumptions made about international migration and domestic migration. For each of the two migration components three migration scenarios were developed: a high, a central and a low. The levels of each were agreed in close consultation with the expert panel. They are intended to indicate plausible levels of migration given our understanding of past migration patterns and the potential drivers of future migration.

Long-term international assumptions

For international migration a level of net migration was agreed for each migration scenario and then gross in- and out-flows were modulated from the baseline ten-year average to achieve that net level[5]. The central international variant is the ten-year average (2010-2019). Th net level for the high scenario is 125,000 per annum and for the low scenario 50,000 per year.

Long-term domestic assumptions

For domestic rates, the low variant was based on the five-year period 2008-2012. This is the period following the 2008 Financial Crisis, which was marked by a relatively low level of domestic migration and in both quantum and character provides plausible scenario for low future migration. Conversely, the high population variant uses an average of the last five years' rates (2015-2019), a period in which we have seen

[5] See detailed international migration methodology section below for further explanation

relatively high levels of domestic migration with a peak in 2017. The central variant uses a ten-year average (2010-2019), a period which covers a range of migration levels.

Table: Migration assumptions in the long-term: London

	Low	Central	High
International In	174,000	204,000	224,000
International Out	124,000	109,000	99,000
International Net	50,000	95,000	125,000
Domestic rates	5-year average 2008-2012	10-year average 2010-2019	5-year average 2015-2019

Table: Migration assumptions in the long-term: UK

	Low	Central	High
International In	472,400	554,800	608,200
International Out	360,400	316,300	287,700
International Net	112,000	238,500	320,537

Note: UK total includes London

The migration variants allow for the possibility of nine variant projections. Variants are named according to the international assumption followed by the domestic assumption. The table indicates the four variants used as the principal 2019-based projections. The full range of variants is:

Label	International migration variant	Domestic migration variant	2019-based variant name
CC	Central	Central	Central Upper Bound
CH	Central	High	Central Lower Bound
CL	Central	Low	
HC	High	Central	High population
HH	High	High	
HL	High	Low	
LC	Low	Central	Low population
LH	Low	High	
LL	Low	Low	

The other five variants which arise from the possible combinations of the international and domestic scenarios are reviewed in the sensitivity analysis report which accompanies the release of the 2019-based projections.

Fertility and mortality assumptions

All of the projection variants use the same fertility and mortality assumptions. Rates for 2020 are calculated by trending forward the last five year's rates (2015-2019) using a simple linear extrapolation. Rates for 2021 and beyond are adjusted from the 2020 base using the national rate of change from the 2018-based NPP.

Data sources

Base Population

A series of population estimates up to and including the 2019 starting population is required by the model in order to generate the rates and probabilities used to project forwards. The GLA has made a number of adjustments to the ONS mid-year estimates (MYE) series used as a basis for the 2019-based projections. These adjustments were necessary to account for two issues identified by the GLA:

1. Systematic overestimation of net inflows of children in official estimates from 2012 onward
2. An underestimate of the number of young children in the 2011 census

The GLA originally identified problems with the official estimates of children based on analysis of GP registration, school pupil, and births data, which indicated that estimates for younger age cohorts in many boroughs were becoming increasing inflated over time. The issue appears to primarily affect London local authorities, specifically those with high levels of international migration.

Following discussions with ONS, it seems likely that the issue is primarily related to a mismatch between the assumed age structures assigned to international in- and out-flows. For estimates up to 2011, the age structures assumed for both immigration and emigration flows were based on data from International Passenger Survey (IPS). For estimates for 2012 onward, ONS apply an age structure informed by 2011 census data for inflows, while continuing to base those for outflows on IPS data. For more information see the ONS analysis[6].

Adjustment methodology

To mitigate the impact that these issues have on the projections, the GLA has modified the underlying estimates of population and international migration for London local authorities that are used as inputs to the models. The process of adjusting the estimates is outlined below:

- For London as a whole, the number of state funded pupils, by age and area of residence, and numbers of pupils in independent schools, by age and location of school attended, are used as the basis for an assumed number of children at each age from 5 to 10 for the period 2010 to 2019.
- Estimates of the number of children at each age from 0 to 4 are modelled from annual births and the proportional annual change in the size of cohorts in the GP register.
- Consistent estimates of net international migration by age and year were inferred from annual change in the size of each cohort together with estimates of net domestic migration and deaths by age.
- Estimated net international migration is disaggregated into gross flows according to a presumption that the accuracy of the original inflow estimates is greater than that for outflows.
- A Greater London population consistent with the modified population and international migration estimates was then created for the years from 2011 to 2019.

[6] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/methodologies/annualmidyearpopulationestimatesqmi#appendix-1-analysis-of-estimates-of-children-and-age-distributions-of-international-migrants

- Local authority estimates of population and international migration were adjusted to be consistent with the revised London estimates, with the distribution of children between boroughs being determined by the distribution of children present on the GP register.
- For each year, the total difference between the original and modified international migration estimates in each local authority is redistributed to flows of those aged 18 to 27 based on proportional differences between pre- and post-2011 international migration age structures.

Similar adjustments have been applied to estimates and projections produced by the GLA in recent years and experience has shown them to be far more robust than those based on the unmodified mid-year estimates data when used as the basis for projections of future demand for school places.

These adjustments ensure a greater confidence in the 2019 starting population and the rates derived from the backseries. More details on the impact of this adjustment can be found in Appendix C of this document.

Model Methodology

The following sections detail how each of the components of population change are calculated within the model.

Births

The 2019-based model takes the age-specific fertility rates (ASFRs) for each local authority from the 2018-SNPP for the year 2019 (the SNPP's first projection year) and smooths them by fitting double-peaked Hadwiger mixture curves (see Appendix A). These ASFRs are applied to backseries populations to obtain births estimates which can be compared to recorded births. The ratio of estimated to actual births is calculated in each year and then the last five years' ratios are trended forward using a simple linear regression model. The trended ratio is applied to the smoothed 2019 curve to produce a 2020 ASFR curve for each local authority.

Assumed fertility rates beyond 2019 follow age-specific fertility trends taken from the ONS 2019-based National Population Projections (NPP).

Detailed births methodology

For each local authority:

1) A set of initial fertility rates for 2019 are calculated by smoothing the SNPP ASFRs for 2019 using a function which fits double-peaked Hadwiger mixture curves (see Appendix A for full details). This process modifies the rates to include ages 45-49.

2) The smoothed rates are applied to estimates of the female population to produce estimates of the total number of births for each year over the period 2015 to 2019.

3) The estimates are compared to the actual births data taken from the ONS mid-year estimates, and a local authority-level scaling factor is derived for each of the five past years.

4) The five scaling factors are trended forward using a simple linear regression model to give a trended scaling factor for the local authority.

5) The trended scaling factor is applied to the smoothed 2019 ASFRs to produce a set of ASFRs for 2020.

6) For years beyond 2020 fertility rates are rolled forward by applying the annual proportional change in age-specific rates from the ONS 2018-based NPP principal fertility assumptions.

7) Projected births are calculated by applying the age specific fertility rates in each year to the projected female population. Births assigned a sex based on the ratio of 105 males to 100 females.

Deaths

Mortality rates are calculated using a similar method to fertility rates. In this case, the raw (unsmoothed) age-specific mortality rates (ASMR) for 2019 are taken from the outputs of the 2018-based SNPP. These are applied to mid-year populations for 2015 to 2019 and the resulting total deaths compared to recorded deaths. Scaling factors for each year are derived and the mean of these is applied to the 2019 curve to produce the 2019 ASMRs. Rates beyond 2019 follow the age-specific mortality trends taken from the 2019-based NPP.

Deaths from COVID-19 are modelled and then subtracted from the population in a separate process. See the section below on unattributable population change and Append B on modelling covid mortality from official data sources.

Detailed deaths methodology

For each local authority:

1) A set of initial age-specific mortality rates for 2019 are taken from the SNPP outputs for 2019.

2) The rates are applied to estimates of the population to produce estimates of the total number of deaths for each year over the period 2015 to 2019.

3) The estimates are compared to the actual deaths data taken from the ONS mid-year estimates and a local authority-level scaling factor is derived for each year.

4) The scaling factors are trended forward using linear regression to give a calculated scaling factor for each local authority.

5) This trended scaling factor is applied to the 2019 ASMRs from the SNPP to produce a set of local authority ASMRs for 2020.

6) For years beyond 2020 the ASMRs are adjusted by applying the rate of change by single-year-of-age from the ONS 2018-based NPP principal mortality assumptions.

7) Projected deaths are arrived at by applying the mortality rates in each year to the projected population.

International Migration

Both international in- and out-migration are calculated by applying a constant flow for the duration of the projection. This is change in method from previous round of GLA projections where international out-migration was calculated by applying a set of derived out-migration probabilities to the resident population. There are three migration scenarios each using a different set of in and out flows, they are:

- The central migration scenario averages ten years of flow data (mid-2010 to mid-2019);
- The high migration scenario uses flows modelled from the central migration scenario to give a net international flow for London of 125,000 persons;
- The low migration scenario uses flows modelled from the central migration scenario to give a net international flow for London of 50,000 persons.

Detailed international migration methodology

For each local authority:

1) Average migration flows are calculated using international migration data and population estimates from adjusted Mid-Year Estimates for the ten-year period 2010-2019.

2) The average flows are used as the central scenario.

3) The average net flow for London over the ten-year period 2010-2019 is calculated. This is compared to the high net scenario of 125,000 persons per year. One third of the difference is added to the average inflow total for London and two thirds are subtracted from the average outflow total for London.

4) Scaling factors for in and out flows are derived by comparing the adjusted flows to the original averaged flows.

5) The scaling factors are applied to all local authority age-sex flows. This process yields gross in and out international migration flows consistent with the high net migration scenario.

6) For the low migration scenario, the process in points 3 to 5 is re-run using a net flow of 50,000 persons.

7) In the projection model the inflow is added to the population and the outflow is subtracted.

Domestic Migration

Domestic migration is calculated using a multi-region model to project the flows between 338 areas:

- 33 London boroughs
- 281 local authorities in England
- 22 local authorities in Wales
- Northern Ireland and Scotland

Domestic migration probabilities by age and sex are calculated from ONS internal migration data and adjusted mid-year population estimates:

The central scenario uses ten years of data (mid-2010 to mid-2019)
The high scenario uses five years of data (mid-2015 to mid-2019)
The low scenario uses five years of data (mid-2008 to mid-2012)

Detailed domestic migration methodology

1) Base age and sex specific out-migration probabilities are calculated for each area pairing. These probabilities use domestic out-migration estimates from the adjusted Internal Migration series and population estimates from the adjusted Mid-Year Estimates for the defined period.

For each year this creates a 4-dimensional domestic migration matrix comprising 20,792,408 rates:

338 areas x 338 areas x 91 ages x 2 sexes.

2) An average of each of the rates for the defined period is taken (central, high, low).

3) For the projection years, the age and sex specific rates are applied to the population to calculate flows between each pair of areas.

4) For each area age and gender domestic in-migration and domestic out-migration figures are calculated by summing from the individual area to area flows. For regions and nations moves within the defined area are discounted from the gross flows as they are aggregated.

5) In-migration totals are added to the population and out-migration totals are subtracted.

Population adjustment

Where additional adjustments to the population are necessary this is achieved through the application of an exogenous population adjustment component. This adjustment is calculated outside the modelling process and is applied at the end of the projection year loop following all other processes. In the 2019 model such an adjustment has been used to subtract the additional deaths from the population resulting from the coronavirus pandemic[7].

Population Outputs

In addition to the projected population by single year of age (SYA) and sex, the model outputs include:

- Total Births
- Births by mother's age
- Total deaths (by SYA/sex)
- Domestic & International Gross and Net flows (by SYA/sex)
- District, regional and national aggregations

The release of the 2019-based projection includes projections and associated data for all local authorities in England and Wales as well as for Northern Ireland and Scotland.

Households

The GLA model produces projected households as a standard output. Households are arrived at by applying the 2018-based ONS-based household projections methodology[8] and the DCLG's 2014-based household projections methodology[9] to the projected population.

[7] See Appendix B on COVID -19 mortality modelling

[8] The ONS 2018-based household projection methodology document can be viewed here: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/householdprojectionsforengland

[9] The DCLG 2014-based household projection methodology document can be viewed here: https://www.gov.uk/government/statistics/2014-based-household-projections-methodology

Outputs from the 2018-based ONS household model are considered the principal household projections. This model is used by ONS to produce the official household projections for England. The 2018-based model is an update of the 2016-based model. The model methodology has not changed but updates to the communal establishment population are included.

The outputs of the household model consist of the following:

- Stage 1: households by 5-year age group[10], sex and local authority
- Stage 2: households by 5-year age group and household type by local authority

Household types in stage 2 are:

- Households with one dependent child
- Households with three or more dependent children
- Households with two dependent children
- One person households: Female
- One person households: Male
- Other households with two or more adults

The ONS household model provides updated communal establishment populations up to and including mid-2018. For years after 2018 the communal establishment population is held constant at the 2018 level for ages 0-74. For ages 75 and over the communal establishment population is calculated in year of the projection as a proportion of the total population. The proportion is held constant at the rate implied in the 2018 estimate.

[10] Age groups are 0-15, 16-19 and then 5-year groups to 85-89 with a final 90 and over group.

Appendix A: Smoothing age-specific fertility rates

Modelled age-specific fertility rates (ASFR) in the GLA model are smoothed to reduce noise. This was implemented in response to the recommendations of the review undertaken by the ESRC Centre for Population Change at the University of Southampton. This final report from this review is available on the London Datastore[11].

Base age-specific fertility rates (ASFR) are taken from the 2016-based ONS subnational population projections (SNPP). The 2016 SNPP is the first set of subnational projections to include ASFRs in its outputs.

For the 2017-based projection, a smoothing process has been applied to local authority-level SNPP ASFR curves in advance of their incorporation into the model. This process is intended to reduce random fluctuations in the data. The approach used is to use a function to fit double-peaked Hadwiger mixture curves (Chandola *et al*. 1999)[12] to the age-specific fertility rates.

The double-peak Hadwiger curve is given by the expression:

$$f(x) = am\left(\frac{b_1}{c_1}\right)\left(\frac{c_1}{x}\right)^{3/2}\exp\left\{-b_1^2\left(\frac{c_1}{x}+\frac{x}{c_1}-2\right)\right\} + (1-m)\left(\frac{b_2}{c_2}\right)\left(\frac{c_2}{x}\right)^{3/2}\exp\left\{-b_2^2\left(\frac{c_2}{x}+\frac{x}{c_2}-2\right)\right\}$$

Where:
x is age of the mother at birth

(x) is the fertility rate at age x f

m is a mixture parameter that determines the relative sizes of the two component distributions

a, b_1, c_1, b_2, c_2 are other model parameters related to total fertility and the level and trend of the mean ages of fertility in the two component distributions.

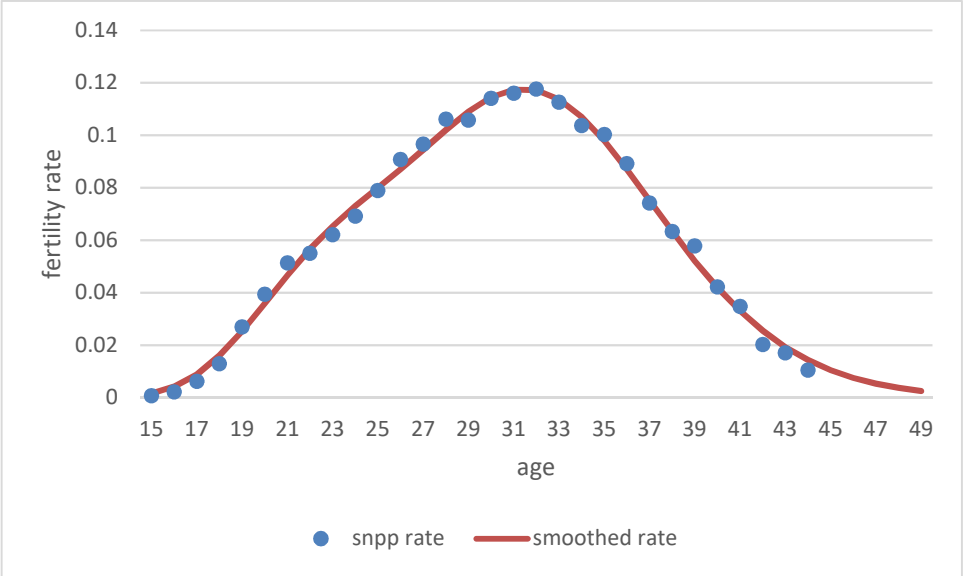
The input data to the function is a set of ASFR for the year 2017 for each local authority for ages 15 to 44 (the range for which ONS outputs ASFR data from the 2016-based SNPP). The output is a set of smoothed rates for ages 15 to 49, with ages 45 to 49 calculated by extrapolation of the fitted curve (see Figure 4).

A Levenberg-Marquardt Nonlinear Least-Squares algorithm is used to fit a curve to each set of data, with starting points chosen based on previously fitted curves from 2011, and convergence tests as described here: https://cran.r-project.org/web/packages/minpack.lm/minpack.lm.pdf using the package defaults for convergence conditions. The parameters of the fitted curve are then used to calculate new rates for each age.

If convergence does not happen within 200 iterations, a grid search method is used to run the Levenberg-Marquardt Nonlinear Least-Squares algorithm with a range of starting values in order to find the best fit. If no fit is found then the data for that local authority is left unchanged.

Figure A1: Raw and smoothed fertility rates (Brent, 2017)

[11] https://data.london.gov.uk/dataset/projection-methodology-independent-review
[12] Chandola, T., Coleman, D.A., Horns, R.W. (1999) Recent European fertility patterns: fitting curves to 'distorted' distributions. Population Studies, 53, 3:317-329.


0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
fertility rate
15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49
age
snpp rate
smoothed rate

Appendix B: Modelling deaths from COVID-19

Mortality in the GLA population models is calculated by applying averaged mortality rates to a base population. This method produced projected deaths in line with past trends in mortality. However, it cannot account for significant one-off events such as the impact of the COVID-19 pandemic. These additional deaths are accounted for separately by applying a covid-specific adjustment to the population in affected years.

Population projections are produced for mid-year (30 June). The 'first wave' of covid deaths occurred largely in the year to mid-year 2020. Deaths for the current year, 2021, are still unknown and must be further modelled with assumptions about the severity and impact of the 'second wave'.

For use in the model we require total deaths by local authority, sex, and age (0-90) for the relevant years. Published data on COVID -19 deaths are not available for that disaggregation and so must be modelled from available sources.

Data sources

The sources of data are:

- Deaths registered weekly in England and Wales (ONS)[13] –
  weekly covid deaths by age and sex (5-year age bands) at the regional level in England and Wales
- Death registrations and occurrences by local authority and health board (ONS)[14] – weekly total covid deaths by local authority in England and Wales
- Weekly Deaths in Northern Ireland (NISRA)[15] –
  weekly total covid deaths for Northern Ireland
- Deaths involving coronavirus in Scotland (NRS)[16] –
  weekly total covid deaths for Scotland

The two sources for deaths in England & Wales have different totals for the same periods. For mid-year 2020 the age and sex data have a total of 50,139 deaths in England & Wales, while the local authority data have a total of 50,077 deaths.

[13] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/weeklyprovisionalfiguresondeathsregisteredinenglandandwales

[14] https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/causesofdeath/datasets/deathregistrationsandoccurrencesbylocalauthorityandhealthboard

[15] https://www.nisra.gov.uk/publications/weekly-deaths

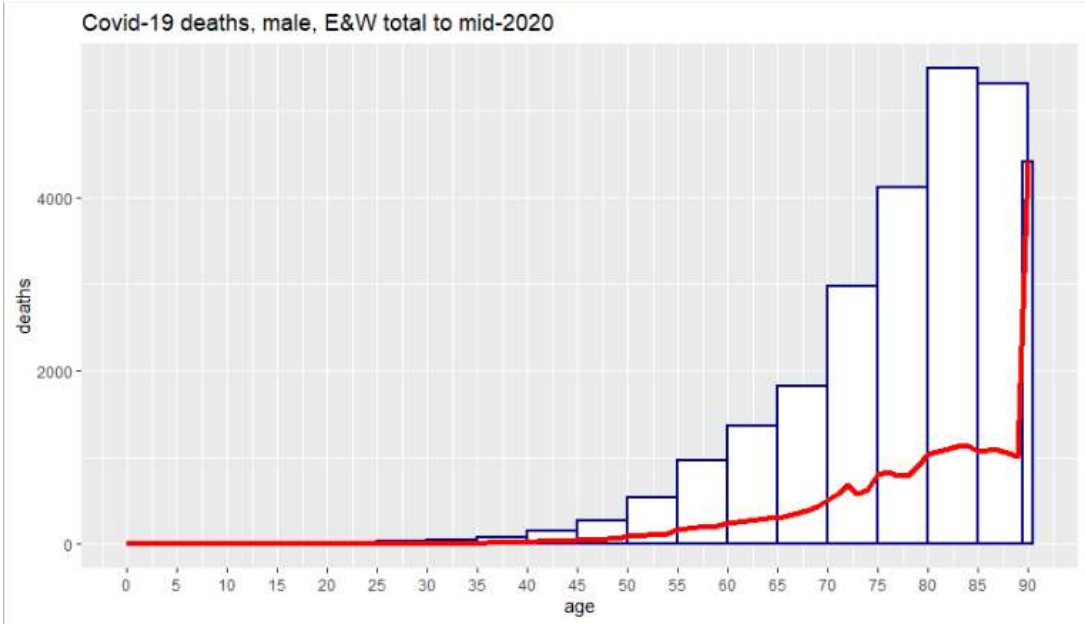
[16] https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/vital-events/general-publications/weekly-and-monthly-data-on-births-and-deaths/deaths-involving-coronavirus-covid-19-in-scotland

Age structure of COVID-19 deaths

Total deaths in England & Wales from COVID -19 in the year to mid-2020 were 50,139 (27,596 male and 22,543 female). Deaths by sex and 5-year age band in England and Wales for the have been modelled to single year of age using UK mid-year estimate deaths data for 2019. This is achieved by distributing the covid deaths within each 5-year band according to the distribution of all deaths in 2019 within that band.

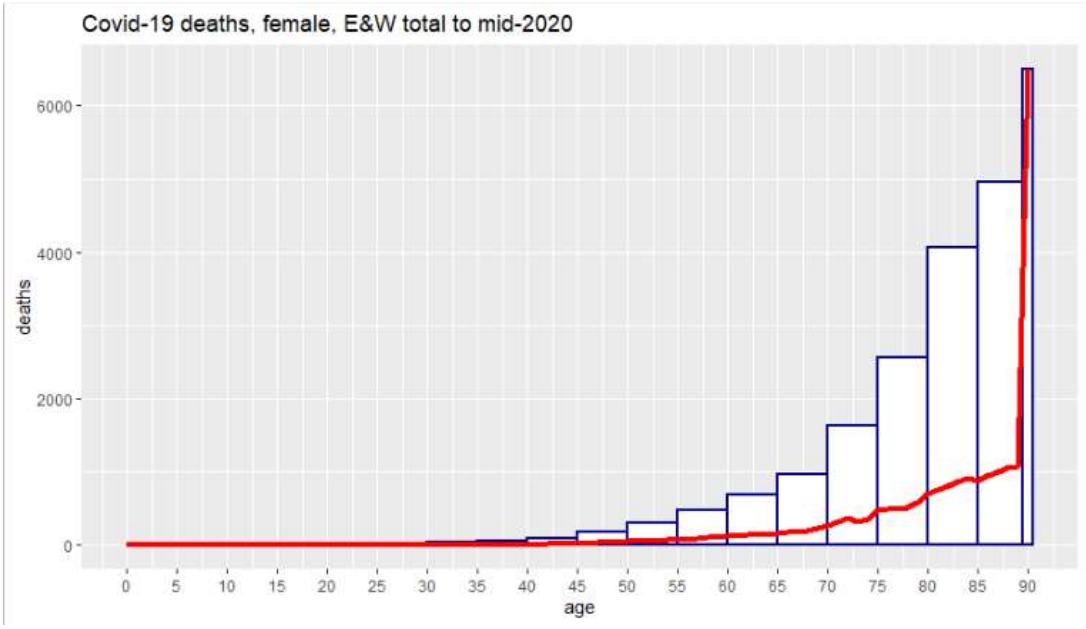
The following charts show the 5-year age banded distribution in the official data as the blue outlined bars. The red line is the same data distributed by single year of year according to the above method.

Figure B1: Covid deaths by 5-year age band and modelled single-year of age



Source: ONS, Deaths registered weekly in England and Wales

Figure B2: Covid deaths by 5-year age band and modelled single-year of age



Source: ONS, Deaths registered weekly in England and Wales

Mid-2020 covid deaths

The single-of-age and sex structure has been applied to the local authority totals for districts in England & Wales and to the national totals for Scotland and Northern Ireland for the year to mid-2020. This provides the necessary detailed model input for the year to mid-2020.

Mid-2021 covid deaths

Our modelling assumes that there will be half as many deaths in 2021 as were observed in 2020. The modelling assumes there will be no deaths from COVID-19 from mid-2021 onwards.

Table: Modelled COVID-19 deaths by region

Region	Mid-2020	Mid-2021
North East	2,784	1,392
North West	7,561	3,781
Yorkshire and The Humber	4,659	2,330
East Midlands	3,785	1,893
West Midlands	5,595	2,798
East of England	4,928	2,464
London	8,421	4,211
South East	7,032	3,516
South West	2,857	1,429
Northern Ireland	844	422
Scotland	4,173	2,087
Wales	2,455	1,228
UK Total	55,094	27,547

Source: mid-2020 ONS, NRS, NISRA; mid-2021 GLA modelled

Appendix C: Impact of changes to base population

The impact of the GLA adjustment to the base mid-year estimate population is in the age structure rather than the overall population. The adjustment moves population from ages 0-10 and redistributes it to ages 18-28. In 2019 there are 82,326 fewer children aged 10 and under in the adjusted base population than the unadjusted. The overall population remains the same in the adjusted backseries.

When projecting there are some differences between a projection run using the adjusted base and one run using the unadjusted base. These are second order effects resulting from rates of fertility, mortality and migration being applied to the adjusted populations and those differences working through the projection.

In the 2019-based variant Central Upper variant the projected 2050 population is 10.915 million. In the same projection run with an unadjusted mid-year estimate series the population reaches 11.057 million in 2050. A difference of 141,800 persons (1.2%).

Figure C1: 2019 Age structure, London

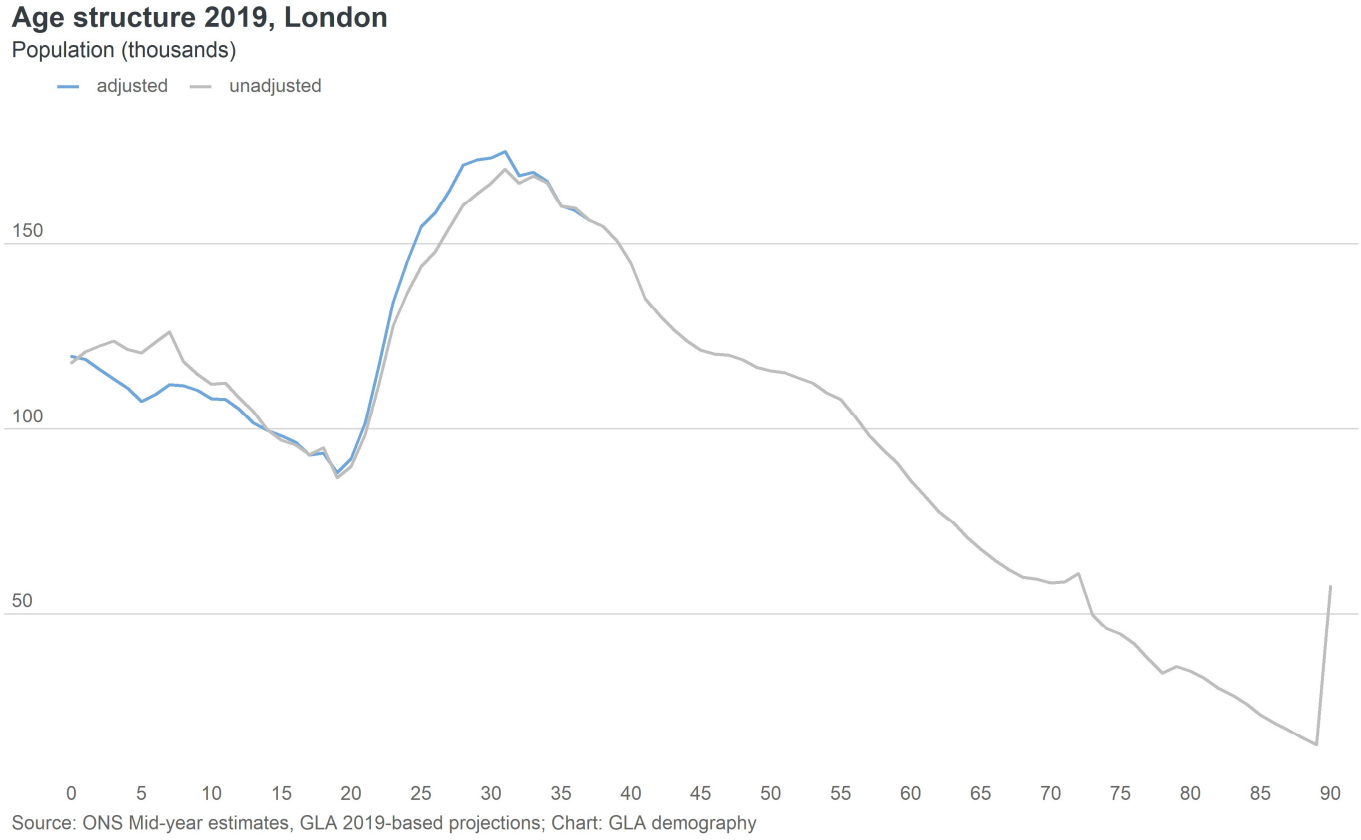
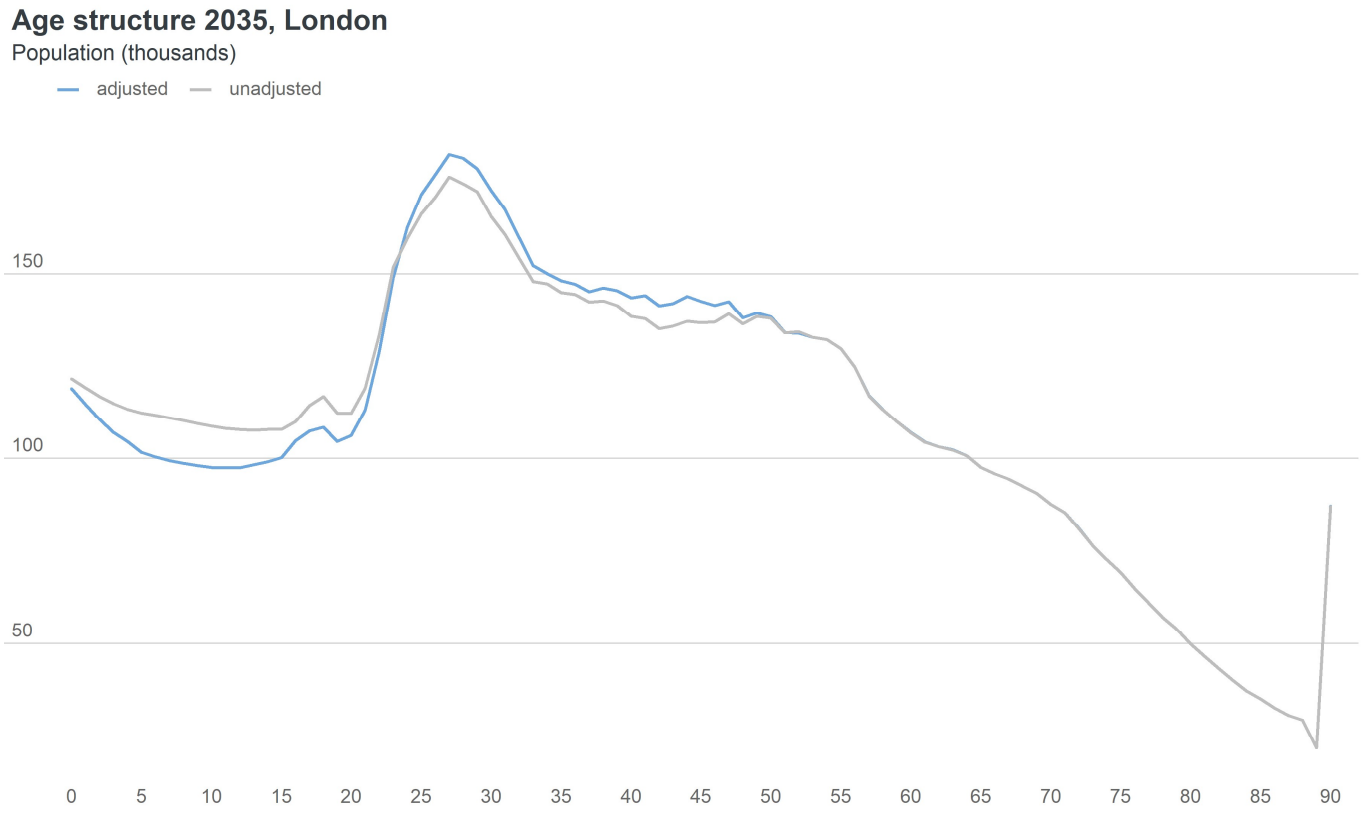
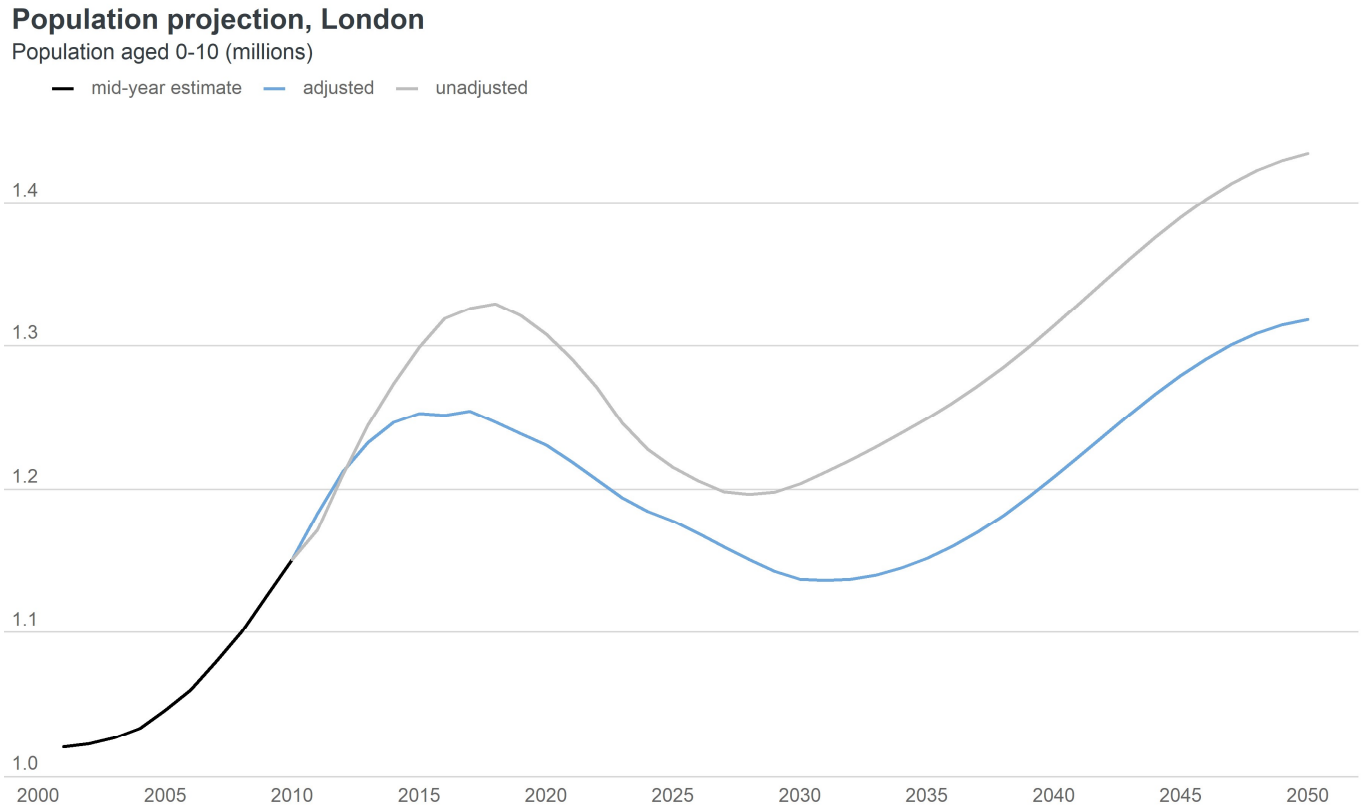


Figure C2: 2035 Age structure, London



Source: ONS Mid-year estimates, GLA 2019-based projections; Chart: GLA demography

Figure C3: Population aged 0-10



Source: ONS Mid-year estimates, GLA 2019-based projections; Chart: GLA demography

Appendix D: Internal Migration series

The ONS Internal Migration series makes available estimated local authority to local authority flows by single-year-of-age and sex for the period mid-2002 to mid-2019. The model takes advantage of this series to project flows based on 338 areas (all LAs in England and Wales plus Northern Ireland and Scotland) by single-year-of-age and sex.

The mid-2017 to mid-2019 flows estimates incorporate new input data sources and a revised estimation methodology. The Patient Demographic Service (PDS) administrative dataset has been incorporated in order to replace the NHS central Register (NHSCR) which was discontinued in February 2016.

In addition, improvements have been made to the assumptions relating to the behaviour of higher education leavers. ONS have acknowledged that the standard method for capturing internal migration moves – monitoring health registrations – works well for some groups and less well for others. In particular, young adults can be slow to register with the health service following a move and so the previous internal migration methodology was prone to understating the magnitude and distribution of post-university flows. As such, starting from the 2017 flow estimates, a new Higher Education Leavers Methodology (HELM) was implement to better account for these graduate flows[17].

The impact of the changes in 2017 is to cause something of a break in the series. The new methodology and data sources result in an increase in the number of moves overall in the UK. The impact for London of the changes varies significantly from borough to borough. Overall the difference between the old and new methods for 2017 is an increase in inflow to London of 21,785 and an increase in outflow of 18,652. The impact on net flows is a less significant increase of 3,133.

[17] Full details can be found on the ONS website:
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/methodologies/methodologyguideformid2015ukpopulationestimatesenglandandwalesjune2016#internal-migration

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