SUB-NATIONAL PROJECTION METHODS FOR SCOTLAND AND SCOTTISH AREAS: A REVIEW AND RECOMMENDATIONS

A Consultancy for National Records of Scotland, Edinburgh

Philip Rees[1], Pia Wohland[2], Paul Norman[1], Nikolas Lomax[1]

[1]School of Geography, University of Leeds, Leeds
[2]Institute for Health and Society (IHS) & Newcastle University Institute for Ageing (NUIA)
Newcastle upon Tyne, NE4 5PL

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EXECUTIVE SUMMARY

This report responds to a request for advice by National Records of Scotland (NRS) on how to adapt and improve the methodology used for the Scotland Sub-National Population Projections (SNPP). The 2014-based Scotland SNPP are currently being prepared.

The current state of Scotland's Sub-National Population Projections and future requirements

Section two of the report reviews NRS's current methodology and their requirement for improvement. NRS have three broad **requirements** linked to the Scotland SNPP: how should they integrate with the new model for the UK National Population Projections (NPP) being prepared by the Office for National Statistics (ONS), how might they improve the design of the SNPP in the light of developments elsewhere in official, academic and commercial SNPPs and NPPs and how should they develop consistent projections for sets of areas which overlap with the standard Council Areas used in the Scotland SNPP.

New developments in the National Population Projections

Section three of the report discusses the new methods proposed for the UK NPP by ONS. The new methods are based on recommendations in a 2012 review by Jakub Bijak (University of Southampton) on *Migration Assumptions in the UK National Population Projections* (Bijak 2012). The review recommended that both international migration and migration within the UK between Home Countries be explicitly represented as gross migration flows or rates in the NPP. ONS is implementing this recommendation in the 2014-based NPP. For internal migration between the four countries Bijak recommended adoption of a multi-regional cohort component model using out-migration rates, as used in the England SNPP. Bijak did not comment directly on how assumptions for the inter-Home Country migration rates might be set. ONS have explored the consequences of assuming constancy in those rates, finding that the trend toward a stable population system generated implausible migration balances between the Home countries. To prevent the population system being sucked into the "Black Hole" of stability, ONS draw on work by Patrice Dion of Statistics Canada that modifies out-migration rates by the changing population shares of destination, making them responsive to both origin and destination populations. We also discuss how Bijak's recommendation for probabilistic projections might be explored. However, the development of probabilistic projections for sub-national population projections is a longer term project, because the methodology is in its infancy.

The state of the art in sub-national population projections

Section four of the report reviews current practice in implementing SNPPs by a set of national statistical agencies covering England (ONS), Wales (WG), Northern Ireland (NISRA), Germany (BBSR), Canada (Statistics Canada), New Zealand (Statistics New Zealand), New South Wales, and Eurostat. We review a sample of models used in academic research: the original multi-regional model (Willekens and Rogers 1978), a multi-state generalisation (van Imhoff and Keilman 1991), a nested hierarchical model

(Kupiszewski and Kupiszewska 2011), a bi-regional model used with ethnic groups (Reeset al 2012b) and the multi-country model incorporating education from the Wittgenstein Centre, Vienna (Lutz et al 2014). Alternative approaches developed by local government (POPGROUP, Greater London Authority) are described. We conclude with a brief mention of consulting firm projection offers (CHELMER, EXPERIAN), though for these virtually no detail is available in public documents. A summary evaluation of the pros and cons of each approach is compiled. The review also discusses and argues for a different set of variant projections, which produce systematic estimates of the impact of the different component assumptions used in a projection (Rees et al 2013). These impact scenarios help answer precisely the user question: "what is driving the projection in my local area?"

A spatial framework for sub-national population projections

Section five of the report proposes a spatial population framework in which the official, academic and commercial SNPP models can be situated and in which recommendations about Scotland's SNPP can be placed. This framework shows how Scotland's SNPP is connected to the UK NPP and what information is needed to estimate those connections. A method for spatially decomposing the migration inflows and outflows from other Home Countries into Council Area flows, can be based on a UK wide local authority to local authority migration flow series developed in 2013 by Lomax and being currently refined. This needs to be supplemental by new estimates for each Council Area of immigration and emigration flows, drawing on administrative sources (NHS, DWP and HESA statistics) as well as the 2011 Census.

Projecting the populations for geographies other than Council Areas

Section six of the report discusses methods for these secondary projections. NRS plans to produce 2014-based projections for sets of areas which overlap Council Area boundaries. We recommend that these projections are achieved through geo-conversion of the Council Area projections, in order to maintain consistency. We discuss a general method for converting Council Area populations to alternative sets of overlapping areas, for which projections are needed for planning purposes. The method draws on recent census small area populations and the Small Area Population Estimates for data zones. The method ensures consistency of the projections across planning areas, Council Areas, Scotland and the UK.

Recommendations

Section seven of the report gathers together recommendations for developing the Scotland SNPP. These focus largely on the migration components as existing methods handle mortality and fertility components in a sensible way.

- We recommend using a multi-regional cohort-component projection model in which migration streams are explicitly recognised, moving on from the current single region and net migration approach.

- The migration streams for the model should include migrations between Council Areas in Scotland, between Council Areas and the other Home Countries and between Council Areas and the Rest of the World. The Scotland totals for these flows can derive from the UK NPP.
- We make suggestions about ways in which these flows to and from the rest of the UK and rest of the World can be allocated to Council Areas.
- The multi-regional model should cover the 32 Council Areas and the three other Home countries, making it a model for the whole UK. This would be informed by but not constrained precisely to the UK NPP.
- A constrained version of the projected populations could be easily generated, though it would be more complicated to constrain the components of change and maintain internal consistency.
- Within the UK out-migration rates should be used but adjusted for future years to reflect the role of destinations in determining projected out-migration flows (as in the NPP and Statistics Canada projections).
- For the international migration streams we recommend that assumptions for immigration and emigration flows separately be produced.
- The development of assumptions for the components should explore the combination of should continue time series analysis (e.g. using ARIMA models) with judgement (setting upper and lower limits to extrapolated trends).
- Variant projections can continue to be produced from the principal projection by factoring NPP variants to local areas.
- We strongly recommend the production of scenario projections which enable the estimation of the impact of component assumptions on the projected future populations.
- We agree with Bijak that a longer term goal should be to develop probabilistic projections but only after successful production of national probabilistic projections and demonstration in academic work that sub-national probabilistic projections can be produced.
- A radical revision to the NRS projection software will be needed to implement these new projection methods. So this is probably not feasible for the round of Scotland SNPP currently in production.

Our review of available software found many computer programs for projecting populations. Only the software package POPGROUP (used by NISRA and Statistics Wales) offered professionally maintained software. However, POPGROUP does not currently provide the ability to run a multi-level, multi-region projection model that we recommend for a future Scotland SNPP. There are many programs available written in a variety of software that could be adapted to run the model we propose. However, expertise in writing and adapting code would be needed within NRS or the task could be out-sourced to an expert consultancy such as Edge Analytics who maintain POPGROUP (www.edgeanalytics.co.uk) or Advanced Demographic Modelling who developed NEWDSS (www.advanceddemographicmodelling.com.au).

1 INTRODUCTION: REMIT

National Records of Scotland (NRS) are currently preparing the 2014-based Scotland Sub-National Population Projections (SNPP). NRS requires advice on how to revise their SNPP methodology in the light of innovations being introduced by the Office for National Statistics (ONS) in the 2014-based National Population Projections (NPP) for the United Kingdom, taking account of the best practice developed in research into methods of population projection. This advice is supplied by a team at the School of Geography, University of Leeds (the Leeds Team).

Esta Clark (Head of Population and Migration Statistics Branch, NRS) set out the specific aims of the consultancy project in an email (26 January2015) as follows. Sections of the report where they are covered are indicated in parentheses.

- To review and understand the **current SNPP method** (section 2).
- To provide an understanding of how the **New ONS NPP methodology** will impact upon the current SNPP method and system (section 3).
- Provide an **overview of other SNPP models** in use across the UK, abroad, and detailed in academic literature (section 4).
- Provide examples of models reviewed which meet the following **criteria** (sections 4, 5 and 6):
  - The model meets the practical requirements of NRS, such as **time/cost** to implement;
  - The model produces the **output** NRS requires;
  - The model has the option to be both **constrained** and **not constrained** to the NPP;
  - The model is **conceptually robust** and **transparent**;
  - The model can produce projections at **Council area** and **NHS Board** area level which are consistent with each other (section 6);
  - The model's robustness is sufficient to allow it to be extended to produce **SDP areas** and **National Park areas** consistent with Council area and NHS Board projections (section 6);
  - All projections produced by the model are **consistent** with each other.
  - The model is **trend based**.

The detailed structure of the report is set out in the Table of Contents Table A.1 lists the Scottish areas for which projected population are required.

Section 2 describes the current methodology used by NRS to produce sub-national population projections and reviews the requirements for improvement.

Section 3 reviews the programme of model and assumption revision being carried out by ONS, covering the methodological review of Bijak (2012) and the experiments testing his recommendations.

Section 4 of the report reviews current practice in implementing SNPPs by a set of national statistical agencies covering England (ONS), Wales (WG), Northern Ireland (NISRA), Germany (BBSR), Canada (Statistics Canada), New Zealand (Statistics New Zealand), New South Wales, and Eurostat. We review a sample of models used in academic research: the original multi-regional model (Rogers and Willekens 1978), a multi-state generalisation (van Imhoff and Keilman 1991), a nested hierarchical model (Kupiszewski and Kupiszewska 2011), a bi-regional model used with ethnic groups (Reeset al 2012b) and the multi-country model incorporating education from the Wittgenstein Centre, Vienna (Lutz et al 2014). Alternative approaches developed by local governments (POPGROUP, Greater London) and by consulting firms (CHELMER, EXPERIAN) are described. A summary evaluation of the pros and cons of each approach is compiled.

Section 5 develops a spatial framework that can be used to classify the examples reviewed in the previous section. This framework focuses mainly on ways in which migration is handled and the geographical units included in the projections. We characterise the examples as particular realisations of the general framework. We describe an expanded and improved spatial framework for a future Scotland SNPP model.

Section 6 deals with methods for producing population projections for different geographies. We argue that there should demographic projections for only one set of sub-national zones (Council Areas) and projection outputs for other geographies should be created through geo-conversion, using proxy variables with look down, look up and look across tables. These methods are independent of the model and assumptions chosen for the SNPP for Council Areas.

Section 7 of the report gathers together recommendations for developing the Scotland SNPP, including a check list of SNPP model features that explains the options available and our recommendations.

2 THE SCOTLAND SUB-NATIONAL POPULATION PROJECTION METHOD AND REQUIREMENTS

2.1 The Current NRS Scotland SNPP

This description is based on published documentation on the methods used for the 2012 round of the Scotland SNPP (NRS 2014a and 2014b) and the in-house document giving detailed instructions on content of the system's files and running of the software (NRS 2014c). To describe the current SNPP methods we use a schema developed by Tom Wilson (Wilson 2011), which identifies key issues that involved in the construction of a projection method. Table 2.1 provides a summary of the main features of the Scotland SNPP.

The methods and assumptions are described in the documentation in verbal form which sometimes leaves ambiguities. Full transparency needs an explicit account of the model variables and equations (as in Wilson 2011, Rees et al 2012b). For example, it is not always clear what age-time spaces are used for different variables. Age-time space refers to a graph of age against time (Rees 2008, see Appendix B figure). Demographic data, classified by time of occurrence and time of birth of participant, can be aggregated into four different age-time spaces: the period-age used for the mortality rates input to life table models; the period-cohort used in cohort-component projection for survivorship rates; age-cohorts used for life table mortality probabilities; and the age-period-cohort space used as a building block from which event counts for period-ages or period-cohorts can be obtained. In planning a new SNPP we recommend full specification of model equations and liberal use of age time diagrams.

2.2 The current Scottish SNPP software

The current main SNPP software Population Projections System (PPS95) was developed in 1995/96 and is Excel VBA based. All input files need to be supplied in Excel 1997-2003 format. In addition to the regular projections, the software allows the user to project populations including or excluding migration If migration is excluded, a natural increase only projection is produced. It also possible to calculate projections constrained to the ONS Scotland projections in UK NPP. With regard to migration procedures, the system is set up to use net migration flows. PPS95 consists of 7 VBA modules and a user interface. The VBA modules are well documented with each script also containing a description of its content (GROS 2010). and at many crucial points of the model comments are included to describe in words what was programmed in VBA. In addition, error tests and messages are included to warn and prevent users from making mistakes and helping to get the projections run.

A second part, which is called the migration phase of the projection, was added to the model in 2002 and amended for the last time 2005. This component is used to produce the net migration input data to for PPS95, that is, it disaggregates national net migration assumptions into SYA subnational net-migration. This part allows up to 7 time periods varying in migration assumption.

Table 2.1 Key issues in the construction of a population projection system: the current Scotland SNPP

Issue	Features of the current Scotland SNPP
Purpose	To produce 25 year projections of Council Area, Health Board, Planning Area and National Park populations in age-sex detail for use in Scottish national and local planning and to provide a resource for Scottish businesses, public agencies and researchers for use in their own work
Resources	Staff in the Population and Migration Statistics Branch of NRS
Populations	Usually resident population, Special populations (Armed Forces and Prisoners)
Age detail	Single year of age, with last age 90+
Time detail	Populations every mid-year, Components every mid-year to mid-year interval, from mid-year of most recent estimate for 25 years (e.g. my2012 to my2037
Approach	Macro-simulation, i.e. for aggregate groups for geographic zones, ages and sexes with associated demographic rates of mortality, fertility and migration
Geography	32 Council Areas, 4 Health Board Areas, 2 National Parks, 4 Strategic Development Plan Areas
Internal Consistency	Council Area projections are constrained to sum to the projected Scotland population, births, deaths and net migration total
External Constraints	Beyond the requirement that the Scotland SNPP total equals the Scotland NPP total, no further constraints are applied
Available Data	Full data sets at Council Area scale are available for populations (census and mid-year estimates), births, deaths, migration flows between Council Areas and estimates of total flows between Scotland and the Other Home countries
Migration Concept	Because currently migration is handled as total net in-migration plus net immigration, this question does not arise as transition migration data and movement migration data should yield the same net migration.
Internal migration model(s)	Handled as net flows
International migration model(s)	Handled as net flows
Model computation scheme	A sequential scheme is used (see p4 in NRS (2014a). However, it is not clear that this ensures that mortality rates and fertility rates are multiplied by the correct population at risk. Are these rates multiplied by the start of interval population or by an average population for the time interval? When using event data, the nearest approximation to the person-years of exposure should be used.
Model specification	By implication, a piecewise linear assumption is made. Because single year ages and time intervals are used, this assumption has very little impact.
Programming	The software used is Excel 2003 version workbooks, with some VBA (Visual Basic) and SAS (Statistical Analysis System) routines
Formulation of assumptions	The assumptions are specified using the total fertility rate, life expectancy and net migration flow, based on the 5 year average with net migration between Scotland and the rest of the world scaled to NPP totals. These are translated to Council Area level using local adjustment factors based on a standardization procedure (local events for all sage/the sum over age and sex of expected events based on multiplication of a local population at risk by Scotland level age-sex specific rates).
Deterministic or probabilistic	A deterministic model is used
Projection outputs	These are detailed and readily available. But there is scope for publishing more detail in the form of age specific components of change for Council Areas
Reviewing outputs	Previous projections are reviewed against population estimates and components of change for two years since the last projection.

File name conventions are important in signalling file contents to the user of the projection system. Currently file names are written in capital letters, in lower case letters or in mixed cases. This does not relate to whether they are input or output files. For future we would recommend that better file name conventions be developed. For example, input file name could be in lower case, output file names could be in upper case and intermediate file names in mixed cases.

The current system has many positive aspects, already mentioned above: it is very well documented and reasonably user friendly. On the downside, the system is based on Excel 1997-2003, which is an "aged" version of that software. Use of Excel 2013 would provide access to a much larger number of columns in sheets and many useful enhancements. In the most current version of the Scotland SNPP, some input files are created by SAS. If a new internal migration methodology and other improvements are implemented, we would recommend that NRS develop a new system. This system should keep the positives of the current system – good documentation, user friendliness and mortality and fertility routines largely unaltered. But the development should be done in one or two up-to-date software packages. We would not advise trying to adapt the current projection system to make the recommended methodological changes.

3 NEW METHODS TO BE USED IN THE 2014-BASED ONS NATIONAL POPULATION PROJECTIONS

3.1 The Bijak Methodology Review

This review has been and continues to be highly influential in ONS thinking about projection methods. The review was written by an expert demographer/statistician at the University of Southampton, Jakub Bijak, who won the 2014 Allianz Prize for the most promising young European demographer. This section of the report describes and interprets the main recommendations of Bijak (2012).

3.1.1 The Bijak review focuses on National Population Projection methods

The review focusses on national rather than subnational projections. NRS are already involved in discussions and decisions about the National Population Projections (NPP) led by ONS and also involving NISRA and WG. However, the decisions taken about the national model have repercussions for sub-national population populations. The totals of national immigration or national emigration need allocation to sub-national areas in two steps: (1) from the UK to the Home Countries (e.g. Scotland) which is effected in the NPP and (2) from the Home Countries to local areas (e.g. Scottish Council areas). For England the method for estimating sub-national immigration from national was thoroughly revised by switching to use of administrative data proxies rather than relying on two samples – the International Passenger Survey and the Labour Force Survey (ONS 2011). This built on work by Boden and Rees (2010b), carried out as part of the ETHPOP project. The estimation of local authority emigration relies on a model with determinants that include immigration in previous years and internal out-migration (ONS 2010a, Turner 2014). The 2011 Census provides a good check on the immigration allocation method.

3.1.2 Getting international migration forecasts right is difficult but very important

The problem with immigration and emigration forecasting is acute at the national level, where almost sole reliance is placed on the International Passenger Survey. There are now some recent international estimates of country to country international migration within Europe (the MIMOSA project, led by James Raymer and Joop de Beer; the IMEM project led by the University of Southampton) and at world scale by the Wittgenstein Centre (Abel and Sander 2014). Disney (2014) has explored the use of administrative sources such as the DWP NINo statistics, registrations of NHS new immigrant patients, the HESA foreign student statistics and compared his synthetic estimates with IPS based estimates. The results were not encouraging. One source that Disney did not use was Home Office Visa statistics. These do not cover all migration streams (e.g. EU immigrants, returning British immigrants) but are based on full counts of the streams covered. There are also some estimates of the likely size of the illegal immigrant stock. In future, the Home Office may succeed in implementing the e-Border system for tracking the entries and exits of all passengers into and out of the UK. Exploration of these estimates and data sources might yield better estimates on international migration.

3.1.3 The Bijak review recommends that the NPP be based on a four home country multi-regional model

ONS has largely accepted this recommendation as producing a better and more coherent model for England, Wales, Scotland and Northern Ireland. They have developed a time series of inter-Home country flows and are testing out various methods for forecasting the inter-Home Country out-migration rates. The basic argument for the multi-regional model is that it allows the changing population at risk of migration to influence the projected flows. However, most applications (including ONS's SNPP) have only assumed these inter-region migration rates to be constant into the future. Although many researchers have shown that the structure of inter-regional migration is fairly stable over time, small changes can be important when applied over several decades.

3.1.4 The Bijak review recommends that emigration flows are projected by multiplying a population at risk by an emigration rate

Here we think the arguments in the Bijak review are weak, even though we adopted this suggestion in one of our ETHPOP projections (Rees et al 2011, 2012b). ONS are investigating whether this suggestion produces plausible results. Our work showed that because the UK population is increasing, use of a model in which emigration rates are fixed leads to rising emigration volumes. However, in the last decade emigration does not show rising numbers associated with population growth, which indicates that controls and constraints are at work at destination countries. This is an argument against using constant emigration rates.

3.1.5 The Bijak review recommends time series based assumptions rather than argument based assumptions in deterministic projections

Bijak also criticises the time series method (exponential smoothing), preferring an ARIMA (Auto-Regressive Moving Average) model. By argument based he is referring to the work of Wolfgang Lutz and colleagues at the Wittgenstein Centre (VID/IIASA/WUE) in a succession of world region and most recently world country projections (Lutz et al 2014). This argument based method was adapted and applied by Shaw (2008) for gathering the views of the UK National Population Projections Expert Panel. Views were solicited from the panel which affected judgement based assumptions for the 2008, 2010 and 2012 NPP and were used to produce experimental probabilistic projections centred on the 2008 NPP.

3.1.6 The Bijak review recommends that probabilistic projections replace variant deterministic projections as the main method of measuring uncertainty in projection

Later in his review, Bijak reintroduces expert views in his proposal for probabilistic projections based on a Bayesian method, which he claims is capable of integrating expert views and the evidence of time series data. This partially contradicts his earlier view about deterministic projections. Note that even when probabilistic projections are produced, it is necessary to generate a principal projection trajectory around which uncertainty/confidence bands can be built.

Bijak is correct that many national statistics agencies now run probabilistic projections. The methodology is challenging but feasible for a few regions such as the four home countries that constitute the UK NPP system. Choices need to be made between frequentist methods (e.g. Statistics Netherlands 2005, Lutz et al 2004) and Bayesian methods (the latest World Population Prospects from the UN, discussed in Gerland, Raftery et al 2014). Note that the WPP probabilistic projections are useful only for countries where international migration makes a negligible contribution to population change. The reason is that only the mortality and fertility components of country projections are treated stochastically; international migration is still handled using the deterministic net migration model with its assumption of convergence to zero net migration after a few decades. Such a scenario would only be possible under conditions of income equality between countries and equality in the rate of natural increase. In other words, "pie in the sky".

We would definitely support continuing work by ONS in collaboration with demographers and statisticians in leading university research centres to develop a plausible methodology for establishing the uncertainty around future NPP principal projections. It is much more useful to use a sequence of population values with modelled positions on the probability distribution than to arbitrarily choose a given high migration variant to build, for example, a forecast of future economic growth (OBR 2014 – citation needed). The OBR were using expert judgement as to the likely future population (and one with a faster growing labour force and higher GDP).

However, it must be an absolute requirement of such work that is explained in way that both ONS and users can have confidence in. Accounts of methods reported at conferences and in many papers indicate that current practice falls far short of such a requirement. Researchers have to spell out their methods fully and explicitly and subject their results to critical review. If you compare, for example, the future confidence bands around many probabilistic projections with historical outcomes, these outcomes can drift quickly beyond the upper (95%) or lower (5%) confidence limits (Rees evidence presented to the Filkin enquiry in House of Lords 2013). As with deterministic NPP, there is no substitute for frequent revision in the light of recent events.

3.1.7 Can Bijak's view of the desirability of probabilistic projections be extended to Sub-National Population Projections?
There is far less experience in developing probabilistic projections at sub-national level. There are only a few successful models: the Italian National Statistical Office projects the provincial populations of Italy (Billari et al 2014) and Statistics New Zealand (Dunstan 2011). Probabilistic projections by academics include, Wilson and Bell (2004)'s projection of the population of Australia and Abel et al (2010) Bayesian series forecasts for England and Wales. The main area of research needed is into the uncertainty of the migration variables and whether to link together the sampling of components picking error levels with the

same direction of influence on the population outcome (e.g. high fertility probability + low mortality probability + high immigration probability + low emigration probability). Note that this list has not included migration variables internal to the system about which there is debate.

Should NRS invest effort in developing probabilistic versions of the SNPP? In the long run, we think the answer should be yes, but only once official or academic researchers have demonstrated that plausible probability outcomes can be produced for systems of interest with large numbers of areas and complex combinations of migration variables. This route cannot be successfully negotiated in time for implementation for the 2014 based Scotland SNPP but should be considered for a longer term work programme.

3.1.8 The Bijak review recommends a decision support system to help users cope with uncertainty

This is a sensible recommendation, but there is a singular lack of examples in the population field. Decision support systems are often developed by consultancy firms to supply expertise in different planning fields. What is needed is not a downloadable software package but instead a set of worked examples of how decision makers can use different confidence bands or cumulative probability levels for the population. In developing probabilistic projections it would be useful to engage with potential users in the Housing, Education or Business area and work with them to develop the applications.

3.2 The New ONS Methodology for the National Population Projections 2014

ONS are not taking the recommendations at face value but are experimenting with some of the suggestions made by Bijak (2012), notably the employment of internal out-migration rates to project the migration flows between UK home countries and the use of emigration and immigration rates. Bijak seems to have assumed that one alternative for modelling migration suggested in our ETHPOP work such be adopted. Wisely ONS have explored the suggestion along with other alternatives rather than simply accept some theoretical arguments. The work on the migration methods to be used in the 2014-based NPP are discussed in ONS (2014a-2014f) and in ONS (2015). An overview of this work was presented by Leather (2013). ONS were concerned that their initial experiments with a multi-home country model for the NPP using constant inter-Home Country migration rates produced projected populations for the Home Countries other than England which were too large, because such a migration assumptions redistributes population towards its theoretical stable distribution. We discuss these issues in later sections of the report.

4 REVIEW OF SUB-NATIONAL POPULATION PROJECTION MODELS

This section of the report reviews a variety of sub-national population projection models, drawing from the practice of national statistics agencies in the United Kingdom (ONS 20110b) in sub-sections 4.1, 4.2 and 4.3, and outside the UK in sub-sections 4.4, 4.5, 4.6, 4.7 and 4.8. Models and projections produced by research teams at universities or research centres are described in sub-sections 4.9, 4.10, 4.11 and 4.12. We then review models and software developed for local government use in the UK. The section concludes with an evaluation of alternative models and software for potential use in Scotland sub-national projections.

4.1 Official Sub-National Population Projection Models: England

4.1.1 Context

The ONS produces the single year of age and sex sub-national population projections for 326 local authorities (LAs) in England using the cohort component model (ONS 2014f). The LA projections are used to produce projections for English regions, counties and Clinical Commissioning Groups. The projections are trend based, using assumptions drawn from the previous five years of evidence (six for international migration). LAs and other users are invited to comment on the migration assumptions, but not on fertility and mortality. The total SNPP is controlled to the principal national population projection (NPP) for England in each given year of the projection. SAS is used to run the SNPP model.

4.1.2 Fertility assumptions

Fertility assumptions are based on ASFRs for the previous five years, calculated using data on registered births by age of mother (15 to 44) and sex of child for each LA (mid-year to mid-year) as the numerator. The denominator is derived from the mid-year population at the end of the period. The national ASFR is calculated in the same way for England. The sum of the five year ASFR for each LA is divided by the national ASFR to provide an average differential. This differential is applied to the national ASFR in the NPP to calculate local ASFRs for the SNPP, which is then applied to the population at risk in the LA for the given year. The sex ratio for the projected births is assumed as 105 boys for every 100 girls. LA fertility rates are capped at five times the national fertility rate and the fertility component is constrained to the NPP.

4.1.3 Mortality assumptions

Mortality assumptions are generated in a similar fashion to fertility. ASMRs by sex are produced using five years of data for each LA and also nationally. A ratio is derived by dividing the sum of the LA five year ASMR by the sum of the national five year ASMR. This ratio is used in a given year of the projection to derive the LA ASMR from the national figure, which is then applied to the population in the LA by age and sex. LA rates are capped at no greater than five times the national rate and the mortality component is constrained to the NPP.

4.1.3 Migration assumptions

Migration assumptions are produced for three migration components in the SNPP: internal (within England) cross-border and international. For internal migration, out-migration rates (by single year of age and sex) are calculated using flow estimates derived from NHSCR and HESA data and the population in the LA. Areas with small flows are adjusted and all outflows are allocated a destination. Internal in-migration flows are calculated as the sum of all out-migration from other local authorities to that area. The cross-border component assumes a five year average is held constant for the whole projection period. For international immigration, an average six year inflow is calculated. Emigration is calculated using a six year average, using weights based on national and regional data. For both immigration and emigration, the average is held constant for the projection period. The cross border and international components are adjusted to ensure that they are consistent with the NPP by sex and single year of age.

4.1.4 Special populations

The armed forces personnel are handled as *Special populations:* military populations are removed before the projection model is run and added back in at the end.

4.2 Official Sub-National Population Projection Models: Wales

4.2.1 Context

Sub-national cohort-component projections are produced by the Welsh Government for the 22 LADs (Unitary Authorities) in Wales. Projections for Welsh LADs have been published using mid-year 2006, mid-year 2008 and mid-year 2011 base populations. A projection for Wales as a whole was produced based on 2012 mid-year populations but the next SNPP for Wales are likely to be 2014-based. There was a concern that trends for local government populations in Wales were diverging from those in NPP and the Welsh Government invested resources in developing its own sub-national projections. Subsequently, sum of Welsh Unitary Area projections have turned out to be close to NPP results for Wales and the small differences are no longer a concern (Whiffen 2014). The projected populations for Welsh LADs are not forced to add up to the NPP projection for Wales. In preparing the assumptions for the Welsh SNPP, Statistics for Wales consult with the Wales Sub-national Projections working group (WASP) and a Projections Stakeholder Group.

4.2.2 Methodology

The methodology for the Welsh sub-national projections is set out in a detailed and well-argued technical report (Statistics for Wales 2013a). The accounting framework used follows the general scheme used for population estimates used by ONS for England, which distinguishes special populations (Armed Forces and Prisoners). Independent projections of LAD armed forces and prisoner populations are produced, subtracted at the start of each annual projection interval and then added in at the end. For the "nonspecial" population, a standard single-region cohort-component model is used but with migration handled as four gross migration streams: internal inflows, internal outflows, international immigration flows and international emigration flows (Statistics for Wales 2013b). The model uses age-specific rates of migration with the LAD population as denominator for all four flows. So the out-migration rates are transmission rates and the in-migration rates are admission rates (see section 5.3). There is a mismatch in the model specification between the populations at risk used as denominators in estimating the historical rates and as multipliers in computing the projected flows. This point was made in a review of the Welsh 2008-based SNPP methodology (Rees 2009). The software used is POPGROUP, licensed from the Local Government Association through Edge Analytics (Peter Boden 2015). POPGROUP is based on Excel spreadsheets combined with VBA Macros (see section 4.13).

4.2.3 Variant projections

One innovation introduced in the Welsh SNPP 2011-based projections is the production of variant projections, which have long figured in UK NPP but not in SNPP. Statistics Wales (2013b) generate four variants, two concerned with variation in natural increase components and two concerned with migration. The motivations for producing variants is to indicate the uncertainty in the projections, though an alternative approach is suggested by Bijak (see section 3.1.6). The Lower variant assumes Low Fertility and Low Life Expectancy, probably based on the NPP equivalents for Wales, though this is not made explicit in the documentation. The Higher variant assumes High Fertility and Life Expectancy. In both these projections, the migration assumptions are as adopted in the Principal projection. The potential variability of migration in the future is indicated in the Zero migration variant, which assesses the role of natural increase only in influencing the future population, and a ten year average migration variant, which combines the "fat" years of the early and mid-2000s and the "lean" years of the Great Recession from 2008 onwards, when migration out of the Greater South East to peripheral regions of the UK was muted (Lomax et al 2014).

4.3 Official Sub-National Population Projection Models: Northern Ireland

Sub-national cohort-component single year of age and sex population projections in Northern Ireland (NI) are produced by NISRA. The methodology and demographic assumptions (NISRA 2014) are consulted on and agreed by members of the Northern Ireland Census Advisory Group (NICAG). The projections are computed using POPGROUP software. Projections are generated for the previous 26 Local Government Districts (LGDs), associated aggregate regions (Health & Social Care Trusts, Education & Library Boards and NUTS3 regions) and the 11 new LGDs current from 1 April 2015. Where demographic trends from the recent past are used to inform ongoing assumptions, NI has generally used six years of evidence but is reducing this to five, in line with practice in the rest of the UK. Detailed age-specific fertility and mortality evidence for LGDs is not used because of small number of events (except in Belfast) which can lead to wide confidence intervals.

The *fertility assumptions* by LGD are computed differently from elsewhere in the UK's official SNPP. Single year of age fertility rates for Northern Ireland as a whole are scaled by the ratio of LGD Total Period Fertility Rates to the NI level (recent trends). Thus, the overall level of fertility at local level is accounted for but not any differences in age-specific fertility. This information is available for a back time-series to reveal trends which could readily be used to enhance future ASFR trends by LGD. *Mortality assumptions* are produced by scaling Northern Ireland level single year of age mortality rates (to 90+) by the ratio of LGD Standardised Mortality Ratios (SMRs) to the NI SMR (recent trends). Again, the data to calculate a back time-series of age-specific mortality trends exists which could be informative. For the 2012 based projections, three broad age groups by sex will be used to scale NI rates to LGD level. *Migration* is treated as two components: international combined with UK cross-border and within NI inter-LGD migration. At NI level, only net migration is projected. At local level, gross flows to and from each LGD are used, calculated as the average of the flows from the last four years, with the recent years weighted more than the earlier years. Age-sex information for LGDs is informed by the last complete year's data.

To date, the age-sex structures of student and armed forces populations have been held constant with planned closures of barracks and related changes taken into consideration. From the 2012 based projections, HESA data will be used to inform recent migration flows so there will be no special treatment of student populations.

4.4 Official Sub-National Population Projection Models: Germany

4.4.1 Responsible agency, geography and approach to assumptions

Official sub-national population projections in Germany are produced by DESTATIS (*Statistischesbundesamt*/Federal Statistics Office) co-ordinated with the German states (DESTATIS 2009a, 2009b, 2009c). Projections are produced in irregular intervals. Official sub-national projections are produced for 16 states (*Bundesländer*). Each state has on average a population of 5 million, varying from 650 thousand (Bremen) to over 17 million (*Nordrhein-Westfalen*). As a result of the German federal system each *Bundesland* in turn produces smaller area estimates for local governments (*Kreise* and *Kreisfreiestaeadte*). Overall, there are just above 400 of these local authorities across Germany. These more local government projections within each state are not necessarily constrained to the official DESTATIS projections. In case a projection for these local governments is needed the BBSR (*Bundesinstitut für Bau-, Stadt- und Raumforschung*/Federal Institute for Construction, Urban and Planning Research*)* produces projections by Kreis and Kreisfreiestaedte (BBSR 2015). For the purpose of this report, we will only focus on official projections. The latest projections for Germany were published in April 2015, the last projections for the 16 states were published 2009 and were 2008 based. Populations are projected by single year of age up to the age 100+ from the 31st of December, to end of the following year.

4.4.2 Fertility assumptions

Fertility rates by single year of age for women between 15 and 49 are implemented with a new born sex ratio of 1.0563 boy babies to 1 girl babies, in the latest state projection (2008 based). Fertility assumptions are made by extrapolating past trends. Trends are used for states in two groups, the Eastern states and the Western states and not for each state separately. Assumptions are based on an assumed TFR and age at first birth. For the medium variant, a TFR of 1.4 is considered and the age of first birth is assumed to increase (Pötzsch (2010).

4.4.3 Mortality assumptions

Mortality assumptions are extrapolated from past trends. Assumptions on future life expectancy at birth and age 65 are translated into mortality age schedules. In constructing the life tables that produce survivorship rates, the ratio of infants who died in the first 6 month of their life to infants who died throughout the year is calculated. In 2008 this ratio was 0.90 for boys and 0.89 for girls.

4.4.4 Migration assumptions

International migration is handled as a net migration flow by age and sex, which is calculated as inflow minus outflow. A total net migration number (either 100,000 or 200,000) is applied long term. For some states internal migration has a more pronounced impact on their demography compared to international migration (DESTATIS, 2009a). Assumptions for internal migration are only made for 10 to 20 years into the future. Trends of out-migration rates are kept constant to the observed rates over the last three years for about ten years, then decline for further 10 and fall to zero afterwards. From the model description, we assume a multi-regional model is applied.

4.5 Official Sub-National Population Projection Models: Canada

4.5.1 Responsible agency, software, geography and approach to assumptions

Official sub-national population projections in Canada are produced by Statistics Canada (2010, 2014). Sub-national refers to Canadian provinces (10) and territories (3). The overall population of Canada was over 35 million in 2013 and provinces and territories vary considerably in population size. They contain on average 2.7 million people each but range from 13.5 million in Ontario to just 35 thousand in Nunavut (Arctic Canada). Statistics Canada uses a cohort component model to project the population into the future. Projections are from mid-year to mid-year. The national projected number of population is summed up from using subnational population projections (a bottom up approach). Compared to previous work (projections 2009-2036), statistics Canada has implemented several new approaches and methods which include extensive consultation with demography experts, new methods for projecting fertility and interprovincial migration and an improved method of projecting mortality. Wherever possible, Statistics Canada investigates past trends, international trends and opinion survey data to achieve best assumptions to be implemented in their projections. For each component a low, medium and high projection assumption is developed.

4.5.2 Fertility assumptions

Fertility trends have been somewhat volatile in the recent past in Canada. The Lee-Carter method is used and adapted with a reference period of 10 years and ASFRs are kept constant afterwards. Assumptions are developed on the national level as an intermediate step to develop provincial and territorial assumptions, reflecting both Canada wide and provincial and territorial TFR assumptions. Different assumptions are implemented for non-permanent residents.

4.5.3 Mortality assumptions

Longer term time trends of about 30 years are used to develop mortality projections. In some territories small number issues and missing data lead to reliability problems at ages 80 and over. On these occasions, strength was borrowed from all Canada mortality trends, but mortality trends were adjusted to reflect territory life expectancy at birth. Age specific mortality rates are developed up to the age 110+. The overall resulting life expectancy at birth is not predefined but the result of the process of extrapolating mortality rates.

4.5.4 Migration assumptions

Internal migration assumptions are also discussed in more detail in section 7.3. For international migration provincial and territorial immigration rates are developed. As the initial distribution of immigrants to the different regions is based on self-reported intention to settlement, these numbers are adjusted using additional information from other studies study as well. Emigration is distinguished into emigration, returning emigration and net temporary emigrants. Unlike immigration, emigration is not well recorded in Canada, but on the other hand is currently low. Emigration is also treated as rates. For both Immigration rates and Emigration rates the population at risk is the one in each province or territory.

Statistics Canada has implemented several changes in their projections over recent years. NRS might wish to consult with Statistics Canada to find out how long the new implementation took and whether they developed a new system or managed to adapt an existing one. Canada's experience is a case to be learned from.

4.6 Official Sub-National Population Projection Models: New Zealand

4.6.1 Context

Statistics New Zealand produces population projections for 16 regional council areas, 67 territorial authority areas and 21 Auckland local board areas by single year of age and sex using a cohort component model (Statistics New Zealand 2015a, 2015b). Separately, an area unit projection (of which there are 1,927) is also produced by five year of age and sex. Here the assumed rates are consistent with the higher geography (territorial authority).

4.6.2 Fertility, mortality and migration components

Fertility rates are based on registered births in the previous five year period. The derived ASFR is applied to the base population in each year of the projection. The sex ratio applied to the projection is 105.5

males per 100 females. *Mortality rates* are based on registered deaths for each area in the previous five year period by age and sex. The assumed age-sex specific survival rates are applied to the base population in each year of the projection. *Migration* is comprised of two components: internal (to/from the rest of New Zealand) and external (to/from overseas). These components are only considered as net migration in the projection model. The age-sex patterns are based on inter-census patterns (1981-2013 in the 2013 base) and the National Population Projections.

4.6.3 An ethnic group projection

An *ethnic group projection* is also produced for a shorter time period, by five year of age and sex for selected regions and territories by different ethnic group. The same method is used with two additions: (1) births are projected for men where the mother is not of that ethnic group (to account for births to parents with different ethnicities) and (2) allowance is made for people changing their ethnic identification over time.

4.7 Official Sub-National Population Projection Models: New South Wales

4.7.1 Context

The New South Wales (NSW) Department of Planning developed for its 2008 population projections a new model which has many new features, relevant for the further the development of a Scotland SNPP (Wilson 2011). What is pretty unique about these projections is the detail of the methodology report prepared by Tom Wilson, who was NSW's principal demographer. This can serve as the template for drawing up the specification for further development of the Scotland SNPP. The model continues to be used to produce projections for NSW regional and local areas (NSW 2015a, 2015b).

4.7.2 A systematic account of the issues/decisions in population projection

Wilson (2011) lists clearly the suite of decisions that must be made about the system of interest, the demographic models to be used and the strategy for designing assumptions. Table 4.1 sets out Wilson's scheme, with some minor modifications.

4.7.3 The multi-level, multi-regional projection model

The NEWDSS report describes how projections are implemented at three levels: the State (NSW), regions (13 planning areas) and 199 local zones (Statistical Local Areas)., the report describes in full the mathematical equations that drive the projections. This is rare in official agency publications but is essential for full transparency and open peer review of methods. The objection to this approach is that few people have the capacity to read and check equations. Unfortunately, verbal descriptions of models are often ambiguous. Since most official publications are now published online only, the cost of such technical documents is mainly the labour of authorship. In section 7 of the report we draw on Table 4.1 to organize this review's recommendations.

4.7.4 Matching the projection model to the type of migration data used

The NSW projection system adopts different answers to Table 4.1's questions depending on the spatial scale. For example, a movement approach is used at State and Region level, but switches to the transition approach in the SLA projection models. The reason is that censuses in Australia are administered every five years and ask a migration question about prior residence 5 years earlier. In the UK only measures of migration for the one year interval prior to the census are available, so that it is essential to use NHS Register based patient migration information. However, the current method of extracting this information produces a transition measure. So an alternative challenge in the UK is how to estimate the movement equivalent of the available transition measure because that is the approach used in UK SNPP models (see Raymer et al 2012).

4.8 Official Sub-National Population Projection Models: Eurostat

Eurostat is the Statistical Office of the European Communities, responsible for assembling economic, demographic, social and environmental statistics on behalf of the European Union member states. Unfortunately, the quality of regional population projections has deteriorated radically over time as a result of serious financial malpractice at the Statistical Office in the later 1990s and early 2000s (BBC 2003, Mahoney 2003). As a result a sequence of innovative Europe wide regional population projections with rounds in 1980, 1985, 1990 and 1995 came to an end. These projections had been out-sourced to a variety of Dutch Research Institutes and have been reviewed in Kupiszewski and Rees (1999) for Eurostat prior to the breaking of the scandal. Since 1995, only one round of regional projections has been produced by Eurostat. Giannakouris (2010) describes the assumptions and results for EUROPOP2008 but says little about the underlying model. It is likely that the EUROPOP1995 method was employed. Inter-regional migration within each country was projected using out-migration rates applied to origin region populations along with conventional regional fertility and mortality calculations. International migration into EU regions was represented as net migration flows. Radical improvement in the projection methods and results for the NUTS2 regions of European Union member states was later achieved through the European funded DEMIFER project (see section 4.10).

4.9 Academic Sub-National Population Projection Models: SPACE, LIPRO

Two sub-national projection models which use a multi-regional (multi-state) mathematical approach are summarised in this section: SPACE (Willekens and Rogers, 1978) and LIPRO (Van Imhoff and Keilman 1991). These models present the advantage of being able to deal with in- and out-migration (not just net migration) to and from all other regions in the projection.

Table 4.1 Key issues in the construction of a population projection system

Issue	Questions and remarks
Purpose	What is the purpose of the projection system? Which information is required? Which is the most important?
Resources	What budget and expertise are available to construct the system? What are the time frame and the deadlines? Should the work be done in-house or should the work be out-sourced? Which staff members are available to implement or to manage the new model? What are their skill sets (in particular, statistical, mathematical, programming and document writing)?
Populations	Usually resident or present populations? Any special populations: military, long stay hospitals, prisoners, communal establishment populations such as students or frail elderly?
Age detail	Will one year or five year age intervals be used? What should be the starting age of the final open-ended age group? [The age and time intervals must be the same and uniform, apart from the final age.]
Time detail	Will one year or five year time intervals be used? What should be the last time interval for which projections are produced? [The projection horizon]
Approach	Macro-simulation, micro-simulation or a mixed approach? Macro-simulation uses population groups. [Micro-simulation uses individual population members.]
Geography	Which geographical areas are to be included? How many levels of geography will be modelled?
Internal Consistency	If there is more than one level of geography, how will the projections be made consistent between levels? Top down or bottom up? Will just populations be made consistent or will demographic components of change also be made consistent? [Top down means regarding the most spatially aggregate projection as the most reliable and controlling projections at lower levels to top level projection. If components are to be made consistent, further modelling may be necessary. Bottom up means the most spatially detailed projections as the most probable and creating projections at higher levels through aggregation of both populations and components.]
External Constraints	Will the model incorporate a facility to constrain to external demographic components or populations or to related variables such as housing developments or employment changes?
Available Data	Which data are available? How detailed is the spatial and age disaggregation? How long a time series, prior to the projection start, is there? Do indirect estimation methods need to be employed to 'fill in' missing data or make adjustments?
Migration Concept	Will a movement or transition migration concept be used in the modelling (or both)?
Internal migration model(s)	What sort of internal migration model is best? The options include: fully multi-regional, bi-regional approximation, partitioned, migration pool, other directional migration models, net migration model.
International migration model(s)	How will international migration be modelled? Will international migration be treated as one stream or as multiple streams? [The options include: immigration flows and emigration flows, immigration flows and emigration rates, immigration rates and emigration rates, transmission or admission rates, net migration flows, net migration rates.]
Model computation scheme	Simultaneous, sequential or iterative computations?
Model specification	Should component rates be piecewise linear by age or exponential by age?
Programming	Which programming language should be used to operationalise the model? [Options include a general purpose language (FORTRAN, C, Pascal etc) or a "statistical" language (R, SAS, EXCEL)]
Formulation of assumptions	What variables will be used to set "headline" assumptions? What methods will be used to formulate assumptions? [Options include: time series analysis/extrapolation, projection author expert judgement; survey of experts through questionnaire.]
Deterministic or probabilistic	Will the modelling be deterministic or probabilistic?
Projection outputs	What projection outputs are required (linked to the purpose)? How will the outputs be presented? What format(s) do they need to be written out in?
Reviewing outputs	What measures will be used to assess the plausibility and consistency of preliminary projection results?

Source: Adapted from Wilson (2011)

4.9.1 The SPACE model

Written in FORTRAN, the SPACE model is a multi-regional projection model. The regional populations for each age are set out in a vector, which is multiplied by a growth matrix based on mortality rates, fertility rates and out-migration rates with net international migration rates or flows. In a bi-regional model, in-migration and out-migration are accounted for separately, between each region and every other region. In the multi-regional formulation, specific origins and destinations (i.e. other regions) can be accounted for. Internal migration and international migration can be treated separately in the multi-regional model (although the specified SPACE model takes little account of international migration and in applications net international migration admission rates are used). Some knowledge of matrix algebra is needed to understand the mathematical presentation of the multi-regional model.

4.9.2 The LIPRO model

The multi-regional model is generalised as a multi-state projection model in the LIPRO (LIfestyle PROjections) model and software. The model was designed to produce household projections but can be applied to a range of multi-state demographic projections. It was written in Borland Turbo Pascal and is supplied but not maintained by the Netherlands Interdisciplinary Demographic Institute (NIDI). Individual characteristics used in the model include age, sex and a person's position within a household (e.g. 'cohabiting with one or more children') while the household composition is also defined (e.g. 'a one person household'). Births and deaths can be accounted for, while in- and out-migration are treated separately. The model not only takes in to account the underlying demographic change, but also household composition, where individuals transition from one state to another, for example from unmarried to married.

4.9.3 A marital status application for England and Wales

To exemplify this, the software has been used to produce marital-status projections for England and Wales by the ONS (2010c). For these projections, the inputs comprised marriage, divorce, new widower rates and marital status specific mortality rates, by single year of age and sex, as well as a set of cohabitation assumptions. Within the model, people 'transition' from one state to another, with internal constraints (males divorcing equals females divorcing; males dying equals females becoming widowed, etc.). All projections are also constrained to the NPP populations by age and sex.

4.10 Academic Sub-National Population Projection Models: MULTIPOLES, DEMIFER

4.10.1 The multi-level, multi-region model

Kupiszewski and Kupiszewska (2011) set out the design of a model that projects the populations at more than one spatial scale simultaneously. MULTIPOLES stands for "MULTIstate Population Model for MultiLEvel System"s. The model handles inter-regional migration within each country in a system of interest, inter-regional international migration between the countries in the system and migration between regions in the countries of interest and the Rest of the World. A full mathematical description of the projection is provided by the authors.

4.10.2 The DEMIFER application

The model was used in a study of 27 European countries in Kupiszewski (2013) and in a major Europe wide project, DEMIFER (Demographic and Migratory Flows for European Regions) for 27 European countries and their 287 NUTS2 regions (De Beer et al 2010). Reasonable data are available for inter-regional migration within most European countries and estimates have been made of consistent inter-country migration within the European Union in the MIMOSA project (Raymer et al 2010) and in the IMEM project (Raymer et al 2013). However, the model requires estimates and assumptions for inter-regional migration between countries, for which few specific data are collected. It is necessary, therefore, to model the assignment of regional out-migration to EU countries to specific countries and then to regions within destination countries. Kupiszewski and Kupiszewska (2011) use population shares of origin and destination regions in the absence of better information. For the projection of Scottish sub-national areas within a four home country United Kingdom better information is available from the 2001 and 2011 censuses and LAD to LAD migration estimates for the UK for the years between (Lomax 2013).

4.10.3 The reference scenarios

In the DEMIFER study the MULTIPOLES model was used to project European region populations under three reference scenarios (Kupiszewski and Kupiszewska 2010a, 2010b) and four policy scenarios (Rees et al 2010a, 2010b). The reference scenarios assumed respectively the Status Quo (continuation of 2005-10 component rates without change), no Extra-European Migration and No Migration (equivalent to a Natural Increase only projection). The reference scenarios were used to measure the impact of migration from outside Europe and within Europe on future populations. We show in Appendix C how this approach can be extended to all components via impact scenarios for use in Scottish projections.

4.10.4 The policy scenarios

The policy scenarios link national or EU health, social-economic and demographic policies with potential future component assumptions (Rees et al 2012a). The scenarios reflect two axes of variation in policies. The first is the traditional left-right axis, with policies working toward social solidarity and the reduction of inequalities on the left and policies giving free rein to market forces and individualism on the right. The second is an economic and environmental axis, with policies either responding successfully or failing to respond to prolonged recession and environmental challenges. The second axis was used to drive the European trends in life expectancy and total fertility. The first axis was used to determine the extent of convergence between regions (decreasing inequalities) or divergence between regions (increasing inequalities). The four policy scenario projections were for Growing Social Europe, Limited Social

Europe, Expanding Market Europe and Challenged Market Europe. The outcomes of these scenarios saw a range in the EU's population in 2050 between 463 million under the Status Quo scenario to 605 million under the Expanding Market Europe, although the team took view that the Limited Social Europe was the most likely with a 2050 population of 502 million, almost the same as the 2010 figure of 503 million.

4.10.5 The age-time plan

The key disadvantage of the MULTIPOLES model as currently implemented is that it uses 5 year age and time intervals and so would need to be changed for use in the Scotland SNPP.

4.10.6 Software

The MULTIPOLES code is available in FORTRAN from the authors.

4.11 Academic Sub-National Population Projection Models: ETHPOP

4.11.1 Context

Funded through two ESRC research grants, a team at the University of Leeds developed a set of population projections by ethnic group. The projection data are available along with links to all publications, working papers and presentations via http://www.ethpop.org. The projections were for 355 zones covering the UK (352 LADs in England together with other three Home countries as single zones). Sixteen ethnic groups based on the 2001 census were used meaning that 5,680 populations were projected. Because of the number of computations involved we adopted the bi-regional model (explained below). The general approach to assumptions was, for our Trend projection, to align them to the UK NPP projection assumptions (2008-based). We converted the net international migration assumptions into gross immigration and gross emigration assumptions that yielded the same net international migration profile over time.

4.11.2 Fertility assumptions

Fertility assumptions are developed for each ethnic group separately. For the future it was assumed these trended in the same way as in the 2008-based NPP. Note that a combination of ethnic group specific fertility rates and ethnic group populations meant a projection higher than the NPP, even when the same assumption approach was used.

4.11.3 Mortality assumptions

Mortality assumptions were developed, for the first time, for ethnic groups. Ethnic specific mortality rates and associated life tables were estimated and used to generate the survivorship rates by ethnic group used in our projections. Other ethnic population estimates (ONS) or projections (Coleman) for the UK assumed that mortality rates for all groups were the same. Projections of racial group populations in the USA and New Zealand used death statistics based on recording race at time of death, which reveal very important differences in level between groups. Because ethnicity was not reported on the death registration in the UK at the time we did the work, we had to estimate ethnic specific mortality indirectly. Subsequent research has used different estimation methods which gave different results. We hope to make better estimates in current research and resolve the differences.

4.11.3 Migration assumptions

Migration assumptions for internal migration estimates were based on 2001 Census results updated for the total population using NHS Patient Register counts for annual intervals to 2006-07. Thereafter internal ethnic-specific migration rates were assumed constant over the projection horizon to 2050-51. Internal out-migration is the product of the LAD population at the start of the projection interval multiplied by the out-migration rates. Internal in-migration is a product of the Rest of the UK population at the start of the projection interval multiplied by the out-migration rate to the LAD. Immigration is handled as a time series of flows of immigrants from the Rest of the World to the LAD. Emigration is handled as a time series of flows of emigrants from the LAD to the Rest of the World, in the Trend projection. In an alternative projection, emigration is projected as the product of the LAD population times the emigration rate. This leads to lower projected populations because emigration grows in line with the UK population while immigration remains constrained by policy which keeps the numbers lower. Net international migration therefore shrinks over time under this ER (Emigration Rate) model.

4.11.4 The bi-regional projection model

The projections were produced using a bi-regional cohort-component model that employed transition rates (probabilities of migration given survival) because migration data from the 2001 census were used. Most other UK models adopt movement rates (occurrence/event rates). A full set of single years of age from 0 to 100+ were used to reflect increasing longevity with significant numbers likely to survive in future beyond age 90. The model uses 355 pairs of regions, each pair consisting of a LAD and the Rest of the UK.

4.11.5 Projection results and their dissemination

The ETHPOP model produces projected populations by ethnic group, single year of age and sex for LADs in England plus Wales, Scotland and Northern Ireland as single zones. The results are delivered via a website and database (http://www.ethpop.org) which can be accessed by anyone, once registered. The database provides the ability to download populations from the projections, selecting the geographic zones, ethnic groups, ages, gender and mid-years of interest. A more limited set of projected component flows are available from the database. Full results are available in the form of comma separated variable files from the authors or the UK Data Archive.

4.11.6 Impact scenarios

As well as principal and reference projections, *impact scenario projections* were produced. These make possible the assessment of the impact of component assumptions. These projections are designed to answer the question posed by users of the projections: "what is driving the projections?" The scheme for impact scenarios for fertility, mortality and net international assumptions and for demographic potential was proposed by Bongaarts and Bulateo (1999) and further developed by the addition of estimation of the impact of internal migration impact by Rees et al (2013). In Appendix C we show how these impact scenario projections might work for the Scotland subnational projections, extending the scheme to assess the impact of assumptions for three levels of migration: international, home country and council area.

4.12 Academic SNPP Models: WIC-GLOBAL

4.12.1 Context

The Wittgenstein Centre for Demography and Global Human Capital (WIC-Global), which spans three Vienna research institutions, has recently produced and innovative projections for 195 countries, making up virtually the whole of the world's population (Lutz et al 2014). This is clearly not a sub-national population projection model but we mention it briefly here to draw attention to some methods and some data that might be useful in the Scotland SNPP.

4.12.2 Projections of educational status

The population projections have been extended to include a classification of the population by education status. Lutz and his colleagues have demonstrated the importance of the links between educational status and demographic behaviour: the higher female education status, the lower the fertility in a country (both as a result of postponing childbirth to finish schooling and as a result of lowered family size aspirations); the higher the educational status of a national population the better their health status and life expectancy; migration is also selective by educational status, favouring the literate and qualified. All these effects can be seen at work for sub-national populations within the UK. The educational indicators used the WIC-Global projections are not applicable to a highly developed country with universal literacy, but more appropriate indicators based on qualifications captured in the census could be developed (as in Loichinger 2015).

4.12.3 The first estimates of country to country international migration for the world

WIC researchers Sander et al (2014a) have developed a world time series of estimates of country to country migration for the first time (Sander et al 2014a). These estimates could be used to improve the estimates of international migration streams into and out of the UK, at present dependent on an inadequate International Passenger Survey.

4.12.4 Argument based surveys of expert opinion about the demographic future

WIC researchers administered argument-based surveys of experts of fertility, mortality and migration which were used, along with modelling of time series of associated indicators to set assumptions for each component. These assumptions were aligned to Shared Socioeconomic Pathways[1], scenarios linked to the climate change scenarios of the Intergovernmental Panel on Climate Change. An argument based expert survey of the likely demographic future is used by ONS to inform the UK NPP (ONS 2013).

4.13 Local Government SNPP Models: POPGROUP

4.13.1 Responsible agency, software, geography and approach to assumptions

POPGROUP is a family of demographic models used to generate projections of the population, households and the labour force for specified geographical areas and/or population groups. The software was originally developed at Bradford Local Authority by Ludi Simpson and colleagues, first at Bradford Local Authority and then at the University of Manchester (CMIST 2015, School of Social Sciences 2015). POPGROUP is now supported by the Local Government Association (LGA 2015) and maintained and enhanced by Edge Analytics (2015). Today, Edge Analytics is responsible for managing, developing and distributing POPGROUP products under licence from the Local Government Authority (LGA)/Improvement and Development Agency (IDeA), which owns the software. POPGROUP uses Excel workbooks for data input as well as outputs and is currently optimised to run under Excel 2003. POPGROUP projections are produced by the user themselves using the excel workbooks provided. The software comes with a detailed user manual and methodological description. In the summary below, we focus on projections by areas and not population sub-groups. The POPGROUP model can be used with or without constraints to official statistics.

4.13.2 Fertility assumptions

Assumptions are set by the user. A minimum requirement is single year age age-specific fertility rates for women ages 15 to 49. A gender ratio for birth is provided but can be changed. In addition, TFR or counts of birth can be specified. The model also allows specifying changes over time or in the case that more than one area is projected how the fertility schedule differs between areas.

4.13.3 Mortality assumptions

Assumptions are set by the user. The minimum data requirement is a standard schedule of mortality rates by gender and single year of age. Mortality rates are required for new-born, ages 0 to 89, and age 90+. Area specific schedules can be applied. In addition it is possible to specify counts of death or standardised mortality rations. The user can also specify trends over time.

4.13.4 Migration assumptions

[1] The scenarios are Rapid Development (SSP1), Medium (SSP2), Stalled Development (SSP3), Inequality (SSP4), Conventional development (SSP5).

POPGROUP recognizes four migration streams: internal in-migration, overseas immigration, internal out-migration and overseas emigration. For internal in-migration an age specific migration rates schedule for ages 0 to 89, and age 90+, as well as the population at risk of migrating into an area needs to be defined. For overseas immigration counts must be specified. If not, this flow is assumed to be zero. Data are supplied as totals and age and gender specific counts by 5 year age groups up to 75+. For out-migration schedules of outmigration rates or counts can be supplied to the model. POPGROUP also allows inputting differentials over time or the input of standardised migration rates and their trends over time.

4.13.5 Special populations

Special populations are user defined and will be deducted from the population at the start of each year and will be added again at the end of the year.

4.13.6 The projection model

POPGROUP is designed to implement a single region projection model. In some applications for clients, this framework has been extended to include a few additional regions which interact closely with the main one being studied. But for this model external information, for example, from the England SNPP, is needed because the model is not fully multi-regional.

4.14 Local Government SNPP Models: Greater London Authority

The most sophisticated local authority projection in the UK is that implemented by the Greater London Authority (GLA Intelligence 2014). The GLA has long run a multi-regional population projection model for the 33 London boroughs plus three external zones, East of England, the South East and the Rest of the UK. Information for the first two zones outside Greater London is obtained from the England SNPP, while a combination of the UK NPP and England SNPP provides data for the Rest of the UK zone. The projection is specified for single years of age and one year time intervals.

Particular attention is paid to recent temporal trends in internal migration in developing assumptions for the principal and variant projections. One variant assumes that improvement in the national economy after the Great Recession by 2018 will mean a return to the levels of out-migration from Greater London experienced between 2000 and 2007, leading to higher net internal out-migration. Earlier GLA projections had adjusted inter-borough migration rates in the light of the results of the GLA housing capacity study.

Considerable attention has been paid by the GLA as well to the assignment of UK immigration and emigration flow estimates and assumptions to London Boroughs. In the 2000s there was concern that the ONS method for such allocations was assigning too many immigrants to central London boroughs, an effect probably due to a lack of geographic knowledge on the part of the incoming immigrant interviewed by the International Passenger Survey. Investigations of methods for allocating national immigration estimates based on administrative data for the GLA (Rees and Boden 2006, Boden and Rees 2010a) and for the ETHPOP SNPP (Boden and Rees 2010b) persuaded ONS to improve estimation methods (ONS 2011). More recent immigration estimates incorporate 2011 Census information. Emigration flows are modelled using IPS information on emigration, knowledge of internal out-migration and the previous year's immigration estimate (ONS 2010a).

4.15 Commercial SNPP Models: CHELMER

The Chelmer Population and Housing model was originally developed by the Population and Housing Research Group at Anglia Ruskin University's Chelmsford campus (hence the name) and since 2008 has been managed by Cambridge Econometrics (2015). Only broad methodology and description of outputs are publicly available. Projections would be run by Cambridge Economics and outputs supplied to facilitate in-house analysis. The model can produce projections of population, households and labour force. It operates at various geographies. Projections can be migration-led, housing-led or population-led.

4.16 Commercial SNPP Models: EXPERIAN

Publicly available information on the Experian model is very sparse (Experian 2015). Experian's population projections seem to be very detailed in geography and are available by gender and for residential population in output areas (OA) and postal sector. For that reason they are less detailed in age information with 18 age bands. Experian has produced these projections from 2003 onwards up to 2013. Details on the methodology used are not publicly available.

4.17 Evaluation of Alternative SNPP Models

Table 4.2 summarises the key features of 14 of the 16 SNPP models reviewed and add comments on the advantages and disadvantages of each. We drop the two commercial offerings as virtually no information is provided by their developers. Most have ideas which might be applied in a future Scotland SNPP In the report's final section we source recommendations from 14 of the SNPP models.

Table 4.2 Comparison of sub-national population projection models

SNPP Model	Model	Software	Assumptions	Pros	Cons
4.1 England	MR, SYA	SAS (ONS)	Principal, Variants	Help from ONS	Needs SAS expertise
4.2 Wales	SR, SYA	POPGROUP (Licensed)	Principal	See POPGROUP	See POPGROUP
4.3 N. Ireland	SR, SYA	POPGROUP (Licensed)	Principal	See POPGROUP	See POPGROUP
4.4 Germany	SR, SYA	BBSR Bespoke?	Principal, Variants	Well-crafted model?	Documentation in German
4.5 Canada	MR, FYA	Stats Canada Bespoke?	Principal, Variants	Adjustment of out-migration rates	FYA/T?
4.6 New Zealand	MR	Stats NZ Bespoke?	Principal, Probabilistic	Innovative: ethnic and probabilistic	Bayesian methods hard, relies on expert judgement
4.7 New South Wales	MR, SYA/T, BR FYA/T	NEWDSS (Spreadsheets plus FORTRAN)	Principal, Scenarios	Very well specified, multi-level, mixes concepts	Consultancy from author (Tom Wilson) needed
4.8 Eurostat	MR, FYA/T	LIPRO see 4.9	Principal, Scenarios	None	Poorly specified
4.9a SPACE	MR, FYA/T	FORTRAN (Code available)	User generated	Model well specified	FORTRAN code needs work, Only FYA/T
4.9b LIPRO	MR/MS, SYA/T	TURBO-PASCAL (Program available)	User generated	Model well specified, widely used	Needs PASCAL expertise. Code needs work
4.10a MULTIPOLES	MR, Multi-Level, FYA/T	FORTRAN (Code available)	Main, Reference (2)	Model handles multi-levels	Only FYA/T, Code needs work
4.10b DEMIFER	MR, Multi-Level, FYA/T	FORTRAN (Code available)	Reference (3), Policy Scenarios (4)	Model handles multi-levels applied to regions across	Only FYA/T
4.11a ETHPOP	BR, SYA/T, Impact Scenarios	R (Code available)	Reference (2), Trend (2), Model Variant (1), Impact Scenarios (4)	Model deals efficiently with 5,680 populations: LADs by Ethnicity, Impact Scenarios	Needs R expertise, Code needs work
4.11b NewETHPOP	MR, SYA/T	R (Under development)	Principal, Variant, Migration Model Variants (4), Impact Scenarios (5)	Will produce CA projections for Scotland, Impact Scenarios	Not available until early-2016
4.12 WIC-Global	BR, FYA/T	R (Code available)	Five Socio-economic pathways	Innovative method of assumption setting, adds education to projections	Not a SNPP, no adjustment of out-migration rates
4.13 POPGROUP	SR/BR, SYA/T	EXCEL MACROS (Licence needed)	User generated	Well supported software. Used by Wales and N Ireland	Does not handle MR model. Would need support from Edge Analytics
4.14 GLA	MR, SYA/T, HC	Documentation not explicit	Unconstrained, Migration Variants, Housing Constrained	Implemented for 36 regions	Would need support from GLA

Notes: MR = Multi-Region, MS = Multi-State, BR = Bi-Region, SR = Single Region, SYA/T = Single Year Age/Time, FYA/T = Five Year Age/Time

5 A SPATIAL FRAMEWORK FOR SUB-NATIONAL PROJECTION MODELS

The aim of this section is to describe a spatial framework in which the different sub-national population projections can be placed. This framework focusses on the way in which different migration streams are represented or not represented in SNPP models. Figure 5.1A does this and then the other tables in the Figure 5.1 show realizations of the framework in particular applications. We use the framework to place the SNPP examples reviewed in section 4 into context. A possible framework for the Scotland SNPP is shown in Figure 5.2.

5.1 A general spatial framework for migration flows in a SNPP with examples

Figure 5.1 depicts the sets of migration flows that are considered in SNPP models.

Figure 5.1B shows the system of interest for the 2012-based Scotland SNPP for individual CAs. Only the migrations into and out of individual CAs are incorporated into the projection, currently as total net in-migration. The top LH cell in Figure 5.1B (coloured green) refers to mortality and fertility variables for the CA. The other cells in the first row (out-migrations) and first column (in-migrations) are included, explicitly or implicitly, in the SNPP. The cells in the table coloured in red are regarded as being outside the system of interest (although they may have an influence on the projected populations for a CA via external constraints.

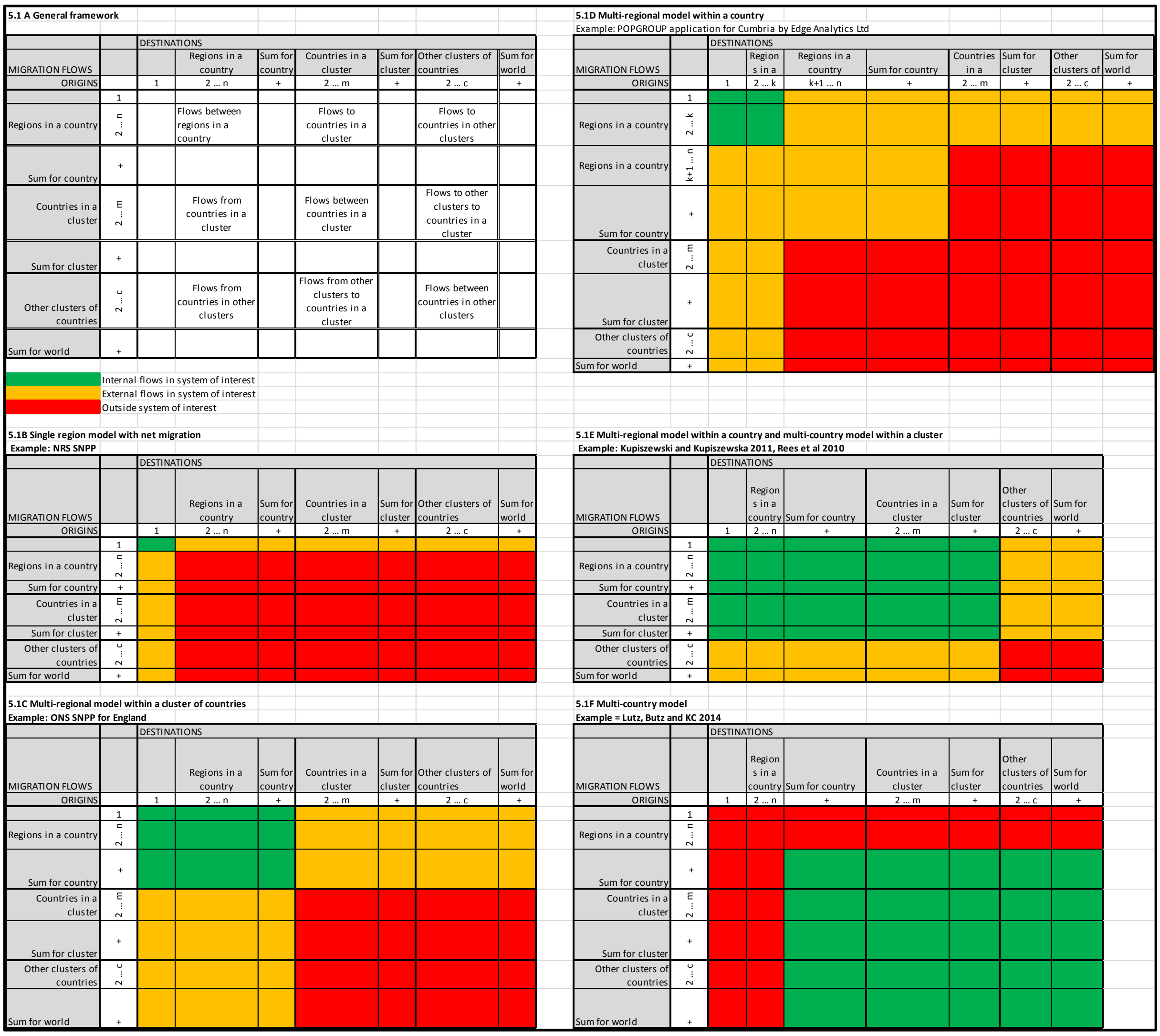
Figure 5.1C recognises that out-migrations from one region become the in-migrations to another region. The internal system of interest is expanded to include a set of regions, either within a country or within a part of a country. An example is the SNPP for England produced by ONS (ONS 2014f), in which flows between 326 lowest tier LADs are represented in a multi-regional cohort-component projection model. This example was described in more detail in section 4.1.

Figure 5.1D shows a shrunken version of the ONS SNPP model for a region of interest. Migration flows between a set of regions within a country which have intensive interactions with the region of interest are modelled explicitly using rates and populations at risk. Populations at risk are borrowed from a larger projection. Edge Analytics uses this strategy with client LADs, borrowing information from the ONS SNPP. This example was referred to in section 4.13.

Figure 5.1E provides an example in which the projection models migrations between all regions within a set of countries and all migrations between those countries. The total in-migrations and total out-migrations from a country are assigned to regions within countries using proxy variables (the regional populations, the within country migration totals for regions). This hierarchical model is described in section 4.10.

Figure 5.1F represents in this framework the migration flows between the countries of the world (estimated by Abel and Sander 2014 using a method developed by Abel 2013), which are used in the world country projections of Lutz et al (2014). No attention is paid here to migration between regions within countries. Future migrations between countries are modelled as total emigrations and total immigrations in a bi-regional cohort-component model. This model provides unique estimates of country to country migration, which might be used in sub-national models. The model is described in section 4.12.

Figure 5.1: Spatial frameworks for handling internal and external migration flows



Source: adapted from Rees (2015)

5.2 A spatial framework for incorporating migration in Scotland's SNPP

Figure 5.2 is a table organised into three horizontal panels (sets of rows) by three vertical panels (sets of columns). The rows are migration origins and the columns are migration destinations. The contents of the table are migration variables, labelled M. Each variable is characterised by two superscripts, separated by a comma. The first pair characterises the origin of the migration; the second pair characterised the destination of the migration. Within each pair of superscripts, there is a letter identifying the territory within which the spatial units fit. So the Council Areas of Scotland are labelled s1 to s32 and $M^{s1.s32}$ identifies migration between Council Area 1 (Aberdeen City) and Council Area 32 (West Lothian).Within the UK the home countries are indicated by superscripts h1 to h4, with h1 referring to Scotland and h2 to h4 the other UK home countries (England, Wales and Northern Ireland). The migration variable $M^{s32,h2}$ refers to migrations with origins in Council Area 32 (West Lothian) and destinations in Home Country h2 (England). The final block for the first panel in Figure 5.2 contains emigrations (international out-migrations) from Scottish Council Areas to foreign countries. The variable $M^{s1,f2}$ refers to emigration from Council s1 (Aberdeen City) to foreign country f2 (e.g. Australia). The first panel column contains the equivalent in-migration variables.

Figure 5.2 also represents various summations of these migration variables. Total out-migration from Council Area s1 to all other CAs within Scotland is represented as $M^{s1,s+}$. Note that the variable *Migrations within CAs* is set to zero in Figure 5.2, because these migrations don't contribute to population change for the CA as a whole. Total out-migration from s1 to other UK home countries is represented as $M^{s1,h+}$. Total emigration from s1 to all foreign countries is represented as $M^{s1,f+}$. If we add these three sets of out-migration totals together, we obtain the total out-migration flow from CAs, represented, for our s1 example, by $M^{s1,++}$. The equivalent in-migration totals for s1 are represented by $M^{s+,s1}$ (from within Scotland), $M^{h+,s1}$ (from the rest of the UK), $M^{f+,s1}$ (from the rest of the world). If we subtract from these in-migration totals the corresponding out-migration totals, we obtain total net in-migration within Scotland to a CA, e.g. $N^{s+,s1}$, total in-migration from the rest of UK to a CA, e.g. $N^{h+,s1}$, total net immigration from the rest of the world to a CA, e.g. $N^{f+,s1}$ and total net in-migration from all areas to a CA, e.g. $N^{++,s1}$.

Figure 5.2: Framework for incorporating migration into projection models: Scotland example

DESTINATION		Scottish Council Areas			Total Out-Migration within Scotland	Other UK Home Countries			Total Out-Migration to UK Home Countries	Other Foreign Countries			Total Emigration to Foreign Countries	Total Out-migration
ORIGIN		s1	...	s32	Σ	h2	...	h4	Σ	f2	...	f197	Σ	Σ
Scottish Council Areas	s1	0	...	$M^{s1,s32}$	$M^{s1,s+}$	$M^{s1,h2}$	...	$M^{s1,h4}$	$M^{s1,h+}$	$M^{s1,f1}$	...	$M^{s1,f197}$	$M^{s1,f+}$	$M^{s1,++}$
	:	:		:	:	:		:	:	:		:	:	:
	s32	$M^{s32,s1}$	...	0	$M^{s32,s+}$	$M^{s32,h2}$	...	$M^{s32,h4}$	$M^{s32,h+}$	$M^{s32,f1}$	...	$M^{s32,f197}$	$M^{s32,f+}$	$M^{s3,++}$
Total In-migration within Scotland	Σ	$M^{s+,s1}$	...	$M^{s+,s32}$	$M^{s+,s+}$	$M^{s+,h2}$	...	$M^{s+,h4}$	$M^{s+,h+}$	$M^{s+,f1}$	...	$M^{s+,f197}$	$M^{s+,f+}$	$M^{s+,++}$
Total Net In-migration within Scotland	Σ	$N^{s+,s1}$	...	$N^{s+,s32}$	0	$N^{s+,h2}$	...	$N^{s+,h4}$	$N^{s+,h+}$	$N^{s+,f1}$	...	$N^{s+,f197}$	$N^{s+,f+}$	$N^{s+,++}$
Other UK Home Countries	h2	$M^{h2,s1}$	...	$M^{h2,s32}$	$M^{h2,s+}$	0	...	$M^{h2,h4}$	$M^{h2,h+}$	$M^{h2,f2}$	...	$M^{h2,f197}$	$M^{h2,f+}$	$M^{h2,++}$
	:	:		:	:	:		:	:	:		:	:	:
	h4	$M^{h4,s1}$	...	$M^{h4,s32}$	$M^{h4,s+}$	$M^{h4,h2}$	...	0	$M^{h4,h+}$	$M^{h4,f2}$	...	$M^{h4,f197}$	$M^{h4,f+}$	$M^{h4,++}$
Total In-migration from Other UK Home Countries	Σ	$M^{h+,s1}$	...	$M^{h+,s32}$	$M^{h+,s+}$	$M^{h+,h2}$	...	$M^{h+,h4}$	$M^{h+,h+}$	$M^{h+,f2}$	...	$M^{h+,f197}$	$M^{h+,f+}$	$M^{h+,++}$
Total Net In-migration from Other Home Countries	Σ	$N^{h+,s1}$	...	$N^{h+,s32}$	$N^{h+,s+}$	$N^{h+,h2}$	...	$N^{h+,h4}$	$N^{h+,h+}$	$N^{h+,f2}$	...	$N^{h+,f197}$	$N^{h+,f+}$	$N^{h+,++}$
Foreign Countries	f2	$M^{f2,s1}$	...	$M^{f2,s32}$	$M^{f2,s+}$	0	...	$Mf^{2,h4}$	$M^{f2,h+}$	0	...	$M^{f2,f197}$	$M^{f2,f+}$	$M^{f2,++}$
	:	:		:	:	:		:	:	:		:	:	:
	f197	$M^{f197,s1}$	...	$M^{f197,s32}$	$M^{f197,s+}$	$M^{f197,h2}$	...	0	$M^{f197,h+}$	$M^{f197,f2}$	...	0	$M^{f197,f+i}$	$M^{f197,++}$
Total Immigration from Other Foreign Countries	Σ	$M^{f+,s1}$	...	$M^{f+,s32}$	$M^{f+,s+}$	$M^{f+,h2}$	...	$M^{f+,h4}$	$M^{f+,h+}$	$M^{f+,f2}$	...	$M^{f+,f197}$	$M^{f+,f+}$	$M^{f+,++}$
Total Net Immigration from Other Countries	Σ	$N^{f+,s1}$	...	$N^{f+,s32}$	$N^{f+,s+}$	$N^{f+,h2}$	...	$N^{f+,h4}$	$N^{f+,h+}$	$N^{f+,f2}$	...	$N^{f+,f197}$	$N^{f+,f+}$	$N^{f+,++}$
Total In-migration from All Areas	Σ	$M^{++,s1}$	...	$M^{++,s32}$	$M^{++,s+}$	$M^{++,h2}$	...	$M^{++,h4}$	$M^{++,h+}$	$M^{++,f2}$	...	$M^{++,f197}$	$M^{++,f+}$	$M^{++,++}$
Total Net In-migration from All Areas	Σ	$N^{++,s1}$	...	$N^{++,s32}$	$N^{++,s+}$	$N^{++,h2}$	...	$N^{++,h4}$	$N^{++,h+}$	$N^{++,f2}$	...	$N^{++,f197}$	$N^{++,f+}$	$N^{++,++}$

Key to colours:			
Migration within Scotland		M	Migration flow
Migration between Scotland and the Rest of UK		N	Net migration
Migration between Scotland and the Rest of the World		s1, s32	Indexes for Scottish Council Areas
Migration within the Rest of the UK		h2, h4	Indexes for UK Home Countries
Migration within the Rest of the World		f2, f197	Indexed for Foreign Countries
Totals for Migration Flows		+	Summation over the index replaced
Total for Net Migration			

Sub-national projection models can include some or all of these migration variables. For example, the 2012-based SNPP used only total net in-migration to CAs in the projection though took account of the components of this total in making estimates for the five year base period for projection. Bijak (2012) presents strong arguments that these variables be de-composed into their gross in- and out-components (see section 3.1). There are also strong arguments for representing sub-national area to sub-national area migration explicitly (e.g. all CA to CA migrations) so that migration outcomes in the future can be linked to the origin area population at risk of generating migrations. This argument has been taken on board in the ONS SNPP model which includes the rates of migration between local authority districts (LADs) within England (see section 4.1).

This argument has not, to date, applied to modelling all migration flows between LADs within the UK, because estimates of migration between different Home Countries within the UK have been uncertain. However, two developments have changed this situation. First, ONS has estimated a consistent time series of migration between UK home countries (ONS 2014a) and is exploring alternative options for modelling these cross-border flows for use in NPP2014 (see section 5.2). Second, Lomax has estimated as time series of LAD to LAD flows by age and sex for the whole UK combining 2001 Census data and NHS Register migration data for 2001-2010 using a variety of modelling techniques (Lomax 2013, Lomax et al 2011, 2013 and 2014). This time series is currently being revised through addition to 2010-11 NHS and 2011 Census migration data as part of the NewETHPOP research project (Rees et al 2015).

6 PRODUCING PROJECTION OUTPUTS FOR SEVERAL GEOGRAPHIES

6.1 Context

NRS will produce population projections for Council Areas (CAs) using a demographic cohort-component method. In addition, NRS need to produce equivalent information for various geographies[2]: (1) Health Board Areas, (2) National Parks and (3) Strategic Development Plan (SDP) areas. Note that:

- Current Health Board Areas are perfect aggregations of Council Areas;
- National Parks and SDP areas overlap Council Areas;
- SDP areas are mainly aggregations of Council Areas (Fife is split).

6.2 Carrying out projections for different sub-divisions of the overall area

If projections are required for different subnational subdivisions, then the calculations could be carried out separately for each set of boundary specifications. Output variations between separately calculated projections will arise because:

- The base population age-sex structure is different in different places, and there will be:
- Different demographic rates and momentum; and
- Differences in migration event counts when area boundaries are in different places.

There will also be differences due to the projection model specification with respect to:

- Assumptions about variations in rates for different sets of areas;
- Whether, single-, bi- or multi-regional model;
- Whether the model has complete coverage of all areas or just those of interest (and there are, for example, 'Rest of Scotland' and 'Rest of the UK / World'); and
- Whether the set of subnational areas is constrained to the National projection or unconstrained. The sum of the unconstrained CA projections will not necessarily be the same as the sum of the unconstrained projections for alternative geographies. Even constraining to the same national age-sex counts may produce locally different outputs (e.g. the two parts of Fife separately projected may not sum to Fife projected as a whole).
- Moreover, the projection into the future would be informed by demographic trends from the past and this would require a back-series of age-sex estimates to be calculated and the assembly of previous demographic event counts all for the specific geography of interest.

6.3 Converting socio-demographic data between geographies

A variety of methods have been used to convert population related data from one set of geographical units to another (Norman et al 2003). If projection outputs are to be converted from one geographical system (the 'source' units) to another system (the 'target' units), then:

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[2] See PDFs in List of Maps http://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-projections/population-projections-for-scotlands-sdp-areas-and-national-parks/2012-based/list-of-maps

- Aggregations of areas (whole source 'building bricks') which nest perfectly into the target geography will produce more reliable data . 'Reliable' here may have two meanings: first, in terms of the geographical conversion; second, in terms of the projection outputs since larger areas tend to be less prone to error than smaller areas. However, interpretations of the differential impact of components would most likely be different, for example, with respect to whether natural change or migration has the biggest impact on change and summary measures such as dependency ratios may change;
- Estimates of the intersections of source and target geographies need indicators of the base population size and structure and initial demographic rates in the overlap of the boundary system (the indicators should correlate closely with the data being converted); and
- If outputs are converted between different geographies, there needs to be acceptance that the same overlap indicators at the base (or jump off) time point will apply over the time frame of the projection and that their applicability will reduce over time; and
- Whilst the projected outputs of age-sex counts and births and deaths events may be converted between geographies (with caveats relating to aspects above), routines will need to be implemented to derive migration events and this may just be the net migration residual.

The concepts and practice of converting socio-demographic data between different boundary systems are detailed in Simpson (2002), Norman et al (2003) and Norman (2010). The challenges of producing projections for single, custom, subnational areas (National Parks) are noted by Marshall and Simpson (2008). Some of the problems noted by Simpson and Snowling (2011) about the migration component at small area level are still relevant since the overlap of two larger areas may be small.

6.4 Producing projections for alternative geographies

If the resources (i.e. time and personnel) are not available to produce discrete projections (including past trends, base populations, demographic rate inputs and relevant assumptions) for the different geographical systems then we suggest the following strategy for NRS:

- Produce a range of demographic projections for Council Areas and then convert age-sex outputs to the alternative geographies.

This conversion will entail firstly:

- Using 'look down' tables to inform the constituent building bricks of CAs (OAs and Datazones) for the 2011 Census;
- Using 'lookup' tables for OAs and Datazones to the target, non-CA geographies;
- Developing linkages between source and target geographies using unit postcodes and addresses (both as point locations) which will allow versatile conversions where OAs / Datazones do not aggregate into the larger target geographies. Postcodes have sufficient resolution for the purpose.

If OAs / Datazones nest perfectly into both source and target geographies, there is no need to use postcode / address distributions.

Then, using the Figure 6.1 scheme:

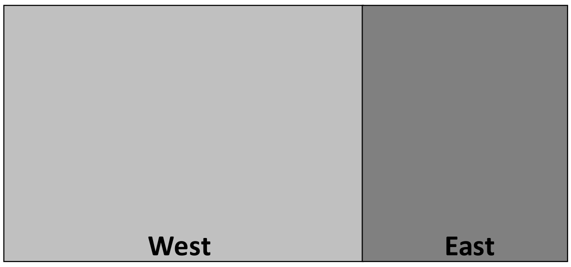
- Develop disaggregation weights from the large (CA) to the smaller (contained) geographies using 2011 Census data. Total population proportions can initially be used to disaggregate but age-specific proportions would nuance this. This is important since not only is population unevenly distributed across a CA but the sub-CA age structure will vary too. Several broad life stage groups may be sufficient.
- Convert the CA age-sex counts to the constituent building bricks (Datazones, OAs or postcodes) using the look down table and weights;
- Aggregate these small area estimates to the target geography (in 2011, the converted data should be very close to census data for the specific geographies).

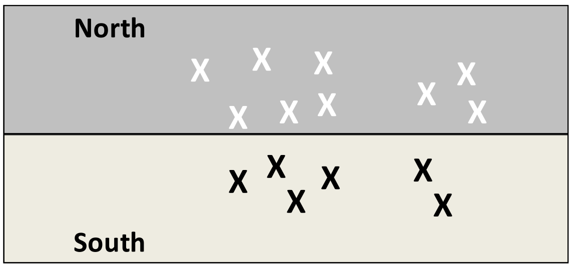
As noted above, a problem with disaggregating outputs for CAs, even using age-specific indicators, is that the assumption will be that the sub-CA age-sex structure is the same in the future as in 2011, the year the weights will be based on (or until the jump off point). A challenge could be to project the look down proportions, which may change over the time frame of the projection because of local developments (new housing, new demolitions, new small area demography). Comparison of 2001 and 2011 Census small area populations may establish trends which can be used, to pick up, shifts in ageing and household size. As the projections need to be trend based and not involve scenarios, the influence of housing or employment developments cannot be projected. To some extent such developments are built into CA trends or into small area extrapolated changes. What it is difficult to project is, by definition, surprise.

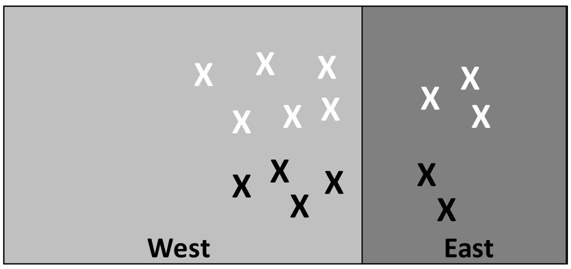
An advantage of producing CA level projections (with varying component assumptions and constraint choices) and then converting to alternative geographies is that there is complete coverage and consistency of subnational projections summing to the same national figures. The disaggregated parts of Fife will still sum to Fife. The same will be true of the births and deaths components, if these are part of the projection outputs. However, the migration component might best be calculated as the net migration residual of the population change and natural change.

Figure 6.1 Converting socio-demographic data between geographies

<table>
<tr><th>Geography: source & target units</th><th>Process to convert</th></tr>
<tr><td>


</td><td>Source units
In the ‘source’ geography for which the data exist, population totals are:
• North = 9,000 people
• South = 6,000 people

Target units
Data are needed for the ‘target’ geography which in this case is a different subdivision of the overall area.
Apportionment of counts by area overlap is inappropriate as people are not distributed evenly across space.</td></tr>
<tr><td colspan="2">• Postcodes (or other small area indicators) can link source and target geographies and provide population overlap estimates. Postcode distribution is a good proxy for population distribution.</td></tr>
<tr><td>


</td><td>Determining the links
Count postcodes in the source geographies:
• North = 9
• South = 6
Count postcodes in source-target intersections:
• North & West = 6; South & West = 4; North & East = 3; South & East = 2

Converting the data
‘Target’ geography estimates:
• West 10,000 = (9,000 x 6 / 9) + (6,000 x 4 / 6)
• East 5,000 = (9,000 x 3 / 9) + (6,000 x 2 / 6)</td></tr>
<tr><td colspan="2">• Since there are urban-rural gradients in the number of people living per postcode, postcode counts can be enhanced by address or household counts;
• Since population may not be evenly distributed by age, the weighting can be enhanced by age-specific indicators;
• The postcode distribution is a very good indicator of population distribution but for relatively large areas (like converting between council areas), Output Area populations can be used to apportion populations (and readily provide age structure).</td></tr>
</table>

7 RECOMMENDATIONS

This final section of the report summarises the subject matter covered in the earlier sections. We begin in section 7.1 with an overview of the decisions that need to be made when implementing a new Scotland SNPP method. In the table we list the options against each decision. Then we present the arguments for choosing particular options for those decisions that are germane to the methodology, saying only a little about operational decisions which are matters for discussion within NRS. In section 7.2 we discuss why it will be advantageous and feasible to move from a single region to a multi-region projection model. In section 7.3 we explain the Statistics Canada approach proposed by ONS for modifying out-migration rates in response to destination population change, which is a sensible innovation. In sections 7.4 and 7.5 we show how the Scotland SNPP can be consistently related to the UK NPP. In section 7.6 and 7.7 we propose a method for allocating to Council Areas the internal and international migration flows to and from Scotland, produced in the UK NPP. In sections 7.8 and 7.9, we discuss how the estimates of Council Area immigration and emigration might be improved, building on ONS experience in the England population estimates and SNPP. In a final section, we discuss the arguments for and against variant, scenario and probabilistic projections.

7.1 Things that must be decided when constructing a new Scotland SNPP

Table 7.1 sets out the decisions needed for a new Scotland SNPP, providing explicit Scotland option or guidance in the right hand column against the left hand column's decision dimensions derived from Table 4.1. The rows of the table summarise the discussion in earlier sections of the report. Some of these decisions are operational (e.g. Strategy, Resources, Available Data, Variants and Scenarios, Programming, Projection outputs, Reviewing outputs). Other decisions involve the "state-space" of the SNPP, but are relatively straightforward to implement or just reflect current practice (e.g. Age detail, Time detail, Approach, Geography, Fertility and Mortality components). "Hard" decisions are needed in defining the spatial framework for the new SNPP and in handling the migration variables needed for the recommended spatial framework. The discussion in the remainder of this section focusses on these "hard" decisions.

7.2 Single versus Multi-regional projection models

From our review of SNPP implemented in the UK and elsewhere, it is clear that a spectrum of projection models have been used, from the very simplest involving just one region to complex models that project the populations of many regions and many countries simultaneously. The current Scotland SNPP projects simultaneously the populations of a set of Council Areas, but the projected populations are not directly connected by projecting the migration from one to another. They are indirectly connected by the requirement that all the individual projected populations for CAs sum to the independently projected Scotland population, which is generated in the UK National Population Projection.

Table 7.1: Decision dimensions for a new Scotland SNPP

Dimension	Options, recommendations for development
Purpose	Deliver SNPP every two years, soon after each UK NPP
Strategy	*Either:* Use existing method and software for 2012 *Or* Develop new method and software for 2014 Future proof method to cope with independence for Scotland
Resources	*Either:* Develop new method and software in-house *Or:* Out-source development of method and software to consultancy Keep production of projections (assumptions, outputs) in-house but consult with users
Age detail	Keep single year of age, but raise last age to 100 and over, to reflect ambition of the Scottish Government to radically improve the health and life spans of the people of Scotland
Time detail	Keep mid-year to mid-year interval but extend horizon to 50 years to capture the fairly certain process of population ageing
Approach	Retain the macro-simulation approach (population groups) Discuss with the Scottish Government the need for an additional micro-simulation approach in the event of full fiscal devolution or independence
Geography	Project Council Area populations and geo-convert to other geographies to maintain consistency Discuss extension of projections to sub-CA level, which will need different methods
Internal Consistency	Fix all other SNPPs to Council Area SNPP
External Constraints	Constrain Council Area projected populations, births, deaths and external migration streams to UK NPP variables
Available Data	Work will be needed to develop the internal, UK and international migration data using CHI and NHS databases, academic estimates and administrative data
Fertility and Mortality Components	Retain the methods used in the 2012-based Scotland SNPP
Migration Concept	Use the movement (migration as events) concept as at present, but seek to improve the internal migration data extracted from the CHI and NHS (in collaboration with ONS) to measure all changes of residence rather than just transitions between start and end of mid-year to mid-year intervals
Internal spatial units	Currently each internal unit is modelled in isolation (single region model) In the new method, model all internal units simultaneously (multi-region model)
External spatial units	These are the other UK Home countries and other non-UK countries Currently, the flows to and from these are collapsed into one net migration variable Represent the gross flows explicitly for the other Home countries and for the Rest of the World as a whole *Either*: use the projected flows from the UK NPP *Or:* incorporate the other Home countries into a multi-level model with a multi-region model at each level Consider projecting separately external flows to/from the European Union, the Commonwealth and the Rest of the World
Representation of migration variables	Use gross migration flows Use movement concept
Form of migration variables	Use intensities multiplied by a population at risk for migration within Scotland and within the UK Use flows for international migration
Form of migration intensities	Use transmission intensities (flows/origin unit population at risk) for within Scotland migration
Forecasting approach	Build trend model of internal migration intensities, using Statistics Canada adjustment method to avoid system drift to stability Build trend model of international flows
Variants and scenarios	Develop impact scenarios to show which component assumptions drive trends at Scotland and Council Area scales and for broad ages Devote resources to stochastic simulations to create projection probability distribution (for 2018 round?)
Temporal assumptions	Assumptions trended to a limit, held constant thereafter
Model computation scheme	Compute iteratively (Wilson 2011)
Programming	Review the options for developing new software (language, coding, sourcing)
Deterministic or probabilistic	Deterministic until confident that probabilistic SNPP works
Projection outputs	In as much detail as possible
Reviewing outputs	Have a systematic programme of comparison against alternatives

Source: Adapted from Wilson (2011), Bijak (2012) and Rees (2015)

The way to connect together CA populations is to project the migration flows between them, which is what the England SNPP does. Of course, this generates a lot of migration variables that need to be projected. In theory, if all age-sex disaggregated flows were to be modelled individually, number of variables would be N×(N-1)×A×G for flows within Scotland and 2×N×M×A×G variables for flows into and out of CAs from other regions outside Scotland. N is the number of CAs (32), M is the number of regions outside Scotland (we assume 4), A is the number of ages (period-cohorts) in the projection model (between 81 and 101, depending on detail needed for the "oldest old") and G is the number of genders (2). In practice, we reduce radically the number of age groups (period-cohort groups) modelled individually to those with different flow patterns which correspond with life course stages e.g. 0-15, 16-24, 25-44, 45-64, 65-74, 75+. Given ONS experience with a much larger number of LADs, such an approach for Scotland is perfectly feasible.

7.3 Method for adjusting future out-migration rates to reflect the role of destinations in determining projected out-migration flows

Dion (2014) reports on changes to the way the inter-provincial migration model, embedded in the Statistics Canada SNPP, is implemented. These changes involve adjusting the out-migration rates in the following way (Dion 2014):

"The adjustment consists of modifying the out-migration rates, for each year projected, on the basis of the average out-migration rates and population sizes observed during the reference period and on the basis of the population sizes at time *t*, i.e., at the beginning of the year to be projected. Hence, the out-migration rate between *t* and *t+1* ($m_{ij}^{t,t+1}$) is modified as follows:

$$m_{ij}^{t,t+1} = m_{ij}^{ref} \times \left(\frac{P_j^t / \sum_k P_k^t}{P_j^{ref} / \sum_j P_k^{ref}} \right) \tag{8.1}$$

where m_{ij}^{ref} is the average rate observed during the reference period, P_j^t is the size of the population of destination, and P_{ij}^{ref} is the average size of the population of destination during the reference period. Alternatively, the adjustment could be calculated as follows, on the basis of the rates and populations for the preceding year:

$$m_{ij}^{t,t+1} = m_{ij}^{t-1,t} \times \left(\frac{P_j^t / \sum_k P_k^t}{P_j^{t-1} / \sum_j P_k^{t-1}} \right) \tag{8.2}$$

Even though it is similar to the models proposed by Feeney (1973) and Plane (1982; 1993) and is based more generally on spatial interaction research, the adjustment model proposed here is informed by a different perspective: the aim is not to try to predict migration flows on the basis of incomplete information but to project internal migration on the basis of clear assumptions about net migration rates."

This is also the perspective adopted in preparation for the NPP2014, that is, a desire that net migration rates do not behave as in stable population models, with rising net out-migration resulting in higher population growth rates in smaller populations. ONS (2015) compares home to home country projected migration flows using fixed out-migration rates and rates adjusted using Dion's formula (8.1 and 8.2 quoted above) and finds adjusted rates more plausible. Plausibility is based on reproduction of the results of the previous net migration model (2012-based NPP). More convincing would be a clear test that the adjusted out-migration method was clearly superior in reproducing migration flows in a historical time series that a fixed rate model. We would recommend that NRS carry out such a test, say, for the 2001 to 2011 decade (informed by the Lomax 2013 estimates).

7.4 The relationship between the Scotland SNPP and the UK NPP

It is desirable, though not essential, that these two projection models are consistent. The review of German experience suggests that pursuing independent *Länder* models led to disagreements about funding at the Federal level. At the moment, the Scotland SNPP model is constrained with respect to population stocks, births, deaths and net migration to the NPP model. However, it should be relatively easy to refine the relationship between the two models. Figure 7.1 develops a specific case of the general framework (section 6) and shows how this might be done. The system of interest is composed of three sub-systems: (1) the sub-system internal to Scotland, the sub-system for flows between to be the CAs of Scotland, which send and receive migration flows from each other, (2) the sub-system linking Scottish CAs to other home countries within the UK and (3) the sub-system linking Scottish CAs to the international migration assumptions of the NPP model.

From the NPP results the Scotland SNPP model can derive the following migration totals:

- totals of in-migrations to Scotland from England, Wales and Northern Ireland,
- totals of out-migration from Scotland to England, Wales and Northern Ireland,
- totals of immigrations to Scotland from countries outside the UK, and
- totals of emigrations from Scotland to countries outside the UK.

Each of these totals is coloured in orange. What is then needed in the SNPP model is a method for allocating these totals to CAs with Scotland, that is, filling the cells coloured in light mauve (migration within the UK) and the cells coloured in dark mauve (international migration).

The NPP also produced projections of births and deaths in Scotland as a whole, which again need allocation (distribution) to the CAs. The current SNPP model has methods for doing this through mortality and fertility scaling factors.

Figure 7.1: Recommended structure for a sub-national population projection model for Scotland (typical period-cohort)

RECOMMENDED STRUCTURE FOR A SUB-NATIONAL POPULATION PROJECTION MODEL FOR SCOTLAND (TYPICAL PERIOD-COHORT)

	Destinations - Scottish Council Areas							Destinations - Home countries			Destination - Other countries	Destination - Non-existence	
	1	2	…	i	…	32	Scotland Total	England E	Wales W	N Ireland N	Rest of the World R	Deaths D	Start Populations SP
1	R^{1}	$M^{1,2}$	…	$M^{1,i}$	…	$M^{1,32}$	$M^{1,+}$	$M^{1,E}$	$M^{1,W}$	$M^{1,N}$	$M^{1,R}$	D^{1}	$P^{1,+}$
2	$M^{2,1}$	R^{2}	…	$M^{2,i}$	…	$M^{2,32}$	$M^{2,+}$	$M^{2,E}$	$M^{2,W}$	$M^{2,N}$	$M^{2,R}$	D^{2}	$P^{2,+}$
…	…	…		…		…	…	…	…	…	…	…	…
i	$M^{i,1}$	$M^{i,2}$	…	R^{i}	…	$M^{i,32}$	$M^{i,+}$	$M^{i,E}$	$M^{i,W}$	$M^{i,N}$	$M^{i,R}$	D^{i}	$P^{i,+}$
…	…	…		…		…	…	…	…	…	…	…	…
32	$M^{32,1}$	$M^{32,2}$	…	$M^{32,i}$	…	R^{32}	$M^{32,+}$	$M^{32,E}$	$M^{32,W}$	$M^{32,N}$	$M^{32,R}$	D^{32}	$P^{32,+}$
Scotland Total	$M^{+,1}$	$M^{+,2}$	…	$M^{+,i}$	…	$M^{+,32}$	$M^{+,+}$	$M^{S,E}$	$M^{S,W}$	$M^{S,N}$	$M^{S,R}$	D^{S}	$P^{S,+}$
England E	$M^{E,1}$	$M^{E,2}$	…	$M^{E,i}$	…	$M^{E,32}$	$M^{E,S}$						
Wales W	$M^{W,1}$	$M^{W,2}$	…	$M^{W,i}$	…	$M^{W,32}$	$M^{W,S}$						
N Ireland N	$M^{N,1}$	$M^{N,2}$	…	$M^{N,i}$	…	$M^{N,32}$	$M^{N,S}$						
Rest of the World R	$M^{R,1}$	$M^{R,2}$	…	$M^{R,i}$	…	$M^{R,32}$	$M^{R,S}$						
End Populations	$P^{+,1}$	$P^{+,2}$	…	$P^{+,i}$	…	$P^{+,32}$	$P^{+,S}$						

Types of Flow		Variables		Subscripts	
(blue)	Flows generated in Scotland SNPP	M	Migrations	1, 2, … , 32	Index for Council Areas
(light blue)	Aggregations of Scotland SNPP flows	D	Deaths	E, W, N, S	Index for Home Countries
(yellow)	Totals generated in the NPP	P	Populations	,	Separates origin and destination superscripts
(pink)	UK Flows allocated from the NPP totals	R	Residuals	+	Indicates summation over the superscript replaced
(orange)	Internation flows allocated from the NPP totals				
(red)	Outside the system of interest				

Notes: This figure applies to all period-cohort where people were present at the start of the interval. For the first period-cohort, from birth during the period to age 0, this is not the case. The framework is adapted by replacing start populations by births and the migration terms by estimates of new-born migrations.

7.5 Constraining the Scotland SNPP to the Scotland NPP totals

With these tight linkages to the NPP results, then when the CA projections are added up to give a Scotland total, this total should be close to the NPP results for Scotland. It should then be relatively straightforward to adjust, pro rata, the CA results to the NPP results. However, this will not necessarily mean that the demographic rates input to the SNPP projection match the outputs. It would then be necessary to adjust rates as well as the flows so that both are in alignment.

A second related question is whether the Scotland SNPP should explicitly include the national populations and components of England, Wales and Scotland or whether the NPP results should be parachuted in as exogenous flows not to be modified in the Scotland SNPP. The number of spatial units in the projection model would increase from 32 to 37, which would not be problematic. All of the assumptions for the other Home countries would be fed in from the 2014-based NPP.

7.6 Allocating NPP totals for internal migration for Scotland to CAs

The current system of estimating inter-LAD migration varies across the UK, depending on Home Country. It is based, mainly, on comparison of successive NHS registers one year apart. Using the unique NHS Identity number, people on the register who report a different postcode in successive registers are classified as migrants. A lookup table from postcode to LAD is used to classify the migrants as inter-LAD mover or intra-LAD movers. The latter can be ignored for SNPP modelling purposes. This main method for generating inter-LAD migration is supplemented in England and Wales by analysis of Higher Education Statistics Agency (HESA) data on the migration from parental domicile to university-linked term-time residence by 18-21 year olds and on the migration from term-time residence to subsequent usual residence on graduation. Finally, an adjustment is made to convert these data from a transition basis to a movement basis, which is needed for both sub-national population estimates and projections. The adjustment is rather rough and it would be advantageous to develop the migration reporting system based on the Community Health Index which captures all mid-year to mid-year changes of patient residential address as well as transitions between residential addresses at one mid-year and the next..

Lomax (2013) has investigated how comprehensive this system is and identified serious gaps, particularly with respect to “cross-border” flows. By “cross-border” we mean those flows between LADs in different Home Countries. He found that LAD to LAD flows were largely absent. He therefore constructed an estimation system that started with the 2001 Census LAD to LAD migration matrix, which explicitly recorded such flows, and adjusted the census flows to marginal totals available from the NHS register based systems year by year from 2001-2 to 2009-10. As part of the NewETHPOP project, he is revising these estimates by adding years 2000-1 and 2010-11 (the census measurement years) and using starter matrices based on interpolation between the 2001 and 2011 census migration origin-destination flows. This is an output that we can supply NRS later in 2015, if required. The key advantage of the Lomax cross-border estimates is that they constitute a time series amenable to trend analysis or selection of period averages for migration rates.

7.7 The system of allocation factors

What might the allocation equations look like? Assume we have a time series of allocation variables based on either the 2011 Census, or a historical time series of estimated flows or allocation factors trended into the future. Let $AF_y^{i,H}$ be the allocation factor for migration from council area i (i=1, … ,32) to Home Country H (H=E, W, N) in future mid-year interval y to y+1. Using the 2011, Census the allocation factor would be

$$AF_{y,y+1}^{i,H} = C_{2010,2011}^{i,H} / C_{2010,2011}^{SH} \quad (7.1)$$

where $\sum^{i=1,32} AF_{y,y+1}^{i,H} = 1$.

Using the time series of estimated "cross-border" migration, the allocation factor would be

$$AF_{y,y+1}^{i,H} = \sum_{t=t1}^{t=t2} M_{t,t+1}^{i,H} / \sum_{t=t1}^{t=t2} M_{t,t+1}^{S,H} \quad (7.2)$$

where t1 = start year of time period considered typical of the future and t2 = end year of time period considered typical of the future.

Using trended values of this time series, the allocation factor would be

$$AF_{y,y+1}^{i,H} = f\left(AF_{t,t+1}^{i,H}, AF_{t+1,t+2}^{i,H}, \ldots, AF_{t+9,t+10}^{i,H}\right) \quad (7.3)$$

where the function might be linear, exponential, convex, asymptotic with or without ceilings or floors, years after which the allocation factors are assumed constant.

Similar sets of equations apply to in-migration flows from other home countries, emigration flows to foreign countries and immigration flows from foreign countries.

7.8 Estimates for immigration to Council Areas

ONS (2011) has developed a method for estimating immigration to LADs in England, using a series of administrative data sets: NHS new patients with a previous address abroad, new National Insurance numbers issued to persons with a previous address abroad, information from the Higher Education Statistics Agency on new entries of foreign students, and Asylum Seeker statistics from the Home Office. Since most of these data bases are also operational in Scotland, a similar method could be used.

7.9 Estimates for emigration from Council Areas

ONS (2010a) has developed an estimation model for LADs in England that draws on information about total internal out-migration (within the UK), information from the International Passenger Survey on origins of emigrants (not reliable below regional level, equivalent to Scotland as a whole) and the estimated immigration in the previous year, reflecting the propensity of many immigrants to emigrate within a short period (e.g. postgrad students, skilled workers or managers in international firms). These estimates are subject to considerable uncertainty but further insight may be obtained from the exercises to align mid-year to mid-year change to change between the 2001 and 2011 censuses.

7.10 Variant projections, scenario projections or probabilistic projections

7.10.1 Methods of handling uncertainty: variant projections

The third set of recommendations in the Bijak (2012) review concerns methods of handling uncertainty, or to put it another way, methods for establishing the confidence intervals around the principal (most likely) projection. The traditional way is to specify a set of variants that use judgement on possible high or low trajectories compared with the principal projection. So, ONS produces 27 variants by specifying high and low variants for fertility, mortality and international migration. NRS produces 7 variants. However, these variants lack any statement about the chance that the population projected will reach the levels projected.

7.10.2 Methods for handling uncertainty: probabilistic projections

Some users demand estimates of such confidence intervals: see for example the Filkin Report (House of Lords 2013) and the evidence about the confidence intervals for older UK populations that Rees offered as evidence at the request of Lord Filkin. Bijak (2012) points out that there is now a lot of experience in generating probabilistic projections for national populations. These are large sets of simulated projections that randomly draw values of leading indicators (e.g. the total fertility rate, life expectancy at age 0, total net migration) from estimated error distributions. The combined results of 1,000 simulations can be described for any year or age group as a cumulative probability distribution from which confidence intervals around the principal projection can be generated.

Two statistical approaches have been employed: the traditional approach based on frequencies of events (the "Frequentist" approach) and the approach based on prior beliefs about uncertainty/confidence tested against the signal from data series (the Bayesian approach, after its posthumous inventor, the Reverend Thomas Bayes). Despite Bijak's confidence in the methodology of probabilistic projections, an examination of many country level studies shows that little attention has been paid to migration. The UN's *World Population Prospects, 2012 Revision* (UN 2013) implements sophisticated probabilistic models of fertility and mortality variation but then plugs in the unsatisfactory deterministic net migration projection converging to zero. Successful sub-national probabilistic projections with more than 2 regions are rare. Intensive research will be needed to develop a probabilistic methodology for a system of 32 regions (CAs) with 6 external flows. So this will not be possible before the 2016 round of projections, at the earliest.

7.10.3 Impact scenarios

An important innovation that could be introduced for the 2014-based projections would be to produce what can be called "impact scenarios", using the scheme developed by Bongaarts and Bulateo (1999), extended to include internal migration impacts as well as international by Rees, Wohland and Norman (2013). For the NRS's 2014-based SNPP the migration impacts are broken down to three: international migration, internal migration between UK home countries and internal migration within Scotland. The other impacts are those of the fertility assumptions, the mortality assumptions and the demographic potential of the current age structure. These impacts are available for each Council Area and age grouping for each year of the projection. These impact scenarios help answer precisely the user question: "what is driving the projection in my local area?"

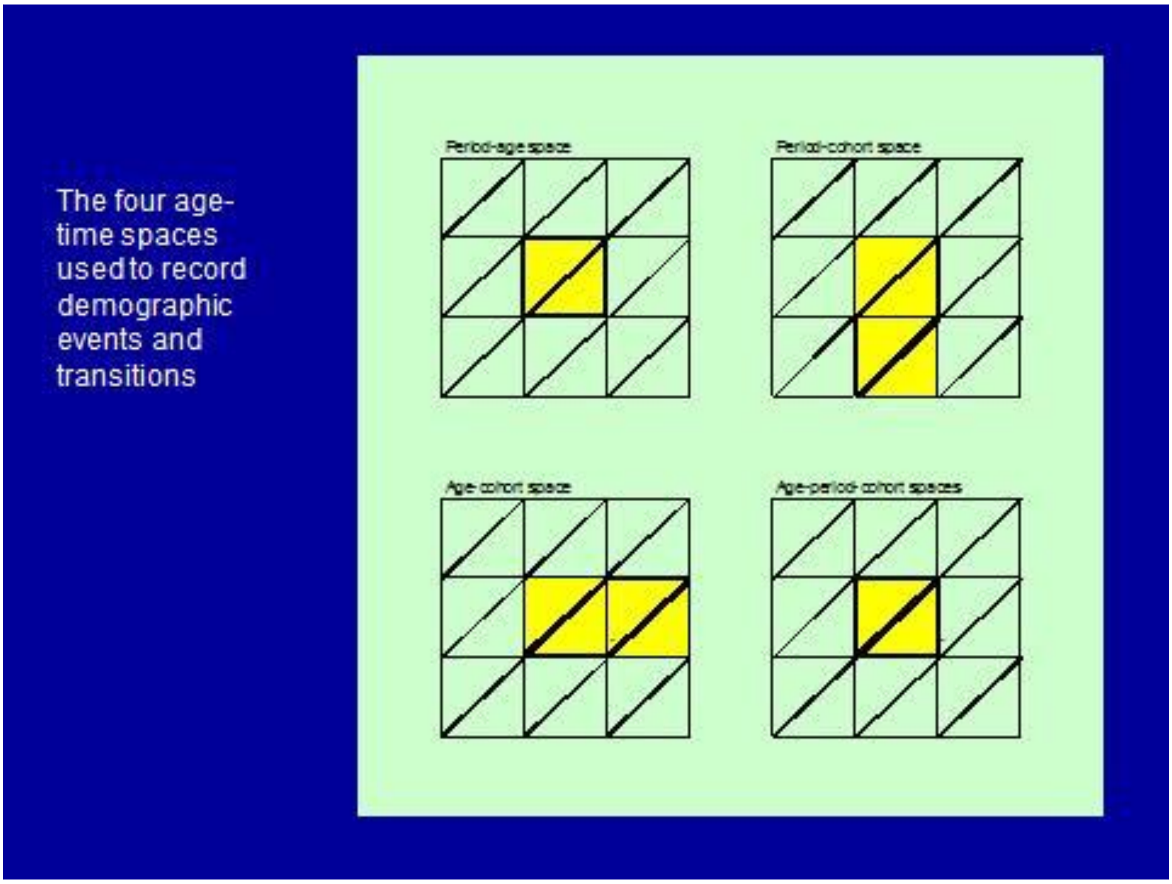
APPENDIX A: LISTS OF SCOTTISH AREAS

Table A.1 Lists of Council Areas, Health Board Areas, National Parks and Strategic Development Plan Areas

Council Areas	Health Board Areas	National Parks	Strategic Development Plan (SDP) Areas
Aberdeen City	Ayrshire & Arran	Cairngorms NP	Glasgow and the Clyde Valley
Aberdeenshire	Borders	Loch Lomond and Trossachs NP	Aberdeen City and Shire
Angus	Dumfries & Galloway		Dundee, Perth, Angus and North Fife; (TAYplan)
Argyll & Bute	Fife		Edinburgh and South East Scotland (SESplan)
Clackmannanshire	Forth Valley		
Dumfries & Galloway	Grampian		
Dundee City	Greater Glasgow & Clyde		
East Ayrshire	Highland		
East Dunbartonshire	Lanarkshire		
East Lothian	Lothian		
East Renfrewshire	Orkney		
Edinburgh, City of	Shetland		
Eilean Siar	Tayside		
Falkirk	Western Isles		
Fife			
Glasgow City			
Highland			
Inverclyde			
Midlothian			
Moray			
North Ayrshire			
North Lanarkshire			
Orkney Islands			
Perth & Kinross			
Renfrewshire			
Scottish Borders			
Shetland Islands			
South Ayrshire			
South Lanarkshire			
Stirling			
West Dunbartonshire			
West Lothian			

APPENDIX B: THE FOUR AGE-TIME PLANS

Figure B1: The four age-time plans used in life table and projection models



APPENDIX C: IMPACT SCENARIO PROJECTIONS FOR SCOTLAND

Table C.1 lists the component assumptions adopted for each impact scenario. The sequence of scenario projections starts with the **P**rincipal (P_p). In the second scenario projection, international migration flows are set to zero, resulting in the No **I**nternational Migration (P_i) scenario. In the third scenario, migration between UK Home countries are set to zero, yielding a No Migration between UK **H**ome Countries projection (P_h). In the fourth scenario, migration within Scotland would additionally be set to zero, producing the No Migration between Council Areas projection (P_c). This is also the Natural Increase only scenario. In the fifth scenario, fertility rates are set to replacement level (around 2.07 at current female mortality rates up to age 50). As the fertility rates assumed in the Principal projection are well below replacement, the projected populations would be higher for this scenario than the previous one. This is the Replacement **F**ertility projection (P_f). In the sixth scenario, mortality rates are assumed constant at the values for the first, benchmark projection interval. This is the Constant **M**ortality projection (P_m). The final row of Table C.1 assumes that the starting population for the projections remains constant over the projection horizon.

The impacts of the component assumptions can then be measured by comparing successive projections in this sequence. These comparisons, set out in Table C.2 can be set up either as differences between successive projections or as multipliers (ratios of successive populations). The differences or multipliers measure the impacts of assumptions about International Migration, Migration between the Home Countries, Migration between Scottish Council Areas, Fertility lower than replacement, Mortality lower than currently and finally Demographic Momentum, which is population change due solely due to the application of constant current Replacement Fertility rates and Mortality rates to the base population age-sex composition.

Table C.3 sets out the equations that link the Starting Population (P_0) with the populations projected under the assumptions used in the Principal projection. The top equation uses the differences; the bottom equation uses the multipliers. These equations are identities as interior terms cancel out.

Table C.4 lists examples of populations for which impact differences or multipliers could be produced. To date there have been few applications of this methodology beyond simple assessments of the impact of international migration assumptions. The technique has the potential to produce insights into the development of Scottish populations in the future which would be unique among national statistical agencies and these insights would be much more useful for policy makers than the mechanical generation of combinations of high, middle and low variants of components, which is the current practice with the UK NPP.

Table C.1: The Scenario Projections and Associated Assumptions

Name	Title of Scenario Projection	Description	International Migration	UK Home Country Migration	Scotland Council Area Migration	Fertility	Mortality
P_p	**P**rincipal	Principal assumptions on migration, fertility and mortality	Principal	Principal	Principal	Principal	Principal
P_i	No **I**nternational Migration	As P_p except international migration set to zero	No international migration	Principal	Principal	Principal	Principal
P_h	No Migration between UK **H**ome Countries	As P_h except migration between UK homes countries set to zero	No international migration	No UK Home Country Migration	Principal	Principal	Principal
P_c	No Migration between Scotland's **C**ouncil Areas	As P_h except migration between Scotland's Council Areas set to zero = overall zero migration = natural increase only	No international migration	No UK Home Country Migration	No Scotland Council Area Migration	Principal	Principal
P_f	Replacement **F**ertility	As P_c except all fertility rates set to replacement	No international migration	No UK Home Country Migration	No Scotland Council Area Migration	Replacement Fertility	Principal
P_m	Constant **M**ortality	As P_f except all mortality rates set to base period values	No international migration	No UK Home Country Migration	No Scotland Council Area Migration	Replacement Fertility	Constant Mortality at Benchmark Rates
P_0	Base Population at Year **0**	The starting jump off population	NA	NA	NA	NA	NA

Notes: The P_0 scenario assumes all future populations are constant at their base population at year 0.

Table C.2 List of Impacts of Assumptions/Components

Impacts	**Differences (in populations)**	**Multipliers (ratios of populations)**
International Migration	$P_p - P_i$	P_p/P_i
Migration between UK Home Countries	$P_i – P_u$	P_i/P_u
Migration between Scottish Council Areas	$P_u - P_s$	P_u/P_s
Fertility Assumptions (difference from replacement)	$P_s - P_f$	P_s/P_f
Mortality Assumptions (difference from no change)	$P_f - P_d$	P_f/P_d
Demographic momentum (change due to base population age-sex composition)	$P_d - P_0$	P_d/P_0

Table C.3 Equations that link start and end populations

Equation with differences
$P_p = P_0 + (P_d - P_0) + (P_f - P_d) + (P_s - P_f) + (P_u - P_s) + (P_i – P_u) + (P_p - P_i)$
Equation with multipliers
$P_p = P_0 \times (P_d/P_0) \times (P_f/P_d) \times (P_s/P_f) \times (P_u/P_s) \times (P_i/P_u) \times (P_p/P_i)$

Table C.4 Variables for which differences or multipliers can be computed

Variable	Description
Years	2019, 2024, 2029, 2034, 2039
Areas	Scotland, Council Areas
Ages	0-15, 16-24, 25-44, 45-64, 65+

Table C.5 Examples of impact multipliers for two LADs in England, 2001-2051

LAD	International Migration	Internal Migration	Below Replacement Fertility	Declining Mortality	Momentum	Combined
Newham	2.14	0.53	0.91	1.07	1.76	1.94
North Norfolk	1.11	1.65	0.94	1.08	0.70	1.29

Source: Rees, Wohland and Norman (2013), Tables 8 and 9
Notes: LAD = Local Authority District

In Table C.5 is presented a small illustration of the ETHPOP impact multipliers for two contrasting LADs in England, for the total population (all ethnic groups combined) over the projection horizon 2001 to 2051. Newham, an east London LAD with the country's most ethnically diverse population in 2011, experiences growth of 2.14 times its 2001 value due to the balance of international migration. This growth is more than cancelled out by an internal migration multiplier of 0.42. This dramatic process of population turnover is repeated across London and other major UK cities. Growth in Newham's population is lowered as a result of below replacement fertility while declining mortality compensates in part for this loss. However, the losses will apply to children while the gains will apply to the elderly. Finally, the current age-composition of Newham's population will contribute growth of 1.76 to its population. Overall, Newham's population change multiplier is 1.94, i.e. a 94% increase in population over 50 years. Note that the projection assumes no constraints (e.g. housing shortages) on this increase, while the Greater London Authority (GLA) have in the past adjusted their migration rates to reflect assessment of the effect of limited additional housing capacity. The second LAD in Table C.5 is a rural coastal LAD in Eastern England, which also experiences inward international migration and high inward internal migration. The fertility and mortality impacts are similar to those of Newham, but the demographic momentum impact is negative, reflecting an aged population structure. These impacts result in only moderate increases of 29% over the 50 years of the projection.

GLOSSARY

ASFR	Age Specific Fertility Rate
ASMR	Age Specific Mortality Rate
BBSR	Bundesinstitut für Bau-, Stadt- und Raumforschung (Federal Institute for Construction, Urban and Spatial Research)
CA	Council Area
CHELMER	A population projection model for local authorities with housing and employment constraints (King, Cambridge Econometrics)
DEMIFER	Demographic and Migratory Flows for European Regions, a model for projecting the population of 28 EU member states and 287 NUTS2 regions (de Beer, van der Gaag, Rees, Heins et al)
ETHPOP	Ethnic population projection model for 352 LADs in England plus Wales, Scotland and Northern Ireland (Rees, Wohland, Norman, Boden)
EXPERIAN	Commercial agency which produces local authority population projections
GROS	General Register Office for Scotland
IIASA	International Institute for Applied Systems Analysis
LAD	Local Authority District (the lowest tier of local government in the UK)
LGD	Local Government District (Northern Ireland)
LIPRO	A multiregional model for life tables and population projections (Keilman and van Imhoff)
MULTIPOLES	A hierarchical multiregional model for projecting national and sub-national populations (Kupiszewski and Kupiszewska)
NI	Northern Ireland
NIDI	Netherlands Interdisciplinary Demographic Institute
NISRA	Northern Ireland Statistics and Research Agency
NP	National Park
NPP	National Population Projection
NRS	National Records of Scotland
NUTS	Nomenclature des Unités Territoriales Statistiques (System of Harmonised Statistical Regions)
ONS	Office for National Statistics
POPGROUP	A cohort-component model with migration for projecting local authority populations in the UK (Local Government Association and Edge Analytics Ltd)
SAPE	Small Area Population Estimate
SNPP	Sub-National Population Projection
SPACE	A multiregional population model for life tables and population projections (Rogers and Willekens)
UK	United Kingdom
VID	Vienna Institute of Demography
WG	Welsh Government
WIC-GLOBAL	A model for projection the populations of 197 countries of the world (Lutz, Butz, KC; Abel, Sander)

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