Office for National Statistics

Article

Dynamic population model for local authority case studies in England and Wales: 2011 to 2022

Dynamic population model (DPM) population estimates for 14 case-study local authorities between 2011 and 2022.

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Notice

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We are continuing to develop the dynamic population model (DPM) to provide timely and coherent estimates of population and population change. This page has now been superseded. View our latest Admin-based population estimates: provisional estimates for local authorities in England and Wales, 2011 to 2022 article and read more about how we are developing the method and model in Dynamic population model, improvements to data sources and methodology for local authorities, England and Wales: 2011 to 2022.

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1 . Main points

- We are continuing to develop our research into the new dynamic population model (DPM), which aims to estimate population and population change in a timely way, to better respond to user needs.
- The DPM uses a statistical modelling approach to draw strength from a range of data sources; this builds on our earlier research to develop DPM estimates for a synthetic local authority.
- We have produced DPM estimates for mid-year 2011 to 2022, for 14 case-study local authorities.
- Using these new methods, DPM estimates for 13 of these local authorities were no more than 2.2% lower or 3.6% higher than Census 2021 estimates.
- We have focused our in-depth analysis in this article on two local authorities: Blackpool, for which DPM estimates were very close to Census 2021 estimates, and Cambridge, which had the highest percentage difference to Census 2021 estimates.
- These are our first estimates from the DPM, and we welcome feedback to inform our future developments.

These are not official statistics and should not be used for policy- or decision-making. They are published as research into a method that is different to that currently used for producing population and migration statistics. We advise caution when using the data.

2 . Overview of the dynamic population model

Transforming population statistics

The census has evolved over time, providing a snapshot every 10 years into who we are and how we live. The census and our census-based mid-year estimates provide the best picture of society at a moment in time. However, the Coronavirus (COVID-19) pandemic has underlined the need for more timely population estimates, and we are committed to maximising the use of administrative data. We are researching new ways to produce population and social statistics.

We are using a variety of data sources to provide more frequent, relevant, and timely statistics. Our population statistics sources guide helps users find the right population statistics for them.

In July 2022, we introduced the dynamic population model (DPM) as our future proposal for producing timely, coherent population statistics. We used data for a synthetic local authority to illustrate how the model responds to alternative assumptions about data input quality. In this article, we provide population estimates for 14 case-study local authorities. These include time-series data from 2011 and timely estimates up to 2022. We engaged with the 14 local authorities included to understand their local insights.

Benefits of the DPM

The DPM:

- uses statistical modelling techniques to combine a range of data sources and demographic insights to estimate the population and population change
- builds on our research to develop admin-based population estimates
- is flexible and adaptive to changing data inputs, including data with known limitations (for example, containing missing data)
- enables production of more timely estimates and coherent estimates of population and population change
- can incorporate measures of uncertainty

This allows us to use existing data sources, such as cross-border moves between Scotland, Northern Ireland, England, and Wales, used in the mid-year estimates (MYE). The DPM also uses new data sources, including admin-based population estimates (ABPEs), now known as Statistical Population Datasets (SPDs).

3 . Data sources in the DPM

The dynamic population model (DPM) uses a range of sources to measure population counts and the components of population change. DPM estimates and the data sources used as inputs in the framework refer to the population at mid-year on 30 June for the reference year.

An important benefit of the DPM is that it is a flexible framework. This means that the data sources used can be changed in line with data availability, for instance for more timely or granular data (such as different geographies). This iteration of the DPM uses the following categories of data.

Births

The DPM uses birth registrations for 2011 to 2022, by mothers' age counted at time of birth, which are assumed to be highly accurate. For 2022, we use provisional figures as some births may be missed for the most recent months because of lags in registrations, which can legally take place up to 42 days after the event.

Deaths

The DPM uses death registrations for 2011 to 2022, counted at date of death, which are assumed to be highly accurate. For 2022, we use provisional figures as some deaths may be missed for the most recent months because of lags in registrations and coroner-related delays.

International migration

Between 2011 and 2020, the DPM uses the Long-Term International Migration (LTIM) estimates. They are predominantly based on the International Passenger Survey (IPS), which was suspended in March 2020 because of the coronavirus (COVID-19) pandemic.

Experimental estimates for 2021 are produced using Home Office Exit Checks data and the Department for Work and Pensions Registration and Population Interaction Database (RAPID). This new method makes greater use of administrative data. The estimates rely less on IPS data and statistical modelling. Data from 2021 onward are not comparable with previous estimates and may be subject to revisions.

International migration estimates for 2022 are based on forecasts. Year ending June 2022 migration estimates published on 24 November 2022 will be incorporated in future iterations.

Internal migration

Between 2011 and 2020, the DPM uses estimates of internal migration from the mid-year population estimates. These use address changes in GP registrations from the NHS Patient Register (PR) and Personal Demographic Service (PDS), and higher education registrations from Higher Education Statistics Agency (HESA) data, to measure moves within England and Wales. HESA data are used to move students to university addresses and to adjust for lags in students' post-study moves, ahead of a recorded GP re-registration.

Data for the period 2021 to 2022 use scaling between mid-year estimates (MYE)-based and PDS-based internal migration estimates between 2018 and 2019. This is then used to impute MYE-based internal migration estimates for 2021 and 2022. These provisional imputed estimates are not comparable with previously published estimates, and there is no adjustment for students' post-study moves.

We are researching ways to produce more timely estimates of internal migration.

Cross-border moves

Between 2011 and 2020, the DPM uses estimates of cross-border moves from the MYE. The total flows to and from constituent countries of the UK are agreed between the Office for National Statistics (ONS), National Records of Scotland (NRS), and the Northern Ireland Statistics and Research Agency (NISRA), based on records of in-migration to the relevant country.

Data for the period 2021 to 2022 use scaling between MYE-based and PDS-based cross-border migration estimates for 2018 to 2019. This is then used to impute MYE-based cross-border migration estimates for 2021 to 2022. These provisional imputed estimates are not comparable with previously published estimates and have not been agreed between the constituent countries of the UK.

We are researching ways to produce more timely estimates of cross-border moves.

Population estimates

Mid-year estimates

MYE data for 2011 represents the 2011 Census, rolled forward from Census Day (27 March) to mid-year (30 June). Because of the proximity to the census, we assume that this estimate is high quality. Later years of population estimates from the MYE are not used.

NHS General Practice Patient Register (PR)

The NHS GP Patient Register is used for 2012 to 2015. In these years, SPD data are not available. PR data give the number of individuals registered with a GP surgery in England and Wales. We adjust for coverage error through comparisons between 2011 PR and 2011 MYE.

Statistical Population Datasets, version 3 (SPDv3)

Statistical Population Datasets (SPD) version 3 are used for 2016 to 2020. Datasets are derived from administrative data by combining various sources of "activity" data and use rules to decide whether to include an individual in the usually resident population. We have compared SPDv3 with 2011 MYE to estimate the coverage error and applied a coverage adjustment to all years of the SPDv3 (see "Assumptions about data sources" in this section for further information). We are working on iteratively improving and updating this coverage adjustment for future releases of the experimental DPM.

Benchmark comparisons

Data from Census 2021 are not used directly within the model but are used to compare against model outputs. Census 2021 data references 21 March, three months before mid-year, so some differences can be expected between the DPM and census estimates.

Assumptions about data sources

To explore this new method, we use existing data sources available to us, making assumptions on their quality based on our current information and knowledge. We recognise that some of these will need to be refined over time.

1. The coverage adjustment ratios for the SPD and Patient Register were calculated by comparing with 2011 MYE, and we have assumed that this rate has remained constant since 2011.

2. We smooth coverage ratios and flow data using generalised additive models (GAMs) for each combination of local authority, sex (if applicable), and year; we do this to reduce error from fluctuations between years and aim to capture the true underlying relationship, which should not change significantly.

3. The 2011 MYE are unbiased, with uncertainty comparable with the 2011 Census.

4. The models for SPDv3 and PR incorporate the standard deviations obtained from the measures of statistical uncertainty for SPDv3 (read more in Admin-based population estimates and statistical uncertainty).

5. The model assumes that birth and death registrations are accurate, however we expect a slight undercount for the most recent months

6. Census 2021 is used as a comparator to assess how the model performs but is not included in the model.

7. We impute SPD denominators for flow rates for 2012 to 2015 and 2021 to 2022 when we have no "true" SPD values.

8. Provisional data used for 2021 and 2022 for births, deaths, internal migration, cross-border migration, and international migration are based on early research and are not comparable with previous estimates.

4 . Known population trends and rates

Demographic expertise and assumptions feed into the model through statistical models for birth, death, and migration rates. The rates are defined as the ratio of the flows to the population that could experience that event.

We use a model for births, deaths, combined immigration, and combined emigration in the estimation process described in Section 10.

Birth and death counts are taken from registrations directly and assumed to be accurate, while all flow rates are assumed to be uncertain. Note that for combined immigration, the rate is defined by the count.

Assumptions about the trends and rates

To explore the dynamic population model, we are using data sources already available to us and making assumptions about their quality based on our current information and knowledge. We recognise that some of these assumptions will need to be refined over time.

The denominator for the calculation of flow rates is the Statistical Population Dataset version 3 (SPDv3), provisionally adjusted for coverage error using the 2011 Census. We have assumed that the adjusted SPDv3 estimates are more reliable than the mid-year estimates (MYE) because the latter can suffer from drift in the years between censuses.

The smoothing of flow rates across age was applied separately for each local authority, sex (if applicable), and year using an adaptive generalised additive model (GAM). This approach over-smooths the rates for some ages (university ages, in particular) in most of these 14 local authorities. We are developing methods to address this.

Uncertainty in the flow rates is incorporated in the system models using a probability distribution, with a mean equal to the smoothed rates and a specified dispersion parameter (measure of spread). The dispersion parameter is unique for each local authority and rate.

We account for uncertainty in migration rates based on the coefficients of variation (standard deviation divided by the mean) of the estimates of combined immigration and combined emigration. We are developing improved methods to measure error in migration statistics.

We include uncertainty for birth and death rates because SPDv3 population estimates (used as denominators) have uncertainty.

5 . DPM estimates for local authority case studies

Following on from our July 2022 publication in which we investigated a synthetic local authority, in this article we have selected 14 local authorities as case studies. These examples from across England and Wales represent some important population features seen in local areas.

The full list of local authorities is shown in Table 1. It includes:

- relatively small district council authorities such as Boston
- large rural areas with a diverse population such as Ceredigion
- London boroughs
- metropolitan areas with a large population such as Manchester
- smaller cities including Cambridge and Warwick

Many areas include significant student populations, which can be difficult to estimate.

Results for local authority case studies

Using Census 2021 as a benchmark comparator, differences between the estimates produced by the dynamic population model (DPM) for mid-year 2021 and Census 2021 are summarised in Table 1. Findings from the local authority case studies include that:

- the DPM estimates for Blackpool are very close (within 0.1%) to the Census 2021 estimate
- Cambridge has the biggest overall difference, at 6.4% below Census 2021
- high concentrations of students, including international and post-graduate students, make Cambridge estimates more sensitive to errors in the flow data, compared with local authorities with more stable populations
- the DPM estimates for Cambridge may be driven down by the forecast-based international migration, which may underestimate migration in 2022

International immigration counts in this publication are based on forecasts in 2022, to be updated with actual official estimates when these are available by age, sex, and local authority.

At the overall level, the DPM estimate for Blackpool is very close (within 0.1%) to the Census 2021 estimate. On average, each single year of age and sex estimate is 3.7% different from Census 2021, below for some ages and above for others. This measure is referred to as the average absolute percentage difference.

Cambridge has the greatest overall difference, at 6.4% below Census 2021. The DPM estimates are generally lower than Census 2021 across the age profile, leading to the average absolute percentage difference being quite similar to the overall difference, at 7.3%.

Westminster has the largest average absolute percentage difference by single year of age and sex, at 11.0%. The overall DPM estimate is 2.6% higher than the Census 2021 estimate, as many differences for individual age and sex groups balance each other out.

Table 1: Comparison between 2021 dynamic population model estimates and Census 2021 for 14 local authority case studies, England and Wales

LA	DPM	Census	Total % difference	Average % difference across all ages
Blackpool	140,954	141,029	-0.1%	3.7
Boston	72,273	70,509	2.5%	4.9
Cambridge	136,339	145,681	-6.4%	7.3
Ceredigion	71,678	71,481	0.3%	6.8
Coventry	354,688	345,315	2.7%	5.4
Guildford	141,191	143,645	-1.7%	6.0
Gwynedd	120,231	117,393	2.4%	5.0
Islington	224,454	216,582	3.6%	7.1
Manchester	551,431	551,944	-0.1%	4.4
Newham	354,636	351,029	1.0%	5.3
North Norfolk	101,581	102,985	-1.4%	4.3
Swansea	240,417	238,489	0.8%	4.5
Warwick	145,220	148,451	-2.2%	6.0
Westminster	209,481	204,233	2.6%	11.0

Source: Office for National Statistics – Dynamic population model

Figure 1 shows the percentage difference between the 2021 DPM estimate and the Census 2021 estimate for each local authority by age group. In many cases, the DPM estimate for those aged 18 to 20 years is much lower than the Census 2021 estimate, particularly in areas with student populations. In contrast, the DPM estimates for people in their early twenties are often higher than the Census 2021 estimates. We demonstrate in the following local authority case studies that this is to some extent the result of how we have smoothed flow rates. Our methods also capture student moves to university at age 19 years (age at the end of the mid-year) rather than at age 18 years (age at the migration event).

Cambridge shows notable underestimates for working age adults, while Westminster DPM estimates are high for older adults and young children.

The higher discrepancies at ages 21 to 25 years and at 90 years and over will be addressed as we refine the models.

Figure 1: Percentage difference between DPM 2021 population and Census 2021 estimates by age group for 14 case-study local authorities

Notes:

1. DPM refers to the dynamic population model.

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In the following sections, we focus on two particular examples: Blackpool, which has close agreement to Census 2021, and Cambridge, which has more differences.

Blackpool

The DPM estimate for Blackpool is very close to Census 2021, with the DPM lower by 0.1%. Between the 2011 Census and Census 2021 estimates, the population decreased by 0.7%, while the DPM estimates the population decreased by 0.8% over the same period.

DPM estimates then increased by 0.7% between 2021 and 2022, which was the largest change in the population estimate. Higher net migration is likely to be the primary driver for this. The change in migration input data in 2021 and 2022 could also be a contributing factor.

Figure 2: The dynamic population model estimate for Blackpool is very close to Census 2021, with a difference of 0.1%

Total population estimates for Blackpool, 2011 to 2022

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Figure 2 compares 2011 to 2022 population estimates for Blackpool. For 2011, the DPM estimate is close to the mid-year estimate (MYE).

DPM estimates increasingly differ from the MYE through the decade. This can be partly explained by the DPM moving from using coverage-adjusted PR to SPDv3 data for population estimates between 2015 and 2016.

Figure 3 shows the ages most affected by the switch. For example, DPM estimates for most ages between age 26 years and age 42 years are higher than the MYE. This reflects differences between SPDv3 and the MYE at these ages. Furthermore, the DPM estimate moves closer to SPDv3 and away from the MYE. This may reflect the drift seen in the MYE between censuses.

Figure 3: Differences between the dynamic population model, MYE and SPD estimates for Blackpool are seen for those aged 26 to 42 years in 2016

Notes:

1. MYE refers to mid-year estimates.
2. SPD refers to Statistical Population Dataset.

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In several of the 14 local authorities, differences with Census 2021 for males and females balanced one another out. This resulted in low difference for the total population estimate.

This is seen in Blackpool, where the DPM female population was 0.7% lower, and the male population was 0.6% higher, than Census 2021 estimates. This resulted in a DPM estimate lower than Census 2021 by 0.1%.

Figure 4: The dynamic population model and Census 2021 estimates for Blackpool are closely aligned for most ages in 2021

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Figures 5 and 6 show that DPM combined emigration counts differ from published migration estimates in two main areas: the DPM modelled migration counts and methods used to derive migration rates. Combined migration includes:

- internal migration
- cross-border flows
- international migration

These figures also include a measure of uncertainty for the DPM estimate known as credible intervals. This is shown as a coloured band surrounding the DPM estimate. Broadly, the credible interval states that, given the observed data, the true population for a given age and sex has a 95% probability of falling within the range shown. Credible intervals are only shown for unaggregated data.

In Figure 5, lower modelled emigration compared with the published estimates can be seen, particularly for those aged 26 to 42 years. However, the difference is small, and the published estimates fall within the credible interval for the DPM estimate. Overall, the migration counts are relatively low in Blackpool, and this leads to a high degree of uncertainty surrounding the modelled outward migration counts.

Peak emigration typically occurs at age 19 years in the published estimates for Blackpool, which is an indication that many individuals move away for university (Figure 5). In Blackpool, the DPM over-smooths peak emigration at age 19 years, resulting in a delayed peak at age 20 years. This leads to, for example, fewer individuals aged 19 years moving out of Blackpool in 2016. We are reviewing our smoothing methods and hope to improve on this in future releases.

From 2021 onwards, internal migration data sources changed from MYE-based internal migration to scaling moves recorded in the PDS. In 2021 and 2022, we observe an increase in the credible intervals for the migration estimates compared with previous years. This could be related to the lack of population estimate data available in those years or a change in migration data.

Figure 5: The dynamic population model over-smooths peak combined emigration at age 20 years compared with age 19 years for males in Blackpool in 2016

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Figure 6: Combined emigration patterns changed for males in Blackpool in 2021 compared with previous years in the time series

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Changes were observed in overall emigration patterns for both sexes in 2021, while the overall immigration and emigration totals for Blackpool increased from 2020 to 2021. Figures 5 and 6 provide an example of changes in male combined emigration. Changes in data sources and the effects of coronavirus (COVID-19) are likely to influence these patterns.

PDS-based moves are likely to have been affected in 2021 by vaccination registrations. Additionally, during the coronavirus pandemic, students were more likely to remain at their home address instead of moving to the local authority where their university is based.

As new data become available, they will be fed into the DPM framework. International migration forecasts for 2022 will be replaced and other migration and population estimates will be revised, as is typical in the production of provisional estimates.

Cambridge

The DPM estimates for Cambridge show the largest difference when compared with Census 2021 estimates, with an overall difference of 6.4% in 2021. The DPM estimate barely changes between 2021 and 2022 (with an increase of 0.2%).

Figure 7: Cambridge shows a 6.4% difference when comparing DPM 2021 estimates with Census 2021

Total population estimates for Cambridge, 2011 to 2022

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Figure 7 compares population estimates for Cambridge from 2011 to 2022. In 2011, DPM estimates are close to MYE, but increasingly diverge over time. A shift is seen between 2015 and 2016 as the model moves between PR and SPDv3 data.

The DPM estimates are lower than Census 2021 and higher than SPDv3. The DPM framework is influenced by data feeding into the model, which is driven by two important factors. The SPDv3 coverage ratio showed an under-count for Cambridge. This causes the DPM estimates between 2016 and 2020 to be above the SPD.

Meanwhile, the high density of students in Cambridge, including international and post-graduate students, makes estimation of migration flows particularly important when estimating the population. MYE-based estimates of population change appear to under-estimate net inward migration. This drives down the DPM estimate, leading to an overall lower estimate compared with Census 2021.

Figure 8: Cambridge population estimates for females from the DPM are close to Census 2021

Notes:

1. DPM refers to the dynamic population model.

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Figure 8 compares 2021 estimates by age for females in Cambridge from the DPM and Census 2021, along with the most recent available data from SPDv3 and MYE (2020). The largest difference between DPM and MYE estimates occurs between those aged 23 and 44 years. At other ages, the estimates are similar. DPM estimates are consistent with SPDv3 and Census 2021 at most ages.

The MYE counts migration by age at mid-year, causing issues for local authorities with a rapid population influx of a specific age. This can be seen in Cambridge where most undergraduates move to university at age 18 years but will be aged 19 years at the following mid-year reference point. This creates under-estimation at the age of event (18 years) and subsequent over-estimation at the following age. We are investigating methods to reflect migration by age at the time of the move.

Figure 9: The DPM over-smooths university-aged migration into Cambridge

Notes:

1. DPM refers to the dynamic population model.

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The effect of over-smoothing migration flow data is visible in Cambridge. Observed migration counts are smoothed across ages, independently for each local authority, year, and sex, to reduce fluctuations across the age profile that occur as a result of natural random variation, particularly where counts are small. However, our current methods over-smooth data for local authorities with large student populations, which experience substantial migration of young adults at specific ages.

Figure 9 compares raw counts, smoothed counts, and DPM final estimates of combined in-migration (internal migration, cross border flows, and international migration into Cambridge). We over-smooth the large peaks and troughs of immigration for people aged between 19 and 23 years. This creates lower or higher estimates of the immigration flows at these ages, compared with the raw counts, re-distributing this spike across other ages. The overall counts remain the same, but the smoothing changes the age profile of the migration estimates. We are developing our smoothing methods to allow these real, sharp changes in migration.

Figure 10: Local authority population pyramids

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6 . Insights from local authority engagement

The 14 case-study local authorities took part in a feedback exercise to review and comment on the dynamic population model (DPM) methods, input, and outputs over two sessions. The sessions aimed to help local authorities to:

- learn about the current input data sources used in the new method
- understand the complexity of the model and approaches taken
- provide a detailed review of the DPM estimates and compare these with their own insight on their local authority, to help us understand where the model performed well and where it needs to be improved
- provide detailed information on alternative data sources for potential inclusion in future iterations of the DPM

The local authorities provided a wealth of helpful feedback across the DPM and within specific themes, which are detailed in this section.

DPM population estimates in 2021 and 2022

- Although some local authorities felt the estimates were appropriate, others felt the overall estimates of population were too low.
- Some feedback suggested that the expected return of usual residents to their local authority was not reflected in DPM estimates for 2022, after coronavirus (COVID-19) restrictions were removed.
- There was feedback that, in some cases, sex ratios needed to be reviewed and improved.

DPM migration estimates

- Some local authorities felt that overall inward migration estimates were too low, especially in more recent years of 2019 to 2022, particularly for student age groups (those aged 18 to 25 years).
- Migration smoothing may dampen expected increases in migration for some local authorities.

Where the DPM will have challenges

- Reliance on similar input data to mid-year estimates (MYE) will result in the same challenges.
- Reliance on the '"usually resident" definition' in early iterations can be limiting for users who require, for instance, the population on a given day and not just people who have lived there for at least 12 months.
- It is not yet clear how the DPM will incorporate qualitative and contextual information.
- Clear communication and engagement on these new methods are required, including more visual representation, technical information, and regular opportunities to feed back on the approach.

Other data sources that can be used in the DPM

- Housing information such as dwelling stocks in an area, occupancy rates, and council tax records.
- Education data such as Higher Education Statistics Agency (HESA) data, school registrations, and non-state-school pupil information.
- Other person-level information such as National Insurance registrations, employment and benefits information, and pension data.

How we are using the feedback

The sessions provided invaluable feedback, which highlighted areas in which the model performed well, and other areas in which it needs to be developed.

We are using this feedback to understand how we can develop the DPM for future iterations during 2023. This includes exploring new data sources and refining some of the model assumptions. We are already exploring some of the issues raised as we develop, and some of the data sources highlighted are already used in the DPM through the inclusion of Statistical Population Datasets (SPDs).

7 . Upcoming improvements

All local authorities research article

In early 2023, we will extend this research output to produce provisional estimates for all 331 local authorities in England and Wales, up to June 2022.

We plan to incorporate the following improvements to address quality issues discussed in this article and in our local authority engagement:

- improved methods for smoothing rates to retain real growth in specific groups (such as student age groups)
- updating data inputs as they become available, for example, births and deaths data and updated migration estimates

Work on future developments outlined in our previous article will continue. We are using detailed comparisons between administrative data and Census 2021 to develop and refine coverage adjustment methods for the Statistical Population Datasets (SPDs). We will do this alongside work to develop a formal coverage adjustment methodology for the longer term.

Producing timely estimates requires "signal" data to provide early notice of emerging trends, such as a drift of people back to inner city areas after the coronavirus (COVID-19) pandemic. We have created a real-time data dashboard to provide timely information. We are exploring new and innovative "signal" data to include in the dashboard, including mobile phone usage, wastewater, and energy consumption such as electricity or gas.

8 . Dynamic population model for local authority case studies data

Dynamic population model local authority case studies: credible intervals
Dataset | Released 23 November 2022
Credible intervals for the dynamic population model (DPM) local authority case studies.

Dynamic population model local authority case studies: population and migration estimates
Dataset | Released 23 November 2022
Estimates of population and migration from the dynamic population model (DPM) for local authority case studies, 2011 to 2022.

9 . Glossary

Dynamic population model

A dynamic population model (DPM) is a statistical modelling approach that uses a range of data to measure the population and population changes in a fully coherent way.

Credible intervals

The range in which the true value of the quantity being estimated is likely to be contained. We use 95% credible intervals in this article by taking 2.5th and 97.5th percentiles from the distributions of counts produced by our estimation process (see Section 10) as the lower and upper bounds of our intervals, respectively. In this case, we can say that the probability that the true value lies in the credible interval is 95%.

Personal Demographic Service (PDS)

The Personal Demographic Service (PDS) from NHS Digital is a national electronic database of NHS patients, which contains only demographic information with no medical details. The PDS differs from the Patient Register (PR) since it is updated more frequently and by a wider range of NHS services. The PDS data available to the Office for National Statistics (ONS) consist of a subset of the records, including those which show a change of postcode recorded throughout the year or a new NHS registration.

Generalised Additive Model (GAM)

A Generalised Additive Model allows the modelling and smoothing of non-linear data. GAMs have been used within the DPM to model and smooth raw flow data. This was done to reduce the amount of random variation and attempt to represent the true underlying pattern. This approach is particularly useful when working with noisy data or rare events.

10 . How the dynamic population model relates to current estimation methods

Structure of the dynamic population model (DPM)

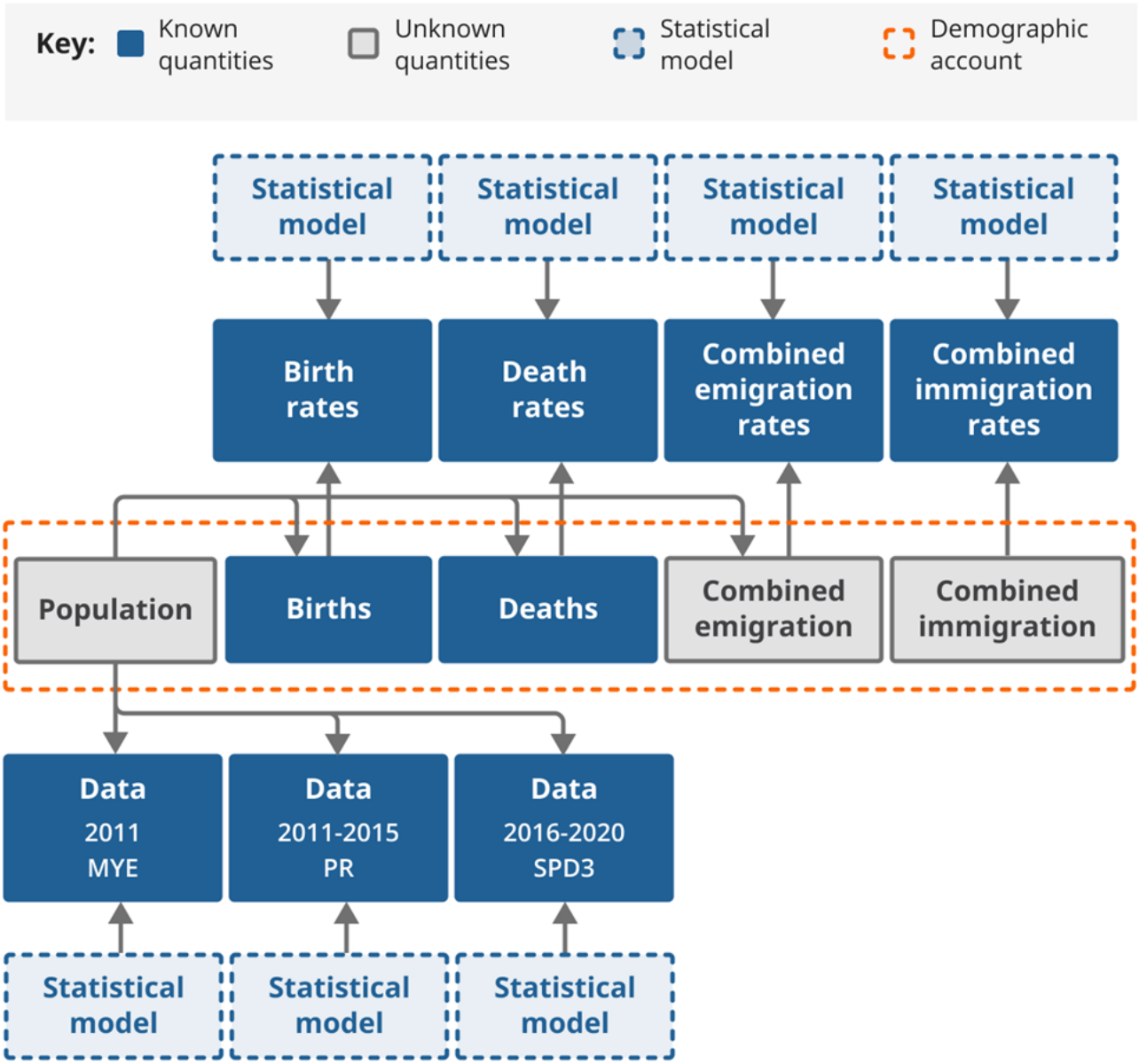
The DPM calculates year-to-June population estimates for 2011 to 2022 by single year of age, sex, and local authority.

Figure 11 shows the structure of the DPM. Components in the dashed rectangle constitute a demographic account for a single local authority - a set of tables of counts of demographic stocks and flows, disaggregated by age and sex. Stocks are population counts at a point in time, and flows are additions to, or subtractions from, the population. Inflows include births and movement into the local authority. Outflows include deaths and movement out of the local authority.

We refer to all movement into the local authority as combined immigration, which includes international immigration and internal in-migration from local authorities in England and Wales, and cross-border inflows from Northern Ireland and Scotland. All movement out of the local authority is referred to as combined emigration, which includes international emigration and internal out-migration to local authorities in England and Wales, and cross-border outflows to Northern Ireland and Scotland.

Stocks and flows in a demographic account conform to the accounting identity that states that the change in stock of the population over a period is equal to increases in the population because of births and combined immigration, minus outflows because of deaths and combined emigration. This is consistent with the cohort component method used for mid-year estimates (MYE). Where the MYE uses a population stock every 10 years (census estimates), the DPM also uses a population stock (Statistical Population Datasets, version 3 (SPDv3)), but more frequently, to try to overcome some of the challenges within the MYE process.

Figure 11: Components of the dynamic population model



Notes:

1. MYE refers to mid-year estimates, PR refers to the NHS Patient Register, and SPD3 is the Statistical Population Dataset version 3.

The DPM estimates each component of the demographic account. In Figure 11, the blue boxes represent quantities that are treated as known, and the grey boxes represent quantities that are treated as unknown. The four squares at the top marked "rates" represent the underlying rates for births, deaths, combined emigration, and combined immigration. They are estimated using a mix of modelling and real data, and then treated as input data in the model.

The blue dotted rectangles represent statistical models for the population data counts and statistical models for the rates. The direction of the arrows shows that the data we observe are related to the unknown truth through a statistical model. Components above the demographic account describe how the true, unknown counts for each set of flows are generated from a statistical model with "rates" as parameters.

The components below the demographic account are referred to as data models. They describe the relationship between the reported values in the data and the true, unknown counts. The statistical models account for inaccuracies in the reported counts because of uncertainty in coverage and other sources of error. For this iteration of the model, we have used the normal distribution for our data models (MYE, SPDv3 and NHS Patient Register (PR)) with means adjusted for coverage and standard deviations reflecting the calculated uncertainty intervals of these estimates. Section 3 of this article describes assumptions about the data sources.

The estimation process

The estimation process has two distinct stages. In the first stage, we obtain estimates for counts of population, combined immigration, and combined emigration (births and deaths are treated as known). We use a technique called particle filtering to approximate the distribution of the demographic account by generating, sequentially, a large number of values for each component (we use 10,000). This is conditional on the available data and models. We calculate weights with our statistical models for data and rates to make the sample more representative of the target distribution. This filtering approach is applied independently to each year-of-age cohort.

The second stage is to separate the combined migration values from the model into international migration and within-UK migration flows (internal migration and cross-border flows). We constrain each type of migration flow to equal the combined migration values from the model. We do this by multiplying each migration flow by the ratio of the modelled to total input data values. This is repeated for each of the 10,000 combined migration values, generating 10,000 values for each type of migration flow by local authority, age, sex, and year.

Finally, the 10,000 counts for population, births, deaths, immigration, and emigration, for each local authority by age and sex and year, are summarised by calculating the mean (average). The 2.5th and 97.5th percentiles are calculated to provide a corresponding uncertainty interval (95% credible interval).

While the mean estimates of population and flow counts can be added together to give estimates across age and sex for each local authority and year, this is not true for the percentiles. Therefore, we do not present credible intervals for total population or migration, only for estimates by single year of age and sex.

Note that we have aggregated flows by age and time rather than by cohort, as is done in the mid-year estimate publications. The implication of this is that the change in population between two successive ages is not equal to the sum of net flows.

11 . Provide feedback

We welcome your feedback on the dynamic population model (DPM), our transformation journey, and our latest progress and plans. If you would like to contact us, please email us at pop.info@ons.gov.uk.

We have launched our local population statistics insight feedback framework, which enables users of population statistics to provide feedback at local authority level and suggest data sources for us to better understand the quality of our estimates.

You can also sign up to email alerts from the Office for National Statistics Population team for updates on our progress, and to hear about upcoming events and opportunities to share your views.

12 . Collaboration

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13 . Related links

Population estimates for the UK, England and Wales, Scotland and Northern Ireland: mid-2020
Bulletin | Released 25 June 2021
National and subnational mid-year population estimates for the UK and its constituent countries by administrative area, age and sex.

Population and household estimates, England and Wales: Census 2021, unrounded data
Bulletin | Released 2 November 2022
Census 2021 unrounded population and household estimates for England and Wales, by sex and single year of age.

14 . Cite this article

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