Article:

Wilson, T., Grossman, I., Alexander, M. et al. (2 more authors) (2022) Methods for Small Area Population Forecasts: State-of-the-Art and Research Needs. Population Research and Policy Review, 41. pp. 865-898. ISSN 0167-5923

https://doi.org/10.1007/s11113-021-09671-6

Supplementary Information

Table A: Annotated bibliography of papers on small area population forecasting methods

Reference and URL	**Key points**
Alexander, M., Zagheni, E., & Barbieri, M. (2017). A Flexible Bayesian Model for Estimating Subnational Mortality. *Demography, 54*(6), 2025-2041. https://doi.org/10.1007/s13524-017-0618-7	A Bayesian modelling framework is presented to estimate age-specific mortality rates at the subnational level. The model incorporates principal components derived from model mortality schedules into a time series framework, allowing for pooling of information across space and time.
Alonso González, M. L., Fernández Vázquez, E., & Rubiera Morollón, F. (2015). A methodological note for local demographic projections: A shift-share analysis to disaggregate official aggregated estimations. *Revista Electrónica de Comunicaciones y Trabajos de Asepuma, 16*(1), 43-50. http://www.revistarecta.com/n16.html	An adapted shift-share method to disaggregate regional age-sex-specific population forecasts to local areas is proposed. Local area projected population growth is a function of regional total population growth (regional effect), regional change by age group (age effect), and local area age-specific growth (local effect). The method is relatively simple, has modest data requirements, and ensures local forecasts sum to the regional projection. Example forecasts for small areas within the Asturias region of Spain are presented.
Anson, J. (2018). Estimating local mortality tables for small areas: An application using Belgian sub-arrondissements. *Revue Quetelet/Quetelet Journal, 6*(1), 73-97. https://doi.org/10.14428/rqj2018.06.01.04	A multilevel model for subnational mortality rates is described, estimated on the basis of national rates and local overall mortality (Standardised Mortality Ratios) and social conditions (household structure, education, urban/rural, and region). The estimation method is applied to 87 areas of Belgium to construct age- and sex-specific mortality rates. The authors find that these rates can be reliably estimated on the basis of local social conditions thus enabling valid life tables to be estimated for small area populations.
Assunção, R. M., Schmertmann, C. P., Potter, J. E., & Cavenaghi, S. M. (2005). Empirical Bayes estimation of demographic schedules for small areas. *Demography, 42*(3), 537-558. https://doi.org/doi.org/10.1353/dem.2005.0022	Age-specific fertility rates are estimated for small areas in Brazil. The authors devise an Empirical Bayes approach which borrows information from nearby areas more than distant areas and from age-specific rates which are strongly correlated across areas. Almost all fertility age schedules are found to be plausible and sensible.
Athukorala, W., Neelawela, P., Wilson, C., Miller, E., Sahama, T., Grace, P., Hefferan, M., Dissanayake, P., & Manawadu, O. (2010). Forecasting Population Changes and Service Requirements in the Regions: A Study of Two Regional Councils in Queensland, Australia. *Economic Analysis and Policy, 40*(3), 327-349. https://doi.org/10.1016/S0313-5926(10)50033-X	ARIMA models are applied to forecast the total populations of two council areas in Queensland, Australia. Population data over a base period of 1946 to 2009 is used to forecast out to 2025. Also presented are 95% prediction intervals (which appear to be very narrow). Then forecasts are prepared for sub-regions of each council "by using the average population share of each sub-region". The authors describe their approach as "verifiable, transparent, and easy to comprehend" and view it as "more theoretically sound than the cohort-component method of population forecasting".

Reference and URL	Key points
Baker, J., Ruan, X., Alcantara, A., Jones, T., Watkins, K., McDaniel, M., Frey, M., Crouse, N., Rajbhandari, R., Morehouse, J., Sanchez, J., Inglis, M., Baros, S., Penman, S., Morrison, S., Budge, T., & Stallcup, W. (2008). Density-dependence in urban housing unit growth: An evaluation of the Pearl-Reed model for predicting housing unit stock at the census tract level. *Journal of Economic and Social Measurement, 33*(2-3), 155-163. https://doi.org/10.3233/JEM-2008-0301	The authors are interested in the housing-unit model to forecast small area populations, and in this paper they focus on the dwelling component of the model. They apply the Pearl-Reed logistic curve to forecast dwelling growth in urban census tracts in Bernalillo County, New Mexico, USA. The base period covers 1990-2000 and forecasts are made out to 2007. It is concluded that "overall, the Pearl-Reed model performed remarkably well in predicting housing unit stocks at the census tract level in this study."
Baker, J., Alcantara, A., Ruan, X., Watkins, K., & Vasan, S. (2013) A comparative evaluation of error and bias in census tract-level age/sex-specific population estimates: Component I (Net-Migration) vs Component III (Hamilton–Perry). *Population Research and Policy Review* 32(6), 919-942. https://doi.org/10.1007/s11113-013-9295-4	Although labelled as population 'estimates', the authors effectively created small area age-sex population forecasts using two methods. They were: the Component I method (cohort-component with net migration) and the Component III method (Hamilton-Perry). Forecasts for census tracts in selected New Mexico counties were produced for 2010 from a 2000 jump-off date with constraining to total 2010 county population estimates. Over the 10 year forecast horizon, MedAPEs for census tract total populations were 28.4% for Component I and 26.1% for Component III.
Baker, J., Alcántara, A., Ruan, X., Watkins, K., & Vasan, S. (2014). Spatial weighting improves accuracy in small-area demographic forecasts of urban census tract populations. *Journal of Population Research, 31*(4), 345-359. https://doi.org/10.1007/s12546-014-9137-1	The process for creating population forecasts by age and sex for 221 urban census tracts in New Mexico, USA, is described. The forecasts were created by a Hamilton-Perry shortcut cohort model, which gave the first set of projections, and then two types of spatial weighting were applied to the initial forecasts to create two more sets. The spatial weighting involved averaging initial projections for each census tract with those of its neighbours – as defined by rook and queen contiguity matrices. Forecasts were prepared for 2000-2010 and then evaluated against 2010 Census data. The spatially-weighted forecasts proved more accurate than those from the regular Hamilton-Perry model across most age groups.
Baker, J., Swanson, D., & Tayman, J. (2020). The Accuracy of Hamilton–Perry Population Projections for Census Tracts in the United States. *Population Research and Policy Review*, 1-14. https://doi.org/10.1007/s11113-020-09601-y	The paper reports an evaluation of the Hamilton-Perry model applied to about 65,000 census tracts across the USA. A base period of 1990-2000 is used to estimate cohort change ratios and forecasts are produced out to 2010. 5 year age groups and intervals are used, with 0-4 and 5-9 populations forecast using child/adult ratios from the jump-off year. Two sets of forecasts are produced: (i) uncontrolled and (ii) controlled to total populations forecast using linear extrapolation. The authors find that controlling the forecasts "creates noticeable reductions in the MAPEs in every age group for both males and females".

Reference and URL	Key points
Ballas, D., Clarke, G. P., & Wiemers, E. (2005). Building a dynamic spatial microsimulation model for Ireland. *Population, Space and Place, 11*(3), 157-172. https://doi.org/10.1002/psp.359	The authors describe the development of SMILE, a dynamic small area microsimulation projection model for Ireland. It is based on a geography of small area District Electoral Divisions. Input data includes simulated small area base period microdata, containing socio-economic attributes for individuals in each small area, as well as assumptions about fertility, mortality and internal migration. The model was run to produce forecasts for1996 and 2002.
Boke-Olén, N., Abdi, A. M., Hall, O., & Lehsten, V. (2017). High-resolution African population projections from radiative forcing and socio-economic models, 2000 to 2100. *Scientific data, 4*(1), 1-9. https://doi.org/10.1038/sdata.2016.130	The authors describe the creation of a high-resolution annual gridded population forecasts for the whole of Africa for every year from 2000 to 2100. They used a geography of 30 arc second grid squares (about 1 km^2 at the equator). Forecasts were created by disaggregating country-level population projections from the Shared Socioeconomic Pathways database at the International Institute for Applied Systems Analysis (IIASA) in combination with land use projections that follow the representative concentration pathways. The disaggregation process used data on roads, water bodies, country borders, and distance to urban centres.
Breidenbach, P., Kaeding, M., & Schaffner, S. (2019). Population projection for Germany 2015–2050 on grid level (RWI-GEO-GRID-POP-Forecast). *Jahrbücher für Nationalökonomie und Statistik, 239*(4), 733-745. https://doi.org/10.1515/jbnst-2017-0149	The paper reports how population forecasts by age and sex for 1 km^2 grid squares were prepared for Germany for the period 2015 to 2050. A cohort-component model with net migration numbers was used and applied to each grid square. Mortality rates were derived from a Lee-Carter model fitted at the national scale with national mortality rates used for each small area. Net international migration was distributed to grid squares according to the population distribution and has a fixed age structure. Net internal migration was set to zero. Fertility was assumed to rise a little in the future. County-specific age-specific fertility rates were applied to grid squares, with spatial fertility differentials maintained over time.
Bryant, J., & Zhang, J. L. (2016). Bayesian forecasting of demographic rates for small areas: emigration rates by age, sex, and region in New Zealand, 2014-2038. 1337-1363. https://doi.org/10.5705/ss.2014.200t	The authors develop a Bayesian hierarchical model to estimate and forecast emigration rates by region in New Zealand. The model deals with small sample sizes by taking advantage of regularities in migration rates by age, sex, time and region. The authors also develop an approach to deal with missing data and changing geographic boundaries.
Bryant, J., R. , & Graham, P., J. (2013). Bayesian Demographic Accounts: Subnational Population Estimation Using Multiple Data Sources. *Bayesian Analysis*, 8(3), 591-622. https://doi.org/10.1214/13-BA820	The authors provide a Bayesian framework which supports the disaggregated estimation of the components of population change, with detail on region, sex, age, and time. They apply this approach to subnational regions of New Zealand, with consideration to seven components of population change: births, deaths, internal in and out migration and external in- and out- migration. Multiple data sources were used to develop their model, including both census and administrative data (e.g. tax system data, school enrolments, electoral roll). Estimates and forecasts for a subset of model outputs are presented.

Reference and URL	Key points
Cameron, M. P., & Cochrane, W. (2017). Using land-use modelling to statistically downscale population projections to small areas. *Australasian Journal of Regional Studies, 23*(2), 195. https://www.anzrsai.org/assets/Uploads/PublicationChapter/AJRS-23.2-pages-195-to-216.pdf	The paper explains how population forecasts for area units (populations generally between 1,500 and 3,000) were prepared for the Waikato region of New Zealand. Forecasts for larger regions (territorial authorities) created by cohort-component models were distributed to area units via the Waikato Integrated Scenario Explorer (WISE), a detailed land-use projection model. Several regression models were fitted to distribute non-residential population, with residential populations based on the land use change model. A short-term out-of-sample test forecast compared forecasts with those of two simple models, finding the authors' forecasts were competitive with one of the simple models and had only marginally higher errors than the other.
Cameron, M. P., & Poot, J. (2011). Lessons from stochastic small-area population projections: The case of Waikato subregions in New Zealand. *Journal of Population Research, 28*(2-3), 245 - 265. https://doi.org/10.1007/s12546-011-9056-3	The authors present a stochastic cohort-component model for subnational areas and apply it to produce forecasts for districts within the Waikato region of New Zealand. The cohort-component model combines internal and international migration in the form of age-specific net migration rates. Stochastic forecasts are created by taking deterministic age-specific rates and multiplying them by probabilistic factors drawn randomly from separate distributions for fertility, mortality, and net migration. The factors apply to all age-specific rates for each component for the whole forecast horizon.
Chen, Y., Li, X., Huang, K., Luo, M., & Gao, M. (2020). High-Resolution Gridded Population Projections for China Under the Shared Socioeconomic Pathways. *Earth's Future, 8*(6), e2020EF001491. https://doi.org/10.1029/2020EF001491	The paper describes the preparation of small 100 m^2 grid square population forecasts for China for the period 2015 to 2050. The authors used machine learning (XGBoost, random forest, and neural network algorithms) to predict residential land use change and therefore population. The forecasts are constrained to the Intergovernmental Panel on Climate Change's shared socioeconomic pathways (SSPs) population scenarios.
Chi, G. (2009). Can knowledge improve population forecasts at subcounty levels? *Demography, 46*(2), 405-427. https://doi.org/10.1353/dem.0.0059	A regression approach to forecasting the total populations of subcounty areas is described. Four regression models were applied to forecast the populations of Minor Civil Divisions in Wisconsin. The dependent variable was the population growth rate and the explanatory variables included demographic and socioeconomic characteristics, transport accessibility, natural amenities, and land development characteristics. The base period was 1980-90 with forecasts produced out to 2000. Comparisons with 4 simple linear and exponential extrapolative models reveal the regression approach does not outperform extrapolation. The performance of the regression methods is discounted at subcounty levels by temporal instability and the scale effect.

Reference and URL	Key points
Chi, G., & Voss, P. R. (2011). Small-area population forecasting: Borrowing strength across space and time. *Population, Space and Place, 17*(5), 505-520. https://doi.org/10.1002/psp.617	Regression models for forecasting small area population change are proposed which include spatial relationships. These include the spatially lagged growth rates and characteristics of nearby areas. The models were tested on population data for minor civil divisions in Wisconsin, USA, using data from 1960-1990 to forecast out to 2000. The projection evaluations reveal mixed results and do not suggest unambiguous preference for the spatiotemporal regression approach or the extrapolation projection.
Chi, G., & Wang, D. (2017). Small-area population forecasting: a geographically weighted regression approach. In D. A. Swanson (Ed.), *The frontiers of applied demography* (pp. 449-471). Springer. https://doi.org/10.1007/978-3-319-43329-5_21	The authors propose a geographically-weighted regression (GWR) model to forecast the total populations of small areas. It was applied to forecast the populations of Minor Civil Divisions in Wisconsin from 2000 to 2010 using a base period of 1990-2000. There were 33 explanatory variables; the dependent variable was population growth. The GWR model was compared to 4 simple linear and exponential forecasts. The GWR method provides a novel estimation of the relationships between population change and its driving factors, but it underperforms traditional extrapolation forecasts.
Chi, G., Zhou, X., & Voss, P. R. (2011). Small-area population forecasting in an urban setting: a spatial regression approach. *Journal of Population Research, 28*(2-3), 185-201. https://doi.org/10.1007/s12546-011-9053-6	The authors report tests of the 3 types of spatial regression models of Chi & Voss (2011) to forecast the total populations of census tracts in Milwaukee, Wisconsin. The dependent variable was the population growth rate and explanatory variables comprised a range of demographic, socioeconomic, and local area characteristics. Forecasts were produced for 1990-2000 using data from 1980-90. Compared to 4 linear and exponential extrapolations, Mean Absolute Percentage Errors were found to be slightly lower for the 3 spatial regression models.
Congdon, P. (2009). Life expectancies for small areas: A Bayesian random effects methodology. *International Statistical Review, 77*(2), 222-240. https://doi.org/10.1111/j.1751-5823.2009.00080.x	Congdon discusses the advantages of modelling age-specific mortality rates in small areas using a Bayesian random effects strategy. The model set up includes random effects by age, sex and group and allows for correlation between groups. The modelling strategy was applied to wards in Eastern England.
Congdon, P. (2014). Estimating life expectancies for US small areas: a regression framework. *Journal of Geographical Systems, 16*(1), 1-18. https://doi.org/10.1007/s10109-013-0177-4	Conventional analyses of small area life expectancies in the US often require the amalgamation of counties, and do not take correlations between adjacent ages or areas into account. The author proposes a method based on a structured random effects model, which incorporates these age and area effects. A regression extension allows area characteristics - such as the ethnic mix, urban-rural level and socio-economic indices - to be considered. It requires minimal amalgamation of counties, producing life expectancy estimates for almost the entire set of counties. This method was applied to data from US counties to produce stable life expectancy estimates.

Reference and URL	Key points
Dittgen, A., & Dutreuilh, C. (2005). Housing and household size in local population dynamics. *Population (English Edition, 2002-), 60*(3), 259-298. https://doi.org/10.2307/4148195	The authors emphasise the relationship between local populations and housing. Dwelling size influences household size and age structure. Population forecasts were prepared for Paris using a cohort-component model which accounts for fertility, mortality and migration, but has an additional component for the private household population. "The population of the additional dwellings that become available during each 5-year period are added at the end of each period. To determine this population, the number of dwellings in question is multiplied by an appropriate average household size and the result is then broken down using an appropriate age-sex structure".
Dockery, A. M., Harris, M. N., Holyoak, N., & Singh, R. B. (2020). A methodology for projecting sparse populations and its application to remote Indigenous communities. *Journal of Geographical Systems*, 1-25. https://doi.org/10.1007/s10109-020-00329-z	The authors propose a model that is effectively a version of the Hamilton-Perry cohort change model in which the population is projected by 5 year age groups and intervals using cohort change numbers (not ratios). The aim is to be able to cope with sparse data for very small populations. Cohort change is projected with a regression model which uses a range of demographic, social and geographic variables. A regression model is also used to project the number of 0-4 year olds, based on population numbers in older childhood ages. The method was applied to produce short-term projections of local Indigenous populations by age and sex in regional and remote parts of Australia.
Dyrting, S. (2020). Smoothing migration intensities with P-TOPALS. *Demographic Research, 43*, 1527-1570. https://doi.org/10.4054/DemRes.2020.43.55	The author introduces a P-TOPALS model framework to estimate age-specific migration schedules. The framework combines the classical TOPALS approach, which assumes an age schedule can be represented as a combination of an age standard and a spline. Dyrting extends this framework to estimate the splines using a penalised-spline approach, which controls the smoothness of the fit with a single parameter. The method is illustrated on internal migration rates in the Northern Territory, Australia, across a range of different population sizes.
Foss, W. (2002). Small area population forcasting. *The Appraisal Journal, 70*(2), 163. [No URL]	The paper is an accessible guide to the housing-unit method and several extrapolation methods for small area total population forecasts. No new methods are introduced. Example forecasts are presented.
Franzén, M., & Karlsson, T. (2010). *Using national data to obtain small area estimators for population projections on sub-national level* [Paper presentation]. Conference of European Statisticians, Lisbon, Portugal. https://www.unece.org/fileadmin/DAM/stats/documents/ece/ces/ge.11/2010/sp.2.e.pdf	The authors propose that migration age-specific input data for small area cohort-component forecasts be created by applying national-level data for specific dwelling types. The assumption is that people living in certain dwelling type/tenure categories share the same demographic characteristics throughout the country. Data from the Swedish population register and real estate register and cluster analysis was used to identify suitable dwelling types (33 groups in total). For small area forecasts, the authors suggest weighting the age profiles by the population composition of each area.

Reference and URL	Key points
Gonzaga, M. R., & Schmertmann, C. P. (2016). Estimating age-and sex-specific mortality rates for small areas with TOPALS regression: an application to Brazil in 2010. *Revista Brasileira de Estudos de População, 33*(3), 629-652. https://doi.org/10.20947/S0102-30982016c0009	In this paper the authors develop a method to estimate small area age- and sex-specific mortality rates, based on the TOPALS relational model. They applied this method to data from small area in Brazil in 2010. This method may be helpful for making undercount adjustments in small areas with incomplete death registrations.
Gullickson, A., & Moen, J. (2001). *The use of stochastic methods in local area population forecasts* [Paper presentation].The annual meeting of the Population Association of America, Washington DC. [No URL]	The authors present probabilistic population forecasts for one county in Minnesota and the rest of the State. The TFR is forecast with a random walk with drift model; mortality is forecast using a Lee-Carter model; net migration is modelled by randomly sampling from recent crude net migration rates. Probabilistic forecasts are created by running a cohort-component model 1,000 times. The authors applied the model to produce a probabilistic forecast of trauma cases at a major hospital in Minneapolis.
Hachadoorian, L., Gaffin, S. R., & Engelman, R. (2011). Projecting a gridded population of the world using ratio methods of trend extrapolation. In R. P. Cincotta, & L. J. Gorenflo (Eds.) *Human Population: Its Influences on Biological Diversity* (pp. 13-25). Springer-Verlag Berlin Heidelberg. https://www.springer.com/gp/book/9783642167065	The authors describe how population forecasts for small grid squares of the World were prepared using 2 models: (1) a projected share of national population (shift-share) model, and (2) and a share of national growth model. Both models produced some negative populations. A combined model uses share-of-growth for most countries, and shift-share for countries where population growth/decline reverses direction between the base period and the projection period. Jump-off year populations were obtained from the Gridded Population of the World dataset and forecasts were produced for the period 1995-2025. National projections were those of the UN Population Division.
Hansen, H.S. (2010). Small-Area Population Projections - A Key Element in Knowledge Based e-Governance. In K.N. Andersen, E. Francesconi, A. Grönlund, & T.M. van Engers (Eds.), *EGOVIS 2010. Lecture Notes in Computer Science*: Vol. 6267. *Electronic Government and the Information Systems Perspective* (pp. 32-46). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-15172-9_4	The author describes a cohort-component model for preparing small area population forecasts. The population accounting equation (p.35) is unusual in that it separates in-migration to/from existing dwellings with migration associated with changes in the dwelling stock. In-migration of children is not forecast. Local fertility and mortality rates are prepared by taking regional rates and multiplying by a local Standardised Fertility/Mortality Ratio. The model is illustrated with projections for small areas of the municipality of Randers, Denmark, from 2007 to 2020.
Harding, A., Vidyattama, Y., & Tanton, R. (2011). Demographic change and the needs-based planning of government services: Projecting small area populations using spatial microsimulation. *Journal of Population Research, 28*(2-3), 203-224. https://doi.org/10.1007/s12546-011-9061-6	The authors describe SpatialMSM, a spatial microsimulation model for Australia which forecasts population and household characteristics for Statistical Local Areas (SLAs). It is a static microsimulation model which involves using Department of Health & Ageing macro-level forecasts of SLA populations by age and sex out to 2027, disaggregating by labour force status, and then re-weighting the base period small area micro-level dataset to achieve consistency with the area/age/sex/labour force forecasts. The paper focuses on likely future changes in demand for aged care and child care as examples.

Reference and URL	**Key points**
Hauer, M. E. (2017) Migration induced by sea-level rise could reshape the US population landscape. *Nature Climate Change,* 7, 321-325. https://doi.org/10.1038/nclimate3271	The author presents forecasts of migration flows from coastal counties in the US which are likely to be subject to sea-level rise inundation. Populations of those parts of counties subject to inundation formed the out-migrants; in-migration to affected countries was reduced in proportion to the unaffected population of each county. Forecasts were produced from 2010 to 2100. Unobserved component modelling was used to project shifts in the migration system. Florida is projected to experience the largest net loss of population while Texas is expected to gain the most.
Hauer, M. E., Evans, J. M., & Mishra, D. R. (2016). Millions projected to be at risk from sea-level rise in the continental United States. *Nature Climate Change*, *6*, 691-695. https://doi.org/10.1038/nclimate2961	The authors forecast the population at risk of sea level rise in the continental United States. Areas expected to be impacted were modelled using a dynamic flood hazard model. Population forecasts were made for Census Block Groups within counties expected to be severely impacted by sea level rises. A linear/exponential method was used to forecast the populations from 2010 to 2100, with forecasts used to calculate populations at risk from sea level rises of 0.9m and 1.8m.
Hauer, M. E., Evans, J. M., & Alexander, C. R. (2015). Sea-level rise and sub-county population projections in coastal Georgia. *Population and Environment, 37*(1), 44-62. https://doi.org/10.1007/s11111-015-0233-8	The authors propose a housing-unit population forecasting method for sub-county areas, and illustrate it with an application to coastal regions of Georgia, USA. Population forecasts were combined with separate forecasts of sea-level rise inundation to estimate the likely impacts of climate change. The number of dwelling units was forecast with a linear model for growing areas and exponential extrapolation for those declining. The models were fitted by regression and prediction intervals are calculated.
Hauer, M. E. (2019). Population projections for US counties by age, sex, and race controlled to shared socioeconomic pathway. *Scientific data, 6*(1), 1-15. https://doi.org/10.1038/sdata.2019.5	The author presents forecasts for all US counties by age, sex and race for 2020-2100. The Hamilton-Perry model was used for private household populations, with one key variation: cohort change ratios were used for county by race populations which are declining, while cohort change differences (absolute numbers) were applied for growing populations. Both of these were projected with an ARIMA(0,1,1) model. Populations in group quarters (institutional dwellings) were assumed to remain constant. Forecasts were constrained to the Shared Socioeconomic Pathway scenarios for the US.
Inoue, T. (2017). A new method for estimating small area demographics and its application to long-term population projection. *In D. A. Swanson (Ed.), The frontiers of applied demography* (pp. 473-489). Springer. https://doi.org/10.1007/978-3-319-43329-5_22 Website: http://arcg.is/1GkdZTX	The author proposes a Hamilton-Perry method for small area population forecasts in which the Cohort Change Ratios and Child/Woman Ratios are smoothed by incorporating information from higher geographies (prefectures). A short-term historical test of this smoothing method compared to some other approaches (no smoothing; Empirical Bayes; use of prefecture ratios for all constituent small areas) showed it to produce the lowest errors. Population forecasts for 217,000 small areas in Japan from 2015 to 2060 were produced.

Reference and URL	Key points
Jannuzzi P (2005) Population projections for small areas: method and applications for districts and local population projections in Brazil. Paper prepared for the IUSSP conference, Tours, France. https://iussp2005.princeton.edu/papers/51422. Portuguese version of the paper published at: https://doi.org/10.1590/S0102-30982007000100008	The author proposes a coupling of the cohort-component method at regional levels with a system of differential equations, based on models of population dynamics used in ecology, to disaggregate population forecasts to municipalities. This method works best for projections with 5 and 10 year forecast horizons for regions with good census data and vital statistics, but poor-quality small area data. The method was then applied to small areas in Brazil.
Jiang, B., Jin, H., Liu, N., Quirk, M., and Searle, B. (2007). A HMM-based hierarchical framework for long-term population projection of small areas. In M. A. Orgun and J. Thornton (Eds.), AI 2007: *Advances in Artificial Intelligence. AI 2007. Lecture Notes in Computer Science, vol 4830* (pp. 694-698). Springer. https://doi.org/10.1007/978-3-540-76928-6_77	The authors present a small area population forecasting method which is based on the Hidden-Markov model and incorporates a hierarchical framework, such that data from larger geographies are utilised. Compared to the cohort-component model, the method has fewer data requirements, is suited to produce longer-term projections, and can produce prediction intervals and point intervals. The method was applied to data from the suburbs of Canberra, Australia, and outperformed both the cohort-component model and a simple Hidden-Markov model in a 20-year forecast.
Jonker, M. F., van Lenthe, F. J., Congdon, P. D., Donkers, B., Burdorf, A., & Mackenbach, J. P. (2012). Comparison of Bayesian Random-Effects and Traditional Life Expectancy Estimations in Small-Area Applications. *American Journal of Epidemiology*, 176(10), 929-937. https://doi.org/10.1093/aje/kws152	Traditional life expectancy estimations tend to generate unacceptably large biases and standard errors for small areas with population fewer than 5,000 person years. In this paper, Monte Carlo simulations were used to demonstrate that a Bayesian Random-Effects approach outperforms the traditional approach in small-area settings, allowing estimates to be produced for populations down to 2,000 person-years. This improvement is enabled by the Bayesian method's use of correlations between sexes, geographic areas and age groups to support estimation of smaller areas life expectancies.
Kanaroglou, P. S., Maoh, H. F., Newbold, B., Scott, D. M., & Paez, A. (2009). A demographic model for small area population projections: an application to the Census Metropolitan Area of Hamilton in Ontario, Canada. *Environment and Planning A: Economy and Space, 41*(4). 964-979. https://doi.org/10.1068/a40172	The authors describe an approach which combines a multiregional cohort-based demographic model at the regional scale and an aggregate spatial multinomial logit model for small areas. The latter distributes in-migrants to regions to small areas based on migrant and destination area characteristics, including migrant's age, number of schools, number of new dwellings, dwelling average rent, distance to the city centre, and amount of recreational land. The model was applied to municipalities and their census tracts in the Hamilton metropolitan region, Canada.

Reference and URL	Key points
Leknes, S., & Løkken, S. A. (2020). Empirical Bayes estimation of local demographic rates. An application using Norwegian registry data. *Statistics Norway.* https://www.ssb.no/en/befolkning/artikler-og-publikasjoner/empirical-bayes-estimation-of-local-demographic-rates	The authors describe an application of the hierarchical Empirical Bayes estimation method for estimating small area demographic rates using full-count Norwegian registry data. The proposed method is low cost, and efficient, and supports practitioners in dealing with issues relating to noisy small area statistics by borrowing statistical strength from larger area populations, which are used as priors. The study demonstrates the beneficial properties of the method in estimating reliable age-specific rates for fertility, mortality, internal migration, and international migration at the small area scale.
Li, T., & Corcoran, J. (2011). Testing dasymetric techniques to spatially disaggregate the regional population forecasts for South East Queensland. *Journal of Spatial Science, 56*(2), 203-221. https://doi.org/10.1080/14498596.2011.623343	The paper describes how dasymetric methods can be used to disaggregate regional population forecasts to small areas. Several alternative dasymetric methods were tested on the metropolitan region of South East Queensland, Australia. Local population forecasts were distributed to Statistical Local Areas based on their dwelling density category, with each density category assigned a proportion of regional population growth. A method involving 4 density classes was found to produce the best results.
Lomax, N., & Smith, A. (2017). Microsimulation for demography. *Australian Population Studies, 1*(1), 73-85. https://doi.org/10.37970/aps.v1i1.14	The authors describe the utility of microsimulation for population forecasting. They demonstrate how static microsimulation can be used to produce a synthetic population of individuals with characteristics describing age, sex, ethnicity, and location using an example from the London borough of Tower Hamlets, at the Middle-layer Super Output Area geographic level (average population 8,000 persons). This synthetic population is then used the base population for a dynamic microsimulation which projects the population into the future. Data inputs included UK census data and R code is provided to support microsimulations.
Marois, G., & Bélanger, A. (2014). Microsimulation Model Projecting Small Area Populations Using Contextual Variables: An Application to the Montreal Metropolitan Area, 2006-2031. *International Journal of Microsimulation, 7*(1), 158-193. https://doi.org/10.34196/ijm.00097	The authors present results from a dynamic microsimulation model projecting the population for 79 municipalities in Montreal from 2006 to 2031. The core innovation of the model is the modelling of location-specific migration probabilities, with destination choice modelled as a function of distance to the city, current municipality size, municipality development potential, population composition as well as its geographic location. Conditional logistic regression was used to estimate the mobility parameters including in the microsimulation model. Model validation of the population forecasts over a 5 year horizon showed a mean absolute percentage error of 3.4%, but higher for smaller populations. Overall, the authors conclude the population forecast errors are within reasonable 10 year error bands

Reference and URL	Key points
Marois, G., & Bélanger, A. (2015). Analyzing the impact of urban planning on population distribution in the Montreal metropolitan area using a small-area microsimulation projection model. *Population Environment, 37*(2), 131-156. https://doi.org/10.1007/s11111-015-0234-7	The authors describe a microsimulation model to forecast the population of Montreal from 2016 to 2031 and assess the impacts of changes in urban planning upon the spatial distribution of population. Three metropolitan development scenarios were considered: a baseline using the urban plan to indicate planned new housing units; an alternative in which the number of housing units is halved in the suburbs and increased in the core; and a final in which new housing is also reduced in the central core. The authors conclude that urban sprawl cannot be avoided, but that its speed can be reduced through planning choices. Validation of the forecast populations over the 2006-2011 period indicated satisfactory performance – mean percentage error of 3.4%. The authors note that due to data limitations and well as burdensome computation requirements, forecasts below the municipality level were problematic.
Marshall, A., & Simpson, L. (2009). Population sustainability in rural communities: The case of two British national parks. *Applied Spatial Analysis Policy, 2*(2), 107-127. https://doi.org/10.1007/s12061-008-9017-1	The authors present population and household forecasts for two UK national park areas. Considerable input data estimation was required due to the non-standard geographies used. National age-specific rates for fertility and mortality were created by scaling national rates to local summary indicators (e.g. TFR). Forecasts were produced using the POPGROUP software. The projection models were a cohort-component model using net migration rates and a headship rate household model. Dwelling-led projections were also created. The projection model adjusts migration to produce population and household forecasts consistent with the assumed dwelling numbers.
McKee, J. J., Rose, A. N., Bright, E. A., Huynh, T., & Bhaduri, B. L. (2015). Locally adaptive, spatially explicit projection of US population for 2030 and 2050. *Proceedings of the National Academy of Sciences, 112*(5), 1344-1349. https://doi.org/10.1073/pnas.1405713112	Population forecasts for the contiguous USA were produced for 30 arc second grid squares for 2030 and 2050. Projections were first produced at the county scale from 2010 to 2050 using a cohort-component model with net migration rates (though the rates had to be age- and sex-invariant due to data limitations). Constraining to US Census Bureau national and State projections was then applied. Then, projections were spatially disaggregated using a “potential development coefficient” based on several variables, including land use and slope, roads, urban accessibility, and current population.
Merkens, J. L., Reimann, L., Hinkel, J., & Vafeidis, A. T. (2016). Gridded population projections for the coastal zone under the Shared Socioeconomic Pathways. *Global and Planetary Change, 145*, 57-66. https://doi.org/10.1016/j.gloplacha.2016.08.009	The authors describe how spatially detailed population forecasts of coastal populations were produced. Forecasts of total population were produced for grid squares 30 arc-seconds in size (about 1 km^2 at the equator) from 2000 to 2100, which are consistent with the 5 basic Shared Socioeconomic Pathways. The method splits each country into 4 ‘zones’ (coastal-urban, coastal-rural, inland-urban, and inland-rural) and assumes recent growth rate differences continue into the future, with forecasts constrained to independent national population forecasts and urbanisation forecasts. Grid square forecasts are created by assuming the grid square population grows at the same rate as the zonal population.

Reference and URL	Key points
Rayer, S. (2008). Population Forecast Errors: A Primer for Planners. *Journal of Planning Education and Research, 27*(4), 417-430. https://doi.org/10.1177/0739456x07313925	The author reports tests of various population forecasting methods and their errors. Forecasts of total county populations across the USA were created using five simple methods and two averaged methods (one an average of all 5 individual methods; the other a trimmed mean of 3). The averaged forecasts were overall as good as, or marginally more accurate, than any individual method. Extending the length of the base period beyond 10 years had little effect on accuracy. Composite methods, where different methods were used for areas according to their base period growth rates, also gave reasonable outcomes.
Rayer, S. (2015). Demographic Techniques: Small-area estimates and projections. In J. D Wright (Ed.), *International Encyclopedia of the Social & Behavioral Sciences (2nd ed.,* pp. 162-169). Elsevier. https://doi.org/10.1016/B978-0-08-097086-8.31015-7	This encyclopedia entry reviews methods for small area population forecasting and discusses the associated challenges, definitions of smallness, and the data sources that are used. Also outlined are recent developments concerning the incorporation of data from geographic information systems, which allow populations to be estimated and projected for user-defined regions, and allow demographers to make projections which aren't restricted by administrative boundaries.
Rayer, S., Smith, S. K., & Tayman, J. (2009). Empirical prediction intervals for county population forecasts. *Population Research Policy Review, 28*(6), 773. https://doi.org/10.1007/s11113-009-9128-7	A method for creating prediction intervals for small area population forecasts is presented. The authors created a population forecasts for 2,482 US counties over several past decades using 7 trend extrapolation methods and a trimmed mean of these; calculated forecast errors from the trimmed mean forecasts; and then used these to create empirical prediction intervals. 90th percentile intervals based on recent past errors were evaluated as good predictions of the magnitude of error in subsequent forecasts.
Rayer, S., & Smith, S. K. (2010). Factors affecting the accuracy of subcounty population forecasts. *Journal of Planning Education Research, 30*(2), 147-161. https://doi.org/10.1177/0739456X10380056	The paper reports an analysis of subcounty population forecast errors in Florida. The authors found that 10 years of base period data is sufficient to gain maximum accuracy using extrapolative methods. Forecast errors were large for the smallest populations and those with high rates of population change. Errors were lowest for areas which experienced moderate base period population change, and improvements in accuracy were achieved by using trimmed means of several methods.
Reinhold, M., & Thomsen, S. L. (2015). Subnational population projections by age: An evaluation of combined forecast techniques. *Population Research Policy Review, 34*(4), 593-613. https://doi.org/10.1007/s11113-015-9362-0	The authors describe a forecasting approach which takes the average of 7 sets of cohort-component projections. They use the common cohort-component model as the reference case and additionally consider six variants. These variants are: cohort-component with migration, cohort-component without migration, and the cohort-component model constrained to total populations from linear, no change, projected share-of-population, and constant share-of-population models. Several sets of retrospective forecasts were created for districts in the state of Lower Saxony, Germany, for 10 year horizons. The averaged results proved marginally more accurate than any of the individual methods.

Reference and URL	Key points
Riiman, V., Wilson, A., Milewicz, R., & Pirkelbauer, P. (2019). Comparing Artificial Neural Network and Cohort-Component Models for Population Forecasts. *Population Review, 58*(2), 100-116. https://doi.org/10.1353/prv.2019.0008	This paper compared total population forecasts created by long short-term memory (LSTM) models with those generated by a cohort component model, for counties in Alabama, USA. Data used included decennial census data and annual mid-year intercensal population data. Separate forecasts were produced for these data types. Two training regimes were tried: training models on data from all counties and training separate models for each county. Data until 2000 was used for training, with forecasts made to 2010. Single-country LSTM models trained with decennial data performed better than the Cohort Component Model. Other LSTM models and single-county model trained with mid-year data produced comparable or worse forecasts, depending on error measures used.
Scherbov, S., & Ediev, D. (2011). Significance of life table estimates for small populations: Simulation-based study of standard errors. *Demographic Research, 24*(22), 527-550. https://doi.org/10.4054/DemRes.2011.24.22	The authors present an analysis of bias, standard errors and distribution of characteristics of lifetables for small populations. Simulation methods are presented for the case of both stationary (from N=1,000 to 1 million) and stable populations (r = -2% to 2%) with 25,000 simulations included to reduce the likelihood of statistical errors. Findings and recommendations include: (1) estimation bias and standard errors become too high for general use from a population of 5,000 or lower – with the estimation of confidence intervals and other statistical analyses not plausible, (2) population age composition is critical to the accuracy of estimating life expectancy in small populations, (3) there are no advantages in the use of abridged over unabridged lifetables, even with sparse age of death data, and (4) the exact procedure used for open age intervals is critical to life expectancy calculation in small populations.
Schmertmann, C. P., Cavenaghi, S. M., Assunção, R. M., & Potter, J. E. (2013). Bayes plus Brass: estimating total fertility for many small areas from sparse census data. *Population studies, 67*(3), 255-273. https://doi.org/10.1080/00324728.2013.795602	The authors propose a new method for estimating small area total fertility which tackles sparse data challenges, and is automated and reproducible. This method uses Empirical Bayes methods in order to smooth local age-specific rates by borrowing strength from neighbouring areas. Then a variant of Brass's P/F parity correction procedure is applied. The method was applied to data from over 5,000 municipalities in Brazil, using Brazilian Census data from 2000.
Schmertmann, C. P., & Hauer, M. E. (2019). Bayesian estimation of total fertility from a population's age–sex structure. *Statistical Modelling, 19*(3), 225-247. https://doi.org/10.1177/1471082X18801450	Good quality births data often do not exist, rendering estimates of the Total Fertility Rates very difficult. The authors explore the relationship between Total Fertility Rates and the Child/Woman Ratio. They develop a Bayesian approach to estimating TFR from age structures, using demographic information from sources such as the Human Fertility Database as prior inputs to the model. They illustrate their model with an application to an Indigenous population in Brazil and to counties in Georgia, USA.

Reference and URL	Key points
Simpson, L. (2017). Integrated local demographic forecasts constrained by the supply of housing or jobs: Practice in the UK. In D. A. Swanson (Ed.), *The frontiers of applied demography* (pp. 329-350). Springer. https://doi.org/10.1007/978-3-319-43329-5_16	Methods are presented for constraining a local area cohort-component population forecast to assumed numbers of dwellings or jobs. Consistency with either future dwelling or job numbers is achieved by adjusting migration flows, which in turn affects future births and deaths. The extent to which the inward rather than outward migration flows are adjusted, and local rather than overseas flows, is set by user-defined weights. Example forecasts were produced by the POPGROUP software, which incorporates the adjustment mechanisms.
Simpson, L., & Snowling, H. (2011). Estimation of local demographic variation in a flexible framework for population projections. *Journal of Population Research, 28*(2-3), 109-127. https://doi.org/10.1007/s12546-011-9060-7	Three ways of preparing input data for small area cohort-component forecasts are assessed for situations where age-specific fertility, mortality and migration data are unavailable, or available but prohibitively expensive or confidential. The No Local Variation option applies the wider region's fertility and mortality age profiles of rates and the same pair of in- and out-migration age profiles to all small areas. The Local Calibration option creates small area assumptions from a short-run training projection which constrains the No Local Variation assumptions using total recorded births and deaths in each area, and estimates age-sex specific migration from adjacent population estimates by age and sex. The Local Direct comparison projection uses small area fertility, mortality and migration age profiles of rates, directly estimated from data available to government. After empirical testing, the authors conclude that the Local Calibration option provides the most plausible forecasts.
Smith, S. K., Tayman, J., & Swanson, D. A. (2013). *A practitioner's guide to state and local population projections.* Springer. https://www.springer.com/gp/book/9789400775503	This book provides a comprehensive guide to the preparation of State/regional, local and small area population forecasts. It includes a detailed account of various types of cohort-component model, simple extrapolative models, structural models, and microsimulation models, as well as derived projections (school enrolments, households, labour force, etc.). It covers the preparation of fertility, mortality, and migration assumptions, and lots of practical advice on evaluating forecasts, special adjustments, forecast accuracy and uncertainty, model selection, and documentation.
Stimson, R., Bell, M., Corcoran, J., & Pullar, D. (2012). Using a large scale urban model to test planning scenarios in the Brisbane-South East Queensland region. *Regional Science Policy & Practice, 4*(4), 373-392. https://doi.org/10.1111/j.1757-7802.2012.01082.x	The authors describe a large-scale urban model to forecast population, dwellings, employment and other variables for the South East Queensland region of Australia over the period 2001 to 2026. Regional-level forecasts of dwellings and population are disaggregated to small areas via a land use development model of housing which considers (i) residential land capacity, (ii) proximity to existing development, and (iii) the accessibility of local areas to services. The purpose of the model was to support metropolitan regional planning and permit the assessment of alternative planning scenarios.

Reference and URL	**Key points**
Striessnig, E., Gao, J., O'Neill, B. C., & Jiang, L. (2019). Empirically based spatial projections of US population age structure consistent with the shared socioeconomic pathways. *Environmental Research Letters, 14*(11), 114038. https://doi.org/10.1088/1748-9326/ab4a3a	The authors describe the preparation of county population forecasts by broad age group across the USA consistent with various Shared Socioeconomic Pathway scenarios for the period 2010-2100. Instead of the cohort-component model, machine learning regression trees were used to forecast the share of a county's population in each age group based on past demographic characteristics. The model was trained using 1980-2000 census data and tested over the 2000-2010 period. This demonstrated a good fit. National projections by age and local population totals were obtained from elsewhere.
Swanson, D. A., Schlottmann, A., & Schmidt, B. (2010). Forecasting the population of census tracts by age and sex: An example of the Hamilton–Perry method in action. *Population Research Policy Review, 29*(1), 47-63. https://doi.org/10.1007/s11113-009-9144-7	The authors describe the preparation of population forecasts for census tracts and block groups in Clark County, Nevada, for the period 2000-2020. They applied the Hamilton-Perry shortcut cohort model with some constraints. Cohort Change Ratios were estimated from 1990-2000 population change, with adjustments applied by controlling forecasts to census tract population estimates for 2004. Ceiling and floor limits were also applied between 2005 and 2020 to prevent growth becoming too high or low. The paper includes a discussion of how demographers preparing forecasts work with a client to best meet their needs.
Tayman, J. (2011). Assessing uncertainty in small area forecasts: State of the practice and implementation strategy. *Population Research Policy Review, 30*(5), 781-800. https://doi.org/10.1007/s11113-011-9210-9	This paper presents a review of current practices in quantifying the uncertainty of small area population forecasts. They include: (1) alternative scenarios, (2) prediction intervals (both model-based and empirically-based), and (3) expert judgment. The author then goes on to describe some practical ways of implementing these methods, and makes suggestions for further research in this area.
Tayman, J., & Swanson, D. A. (2017). Using modified cohort change and child-woman ratios in the Hamilton–Perry forecasting method. *Journal of Population Research, 34*(3), 209-231. https://doi.org/10.1007/s12546-017-9190-7	The authors develop variations of the Hamilton-Perry where the Cohort Change Ratios and Child/Woman Ratios are modified through averaging, trending, or through a synthetic method that applies state-level changes of the ratios. These approaches were then compared against the standard Hamilton-Perry method where the ratios are kept constant. The analysis was undertaken on data for Washington State counties and New Mexico census tracts. Errors were reduced with the synthetic method, but not through averaging and trending the ratios.
Vasan, S., Baker, J., & Alcántara, A. (2018). Use of Kernel Density and Raster Manipulation in GIS to Predict Population in New Mexico Census Tracts. *Review of Economics Finance, 14*, 25-38. http://www.bapress.ca/ref/ref-article/1923-7529-2018-04-25-14.pdf	Boundary changes pose significant problems for small area population estimates and forecasts. This paper presents a method which uses kernel functions to disaggregate population data from census block counts into tiny pixels in GIS software. Population data can then be re-aggregated back to any larger geography. This approach was used to convert 1990 and 2000 census block counts in New Mexico into data based on 2010 census boundaries. The converted geography data was used to estimate 1990-2000 population change, and then census block population forecasts were created from 2000 to 2010. Evaluation against 2010 census data showed a mean absolute percentage error of 142% for census blocks and 30% for census tracts.

Reference and URL	Key points
Vidyattama, Y., & Tanton, R. (2010). Projecting Small Area Statistics with Australian Microsimulation Model (SPATIALMSM). *Australasian Journal of Regional Studies, 16*(1), 99-126. https://www.anzrsai.org/assets/Uploads/PublicationChapter/416-Vidyattama.pdf	The authors describe the use of a spatial microsimulation model to project small area socio-economic statistics. Specifically, a static ageing spatial microsimulation is presented for Australia at the Statistical Local Area (SLA) level. The model reweights respondents from 2002/03 and 2003/04 Survey of Income and Housing to 2006 Census of Population and Housing SLA benchmarks using iterative constrained optimisation techniques.
Walters, A., & Cai, Q. (2008). *Investigating the use of holt-winters time series model for forecasting population at the state and sub-state levels*. Paper presented at the Population Association of America 2008 Annual Meeting Program, New Orleans, LA. https://paa2008.princeton.edu/papers/80184	The paper describes the performance of the Holt-Winters (exponential smoothing) model, ARIMA models, and simple extrapolative models (linear and exponential) for forecasting total populations. Retrospective forecasts were created for US states, and counties and planning districts in Virginia, USA. Differences in average errors were modest, though Holt-Winters was most accurate overall for 5 year forecast horizons and the exponential model for 10 year horizons. The authors conclude that the "Holt-Winters model provides both feasible and accurate population forecasts at the state and sub-state levels."
Weber, H. (2020). How Well Can the Migration Component of Regional Population Change be Predicted? A Machine Learning Approach Applied to German Municipalities. *Comparative Population Studies, 45*. https://doi.org/10.12765/CPoS-2020-08	The authors present several models to predict within-country and international migration at the municipal level in Germany. The evaluation included regression, decision tree, random forest, and neural network models. Data from 2005-2009 were used to train the models and support the prediction of net migration rates for the 2011-2015 period. The data included socio-economic and demographic indicators, and other characteristics (e.g. distance to universities). The correlations of the predicted net migration rate for 'education migration' (ages 18-24) with actual migration data was $R^2 > 0.5$ while for 'family migration' (ages 0-17 and 30-49) $R^2 = 0.25$.
Wilson, T. (2011). *A review of sub-regional population projection methods*. Queensland Centre for Population Research, The University of Queensland. https://www.researchgate.net/publication/279535374_A_Review_of_Sub-Regional_Population_Projection_Methods	This report reviews many local and small area population forecasting methods, including: trend extrapolation, time series models, regression approaches, simple component methods, economic base methods, the housing-unit model, land use models, shortcut component methods, cohort-component models, and microsimulation. It also considers averaged methods, integrated methods which involve several connected models, and the projection of migration in cohort-component models. Methods are reviewed according to several criteria relevant to state government demographers selecting an optimum projection method.

Reference and URL	Key points
Wilson, T. (2015). New evaluations of simple models for small area population forecasts. *Population, Space and Place, 21*(4), 335-353. https://doi.org/10.1002/psp.1847	The paper presents an evaluation of simple methods for forecasting the total populations of small areas. The selected methods consisted of 10 individual models, averages of every combination of 2, 3, 4 and 5 models, and composite approaches which use different models depending on population size and recent growth rates. Example small area population forecasts for Australia, New Zealand, and England & Wales were evaluated. A small proportion of averaged and composite models proved more accurate than the best individual models, supporting other research which has found that model combining improves accuracy.
Wilson, T. (2014). Simplifying Local Area Population and Household Projections with POPART. In M. N. Hoque & L. B. Potter (Eds.), *Emerging Techniques in Applied Demography* (pp. 25-38). Springer Netherlands. http://dx.doi.org/10.1007/978-94-017-8990-5_3	The chapter describes POPART, an Excel/VBA projection program for individual local or small areas. It includes a bi-regional cohort-component model (based on transition population accounts) with 5 year age group and time intervals, and a householder rate household model. It was designed to simplify the projections process by only using publicly available input data, providing a user-friendly interface with pull-down menus and buttons, and simple assumption-setting primarily using summary indicator assumptions (e.g. the TFR). Example projections for the local government area of Noosa, Australia, are shown.
Wilson, T. (2016). Evaluation of alternative cohort-component models for local area population forecasts. *Population Research Policy Review, 35*(2), 241-261. https://doi.org/10.1007/s11113-015-9380-y	The author describes an evaluation of five types of cohort-component model, which differ in the way they include migration. Retrospective forecasts for 67 local government areas of New South Wales, Australia, were produced for the projection horizon 1991 to 2011, and the results compared to actual population estimates. Two sets of forecasts were prepared: (i) unconstrained forecasts and (ii) forecasts constrained to population totals from an extrapolative model. The constrained forecasts proved considerably more accurate; the constrained bi-regional model gave the most accurate age-specific forecasts (by a small margin).
Wilson, T. (2017b). Does averaging yield more accurate local and regional population forecasts? *Applied Spatial Analysis and Policy, 10*(4), 497-513. https://doi.org/10.1007/s12061-016-9194-2	The paper reports an evaluation of the Constant Share of Population – Variable Share of Growth (CSP-VSG) averaged model for forecasting total populations. It was applied to SA2, SA3 and SA4 geographies of Australia (median populations about 9,000, 57,000 and 224,000, respectively) over several 10 year forecast horizons. Comparisons were made with published population estimates and forecasts from a simple linear extrapolation. The CSP-VSG model outperformed the linear model and gave respectable levels of accuracy. Median Absolute Percentage Errors were 6-8% for SA2s, 3-6% for SA3s and 2-4% for SA4s after 10 years.

Reference and URL	**Key points**
Wilson, T., & Rowe, F. (2011). The forecast accuracy of local government area population projections: a case study of Queensland. *The Australasian Journal of Regional Studies, 17*(2), 204-243. https://www.anzrsai.org/assets/Uploads/PublicationChapter/464-WilsonandRowe.pdf	The authors present an analysis of the accuracy of seven past rounds of official local government area population projections for Queensland, Australia. Error was found to be positively associated with projection horizon length and negatively associated with population size. Areas with large Indigenous populations and areas with lots of mining activity were particularly poorly forecast. Overall, the projections were more accurate than forecasts obtained by simple linear extrapolation.
Wilson, T., Brokensha, H., Rowe, F., & Simpson, L. (2018). Insights from the evaluation of past local area population forecasts. *Population Research Policy Review, 37*(1), 137-155. https://doi.org/10.1007/s11113-017-9450-4	The authors present an evaluation of local area projections produced by State/Territory governments in Australia over the last 30 years for forecast horizons of 5, 10, 15 and 20 years ahead. Forecast errors were found to be high for areas with the smallest populations, especially those with populations under 2,000. The concept of a forecast 'shelf life' is introduced, defined as "how far into the future a forecast is likely to remain within a certain error margin". Shelf lives are calculated from past errors as the number of years ahead the error of 80% of local area forecasts remained within 10% absolute percentage error. This varies greatly by jump-off population size. Empirical prediction intervals are also calculated and applied to recent forecast examples.
Wu, B., & Birkin, M. (2013). Moses: A Dynamic Spatial Microsimulation Model for Demographic Planning. In R. Tanton & K. Edwards (Eds.), *Spatial Microsimulation: A Reference Guide for Users* (pp. 171-193). Springer Netherlands. https://doi.org/10.1007/978-94-007-4623-7_11	This book chapter discusses the benefits of microsimulation methods for the modelling of detailed individual characteristics, and the ability of dynamic microsimulation models to update and project the characteristics of populations of individuals. The authors introduce Moses, a dynamic microsimulation model which allows for detailed forecasts at the small area level. Moses simulates the UK population over the period from 2001 to 2031. The modelling approach is described and visualisations are provided for projected changes in age-sex structure, mortality, and student populations.
Wu, B. M., Birkin, M. H., & Rees, P. H. (2010). A Dynamic MSM With Agent Elements for Spatial Demographic Forecasting. *Social Science Computer Review, 29*(1), 145-160. https://doi.org/10.1177/0894439310370113	In this paper the authors work to develop Moses, a dynamic microsimulation model of the UK which simulates populations at the individual level at a small area level, to support policy and decision making. They demonstrate the use of Moses in two experiments. First, they describe how Moses can be used to model the migration of higher education students, with consideration for the students' education level. Second, the authors describe how their method allows personal history to be used to support the projection of mortality, enabling characteristics such as a person's work history or previous places of residence to be used to calculate their mortality/morbidity probabilities.

Reference and URL	Key points
Xanthos, G., Ladias, C. A., & Genitsaropoulos, C. (2013). A method for forecasting population changes in alpine, semi-alpine and lowland communities of Epirus region in Greece. *Regional Science Inquiry Journal, 1*, 173-179. http://www.rsijournal.eu/ARTICLES/June_2013/11.pdf	The authors report an evaluation of share of population and share of population growth models, including the authors' preferred shift-share model, to predict small area populations in communities within the Epirus region in Greece. The populations of communities proved difficult to predict for all of these methods, with all MAPEs being >20% for a 10 year forecast horizon (though the small area population sizes are not stated).
Zhang, J. L., & Bryant, J. (2020). Bayesian disaggregated forecasts: internal migration in Iceland. In S. Mazzuco, & N. Keilman (Eds.), *Developments in Demographic Forecasting* (pp. 193-215). Springer. https://doi.org/10.1007/978-3-030-42472-5_10	Estimates and forecasts of internal migration by age and sex at the local level are important for local planning, but small counts and erratic patterns can make using traditional methods difficult. The authors present a Bayesian modelling strategy for estimating age-sex patterns of internal migration in Iceland. The model includes effects for age, sex, time, region and various interaction effects.
Zoraghein, H., & O'Neill, B. C. (2020a). A spatial population downscaling model for integrated human-environment analysis in the United States. *Demographic Research, 43*, 1563-1606. https://doi.org/10.4054/DemRes.2020.43.54	The authors describe an evaluation of a model which disaggregates US state populations to 1 km^2 grid squares. A gravity-type model was used for the downscaling, specified individually for each state and for its rural/urban population. Forecast population increase was allocated to grid cells proportional to its modelled 'suitability for growth' based on many variables (with decrease distributed to the inverse of its suitability). An evaluation was undertaken by 'forecasting' from 2000 to 2010 and comparing forecasts with actual 2010 population estimates. Lower errors were found for urban grid square projections with larger populations.
Zoraghein, H., & O'Neill, B. C. (2020b). US State-level Projections of the Spatial Distribution of Population Consistent with Shared Socioeconomic Pathways. *Sustainability, 12*(8), 3374. https://doi.org/10.3390/su12083374	The authors describe how small area population forecasts for the contiguous US were prepared for the horizon 2010-2100. A gravity-based model (as described in Zoraghein and O'Neill 2020a) was used to distribute State population forecasts consistent with three of the Shared Socioeconomic Pathways to 1 km^2 grid squares.