Forecast accuracy and uncertainty of Australian Bureau of Statistics State and Territory population projections

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Abstract
Errors from past rounds of population projections provide diagnostic information which may be used to improve future projections; they can also form the basis of guidance for users on the likely uncertainty of current projections. This paper assesses the forecast accuracy of official Australian Bureau of Statistics (ABS) population projections for the States and Territories of Australia. It is the first major study to do so. The paper assesses projections of total population, population growth, and age-specific populations of the States and Territories. It also examines how ABS projections of total population performed against simple linear extrapolations, and whether they became more accurate over time. Under the assumption of temporal stability in the magnitude of error, empirical prediction intervals are created from past errors and applied to the current set of ABS projections.

Key words
Population projections, forecast error, Australia, States and Territories, prediction intervals

Abbreviations

Australian States and Territories

NSW   New South Wales
Vic   Victoria
Qld   Queensland
SA   South Australia
WA   Western Australia
Tas   Tasmania
NT   Northern Territory
ACT   Australian Capital Territory

ABS   Australian Bureau of Statistics
APE   Absolute Percentage Error
ACPE   Absolute Corrected Percentage Error
CPE   Corrected Percentage Error
ERP   Estimated Resident Population
MAPE   Mean Absolute Percentage Error
MedAPE Median Absolute Percentage Error
MedPE   Median Percentage Error
MPE   Mean Percentage Error
PE   Percentage Error
PRE   Proportionate Reduction in Error
WMAPE   Weighted Mean Absolute Percentage Error

1. Introduction

Population projections for States, provinces, statistical regions and other major subnational areas are produced periodically by government agencies for a variety of planning purposes. Ex-post evaluations of the forecast accuracy of such projections remain comparatively rare, even though there are good reasons for undertaking such work. For example, they may reveal hitherto concealed deficiencies in methods, assumption-setting or data which can be resolved in future projection rounds. In addition, past errors can provide users with guidance on the approximate magnitude of error which current forecasts might be subject to. Ideally, past errors would be used to create prediction intervals for current forecasts, either in the form of empirical prediction intervals based directly on the observed error distributions (e.g. Stoto 1983; Smith & Rayer 2010) or in the form of fully probabilistic forecasts in which error distributions for demographic rates are mimicked by time series models (e.g. Keilman et al. 2002; Bell et al. 2011).

Population projections for Australia's States and Territories have been published on a regular basis by the Australian Bureau of Statistics (ABS) since the late 1970s. They constitute the official population projections for Australia, are generally highly regarded, and are widely used and cited by government, researchers, business, and the media. Yet to date no comprehensive evaluation of ABS State and Territory projections has been published, although brief assessments have been made by Adam (1992) and the ABS (2000a), and an evaluation of ABS projections at the national scale was completed by Wilson (2007). Bell and Skinner (1992) assessed projections prepared by State and Territory governments and academics, but not those of the ABS. Published evaluations of State/regional projections for other countries include Statistics New Zealand (2008) for New Zealand, ONS (2008) for the UK, Rees et al. (2001) for European Union regions, Smith and Rayer (2011) for Florida and Wang (2002) for all US States. In common with national level evaluations these studies have found that forecast errors tend to be positively associated with projection duration and negatively associated with population size.

The purpose of this paper is to determine how well ABS State and Territory projections performed as forecasts of future population, and to make use of past forecast errors to create predictive distributions for the current round of ABS projections. In doing so the paper aims to provide the first detailed analysis of ABS State and Territory forecast error and uncertainty, as well as contributing a new subnational-scale case study to the international literature. Particular features of this analysis which are rare in the literature include an examination of errors by age group and a focus on error distributions as well as averages. Specifically, the paper seeks to address the following questions.
(1) How well did ABS projections by State and Territory perform as forecasts? How accurate were projections of total population, total population change, and age-specific populations?
Second, to examine the amount of 'value added' by the ABS as a result of their methods and careful assumption-setting, ABS projections of population totals are compared with naive projections created by a very simple model. Thus the second question is:
(2) Did the ABS projections of total population provide more accurate forecasts than linear extrapolation?
Third, one would hope that improvements in data, theory and methods in demography would be reflected in more accurate projections over time. The paper therefore asks:
(3) Have ABS projections of State and Territory total populations become more accurate over time?
Finally, past errors are used to inform the future:
(4) Assuming the magnitude of past errors continues into the future, how much uncertainty surrounds the current ABS medium series projections?

On the matter of terminology, many producers of projections stress that they only produce projections and not forecasts, and the ABS is no exception. They assert that their projections "are not intended as predictions or forecasts, but are illustrations of growth and change in the population that would occur if assumptions made about future demographic trends were to prevail over the projection period" (ABS 2008 p 2). However, most users will nonetheless interpret medium series projections as forecasts. Following Smith (1987), the data under examination are termed projections but they are assessed as if they were forecasts, and references are therefore made to 'forecast accuracy' and 'forecast error'.

The paper continues as follows. Section 2 includes a description of the projections and estimates data used to undertake this forecast error analysis and definitions of the various error measures employed. Findings which provide answers to the first three research questions are the focus of section 3, whilst section 4 attempts to apply distributions of past errors to the current set of ABS State and Territory projections in the form of empirical prediction intervals. The conclusions consist of a summary of key findings, lessons learnt from this evaluation, and some suggestions for further research.

2. Data and methods

2.1. ABS population projections data

Population projections data were obtained from the ABS *Population Projections, Australia* publications (and earlier volumes with a variety of titles) in both electronic and hard-copy formats. Data on total and age disaggregated populations from twelve projection rounds were examined, starting with the 1978-based round and extending to the most recent 2006-based set. Projections for broad age groups only were published in the 1978- and 1981-based projections (0-14, 15-44, 45-64 and 65+) whilst at least five year age detail is available for all later rounds.

All projections from the 1981-based round onwards refer to the usually resident population at 30th June each year. The 1978-based projections, however, were produced at a time when ABS used a 'persons present' definition of population, shortly before they switched to a usually resident definition. Error measures for the 1978-based round were adjusted to take account of this difference (as explained below in the section on error measurement).

The ABS has often produced many alternative projection series, and has deliberately avoided labelling any of them as forecasts. Users, however, have a tendency to interpret one of the series as a forecast. From the 2002-based projections onwards three main series have been produced, A, B and C, with series B providing total projected populations lying clearly between series A and C. Understandably, users have generally interpreted series B as the forecast. Prior to the 2002-based projections, the question is more difficult to answer because some rounds contain four main series, whilst other rounds have three main series but with no single series clearly occupying a middle position. The approach taken here was to select series on the basis of total projected population, choosing the middle trajectory where there were three to choose from, and the middle two in cases where four main series were published. In some circumstances, especially where two series possess almost identical total populations, judgement overrode these rules (for example, the 1999-based projections for Victoria and South Australia have two series which hardly differ in total population, so all three series were chosen). The selected series are listed in Table 1 below.

Table 1: ABS population projection series interpreted as forecasts in this study

Jump-off year	NSW	Vic	Qld	SA	WA	Tas	NT	ACT	Publication
1978	A	A	A	A	A	A	A, D	A	ABS (1979)
1981	B, C	B, C	B, C	B, C	B, C	B, C	B, C	B, C	ABS (1983)
1984	A	A	B, C	A	B, C	A, D	B, C	B, C	ABS (1985)
1987	B, C	B, C	A, C	B, C	A, C	B	A, C	A, C	ABS (1988)
1989	A, C	A, C	B, C	B, C	B, C	B, C	A, D	B, C	ABS (1990)
1993	B, C	B, C	A	B, D	A	A, D	A, D	A	ABS (1994)
1995	A	A	A, C	A, D	A, B	A, D	A, D	A, C	ABS (1996)
1997	II	II	II	II	II	II	II	II	ABS (1998)
1999	II	I, II, III	II	I, II, III	II	II	II	II	ABS (2000b)
2002	B	B	B	B	B	B	B	B	ABS (2003)
2004	B	B	B	B	B	B	B	B	ABS (2005)
2006	B	B	B	B	B	B	B	B	ABS (2008)

2.2. Naïve populations projections data

ABS projections of total population from the series listed above were compared to naïve projections of total population with the same jump-off years. These naïve projections were generated by extrapolating from linear regressions fitted over a ten year base period. Linear extrapolation was

chosen because it is easy to calculate and is one of the most accurate of simple population projection methods (e.g. Openshaw and van der Knapp 1983; Smith and Shahidullah 1995).

2.3. Population estimates data

Projections were assessed against subsequently published 30th June Estimated Resident Populations (ERPs), the official usually resident population count for Australia produced by the ABS (ABS 2009). An important assumption in any assessment of population projections such as this is that ERPs represent accurate counts of the usually resident population. Being based on census counts, vital statistics and migration estimates, all of which contain some degree of inaccuracy, ERPs will never provide a perfect count of the population, but they are nonetheless the best estimates available. It should also be noted that ERPs are adjusted following each census. For this paper, ERPs up to and including 2006 were final figures not subject to any further adjustment, but at the time of writing 2007-11 ERPs were post-censal estimates and will be finalised next year to take into account 2011 census results.

2.4. ABS projection method

The projections assessed in this paper were all produced by a standard cohort-component model with population disaggregated by sex and single years of age. Details, including projection equations, are given in ABS (1999). Fertility assumptions are specified in terms of the Total Fertility Rate, mortality assumptions by life expectancy at birth, and both overseas migration and interstate migration assumptions are summarised as annual average net totals. The ABS projection model does handle directional migration flows however. Preliminary projections of directional migration are iteratively adjusted to agree with the specified net totals.

2.5. Error measures

Error is defined as the forecast population minus the ERP. To standardise for varying population sizes between States and Territories and over time, **Percentage Errors** (PE) were calculated:

$$PE^i(t) = \frac{Forecast^i(t) - ERP^i(t)}{ERP^i(t)} 100$$

where $Forecast$ denotes the population forecast, ERP the subsequently published Estimated Resident Population, and t a chosen year in the projection horizon. Positive values indicate over-projections whilst negative values reflect an under-projection. When just the extent (and not direction) of error was of concern **Absolute Percentage Errors** were used. These are Percentage Errors with all negative signs ignored, i.e.

$$APE^i(t) = \frac{|Forecast^i(t) - ERP^i(t)|}{ERP^i(t)} 100.$$

For some purposes a modified Percentage Error measure was used which removes any jump-off year error. This **Corrected Percentage Error** (CPE) (Keilman 1999) is defined as:

$$CPE^i(t) = \frac{Forecast^i(t) - ERP^i(t) - \left(Forecast^i(0) - ERP^i(0)\right)}{ERP^i(t)} 100$$

where 0 denotes the jump-off year. This measure was used in place of PE to calculate errors of the 1978-based projections because they were produced on a 'persons present' population base which is inconsistent with ERPs. Its absolute version, **Absolute Corrected Percentage Error** (ACPE) was employed to measure the error of all the projections listed in Table 1 for the creation of empirical prediction intervals. Section 4 explains how ACPE was used.

To assess the degree of error across many observations, several average error values were used. The first of these, **Mean Percentage Error** (MPE), is calculated as:

$$MPE(t) = \frac{\sum_i PE^i(t)}{n} \, 100$$

where n is the number of observations. MPE is a measure of bias: it indicates whether a set of projections was, overall, too high (positive values) or too low (negative values). **Mean Absolute Percentage Error** (MAPE) is similar to MPE except that it measures the absolute value of error only. It is calculated as:

$$MAPE(t) = \frac{\sum_i APE^i(t)}{n} 100.$$

MAPE gives equal weighting to each APE of which it is the mean. Thus any MAPE for 8 States and Territories includes a weighting of 1/8 for each APE. **Weighted Mean Absolute Percentage Error** (WMAPE), which weights each APE by population size, provides an alternative perspective. It is defined as:

$$WMAPE(t) = \sum_i \left(APE^i(t) \frac{ERP^i(t)}{\sum_i ERP^i(t)} \right) 100.$$

WMAPE is particularly appropriate when population sizes vary considerably, as they do across Australian States and Territories. Effectively this measure regards the absolute size of errors across observations as more important than percentage errors. WMAPE is equivalent to the MAD/mean ratio (Mean Absolute Deviation/mean population) (Kolassa and Schutz 2007) and Mean Percentage Absolute Deviation (Murdock et al. 1984).

Where there is a small sample or a skewed distribution, it is often sensible to use median errors. **Median Percentage Error** (MedPE) is the middle value of a set ranked PEs, whilst **Median Absolute Percentage Error** (MedAPE) is the middle value of a set of ranked APEs.

For assessing errors in projected growth over certain periods, rather than population stocks at points in time, **Stoto's Δr** can be used. It is defined as the forecast annual average growth rate from the jump-off year to year t minus the actual growth rate, multiplied by 100:.

$$\Delta r(t) = \left(ln \left[\left(\frac{Forecast^i(t)}{Forecast^i(0)} \right) / (t-0) \right] - ln \left[\left(\frac{ERP^i(t)}{ERP(0)} \right) / (t-0) \right] \right) 100.$$

Percentage Better describes the percentage of projections forecast more accurately by method A than method B (Armstrong 2001).

To assess the improvement in accuracy of ABS projections over those obtained from linear extrapolation, the **Proportionate Reduction in Error** (PRE) (Swanson and Tayman 1995) was calculated, in this case using WMAPE. It was calculated as:

$$PRE(t) = \frac{WMAPE(t) \, of \, linear \, extrpolation - WMAPE(t) \, of \, ABS \, projections}{WMAPE(t) \, of \, ABS \, projections} \, 100.$$

3. Forecast error

3.1. Error in projecting total populations

Figure 1 illustrates Percentage Errors of State and Territory total populations at 5, 10 and 15 year projection durations plotted by jump-off year population size. Each symbol on the graphs represents the Percentage Error of an individual projection, with those symbols located above the bold horizontal line indicating over-projections, and those below it, under-projections. The '5 year projection duration' graph includes all projection series listed in Table 1 whilst the '10 year' and '15 year' graphs exclude recent projections for which 10 and 15 year errors are not yet known.

It can be seen that errors tend to be larger for smaller populations, such as those of the Northern Territory and Australian Capital Territory, whilst the more populous states, especially New South Wales, have experienced smaller errors. This finding is consistent with many other forecast accuracy studies (e.g. Statistics New Zealand 2008; ONS 2008). However, the population-error relationship is fairly weak, with the smaller states of Tasmania and South Australia generally enjoying more accurate population forecasts than Queensland and Western Australia which have bigger populations. In common with many other forecast accuracy studies the graphs also show widening distributions of error with increasing projection duration.

Table 2 presents selected Percentage Error statistics to accompany the scatter plots of Figure 1. The top panel shows Median Absolute Percentage Errors at projections durations of 0, 5, 10 and 15 years, where a projection duration of 0 years refers to the jump-off year error. Such errors arise from projections starting in non-census years before ERPs are finalised following the next census. With the exception of the Northern Territory these errors are not substantial. As projection duration increases, these MedAPEs tend to increase. In fact, for all States and Territories, MedAPEs at projection durations of 10 years exceed those at 5 years, and 15 year MedAPEs exceed those at 10 years.

To what extent were the projections, on average, too high or too low over their first 15 years? The Median Percentage Errors in the second panel of Table 2 demonstrate little bias for New South Wales and South Australia. The population of fast-growing Queensland was under-projected at durations of 10 and 15 years, whilst the populations of the two territories (NT and ACT) were on average over-projected after 10 and 15 years.

The bottom three panels of the table confirm and quantify the widening of error distributions with increasing projection duration illustrated by the scatter plots. Following Lutz et al. (2004) 80% intervals have been calculated. These intervals refer to the middle 80% of ranked Percentage Errors, so that 10% of Percentage Errors occur above the upper bound and similarly, 10% fall below the lower bound. An 80% interval is useful in this case because with a small number of observations it reduces the likelihood of including outliers (which would not always be the case if a 95% interval had been chosen) whilst still covering the majority of errors. The bottom panel reports the width of the 80% interval (the upper bound minus the lower bound). Clearly there is a strong positive association between projection duration and interval width, or to express it another way, between projection duration and total population forecast uncertainty.
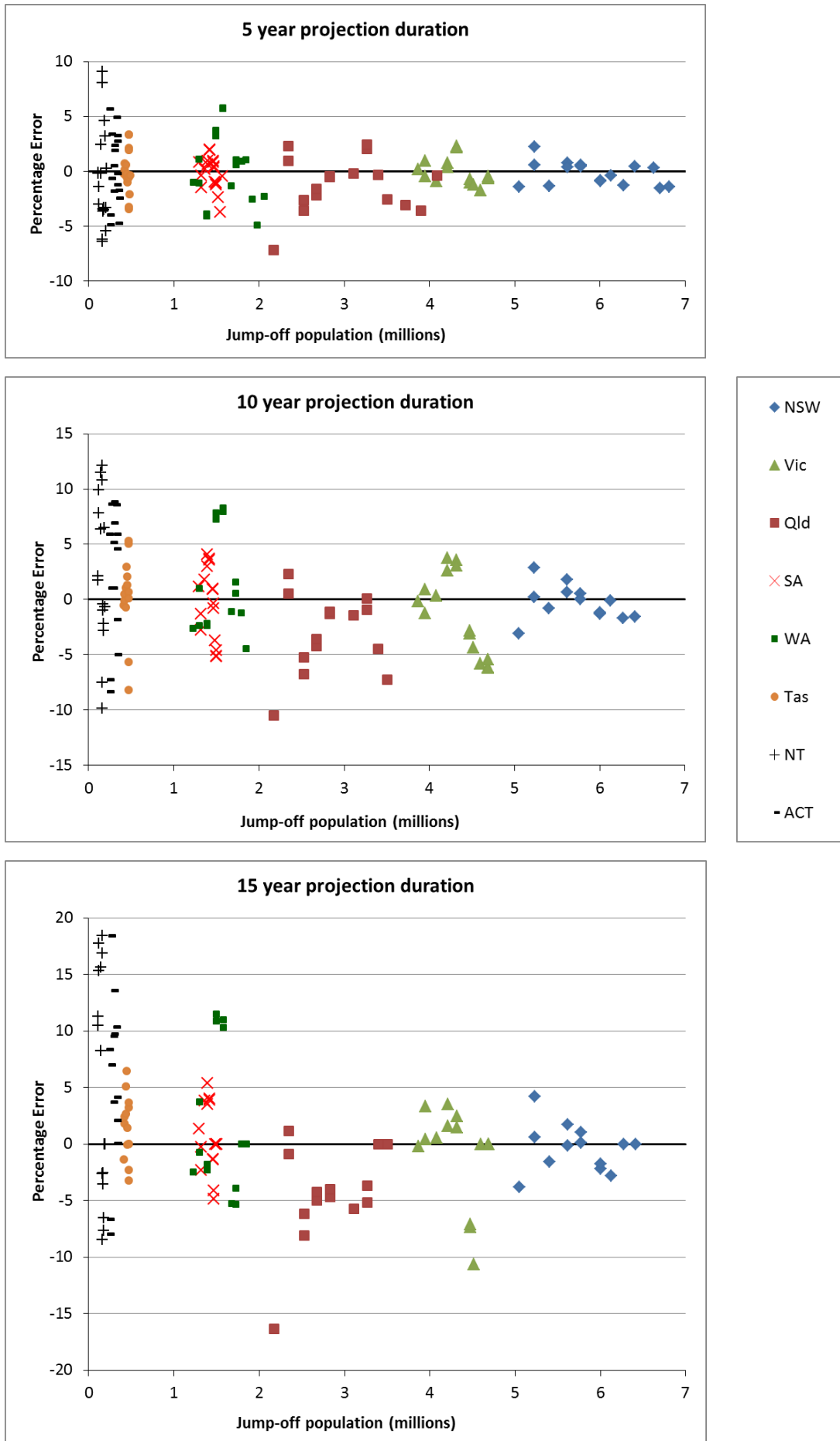
Figure 1: Percentage Errors of ABS State and Territory projections of total population at 5, 10 and 15 year projection durations by jump-off population size.

Source: author's calculations using ABS projections and ERP data

Table 2: Selected Percentage Error statistics for ABS State and Territory projections of total population by projection duration

Projection duration (years)	NSW	Vic	Qld	SA	WA	Tas	NT	ACT
				MedAPE (%)				
0	0.06	0.11	0.20	0.11	0.17	0.11	0.95	0.23
5	0.78	0.94	2.20	0.96	2.32	0.72	3.35	2.52
10	1.15	3.11	2.92	2.87	2.38	1.17	6.44	5.83
15	1.72	2.43	4.82	3.67	4.62	2.50	9.47	8.15
				MedPE* (%)				
0	0.00	0.02	0.06	0.04	0.00	-0.11	-0.95	0.00
5	-0.06	-0.63	-0.53	0.17	0.58	-0.28	-1.44	-0.24
10	-0.08	-1.21	-2.50	0.28	-0.30	0.57	1.92	4.78
15	-0.15	0.56	-4.82	0.53	-1.32	2.08	9.34	7.59
			Upper bound of middle 80% of PE values (%)					
0	0.12	0.55	0.34	0.33	0.78	0.01	0.11	0.48
5	0.68	1.33	2.15	1.16	4.52	2.58	5.29	3.94
10	1.56	3.38	0.38	3.66	7.90	4.41	11.15	8.57
15	1.72	3.34	-1.20	4.03	10.98	4.92	17.47	13.19
			Lower bound of middle 80% of PE values (%)					
0	-0.08	-0.26	-0.49	-0.35	-0.39	-0.54	-2.44	-0.43
5	-1.40	-1.96	-3.57	-1.63	-3.98	-2.56	-5.60	-4.34
10	-1.66	-6.00	-7.08	-4.84	-2.58	-4.21	-5.17	-6.65
15	-2.83	-7.35	-7.92	-3.97	-5.16	-2.23	-7.32	-5.86
			Width of 80% interval of PE (%)					
0	0.20	0.81	0.83	0.68	1.16	0.55	2.55	0.91
5	2.08	3.30	5.72	2.79	8.50	5.14	10.89	8.28
10	3.22	9.37	7.46	8.50	10.48	8.63	16.31	15.22
15	4.55	10.70	6.72	7.99	16.13	7.15	24.79	19.04

Source: author's calculations using ABS projections and ERP data

* Negative values of MedPE indicate projections which were too low on average; positive values indicate projections which were too high.

3.2. Error in projecting population growth

Many forecast accuracy studies focus on the error in projecting the population at specific points in time. For some projection users this is less important than the projected *change* in population over a specified period. A useful measure in this respect is Stoto's Δr, the difference between the forecast and the actual annual average percentage growth rate between the jump-off year and a selected point in the projection horizon (Stoto 1983). Table 3 presents median and median absolute values of Stoto's Δr along with the upper and lower bounds of the interval spanning 80% of the Δr error distribution.

The median absolute values of Δr describe the amount of error irrespective of whether projected growth rates were too high or too low. Over short projection durations of five years growth was, on average, projected most accurately for New South Wales and South Australia. Growth in Queensland and WA was not particularly well forecast, whilst the Northern Territory and ACT suffered the worst growth forecasts. Notice how, unlike the error of population numbers, median absolute Δr often contracts with projection duration. This is due to positive and negative errors from year to year offsetting one another, thus reducing the annual average population growth rate error over time.

The median values of Δr (Table 3, second panel from the top) indicate the extent of bias in projecting population growth rates. Negative values, such as those for Queensland, denote under-projections of annual average growth rates, whilst positive values, such as those for the Northern Territory, signify over-predictions of growth. There was little bias in growth projections for New South Wales and South Australia.

Table 3: Selected statistics of Stoto's Δr for ABS State and Territory projections of population change by projection duration

Projection duration (years)	NSW	Vic	Qld	SA	WA	Tas	NT	ACT
Median absolute Δr (%)								
5	0.17	0.19	0.39	0.16	0.47	0.14	0.54	0.51
10	0.12	0.30	0.30	0.28	0.21	0.17	0.55	0.59
15	0.12	0.16	0.34	0.23	0.31	0.17	0.65	0.56
Median Δr (%) *								
5	-0.01	-0.17	-0.15	0.00	0.09	0.00	-0.26	-0.10
10	0.01	-0.13	-0.26	0.01	-0.02	0.06	0.15	0.47
15	0.00	0.04	-0.34	0.04	-0.07	0.15	0.65	0.50
Upper 80% bound of Δr distribution (%)								
5	0.15	0.26	0.36	0.20	0.77	0.52	1.10	0.80
10	0.16	0.33	0.03	0.32	0.68	0.44	1.18	0.79
15	0.12	0.22	-0.08	0.28	0.66	0.33	1.11	0.78
Lower 80% bound of Δr distribution (%)								
5	-0.28	-0.41	-0.61	-0.33	-0.69	-0.50	-0.68	-0.78
10	-0.16	-0.66	-0.73	-0.46	-0.26	-0.43	-0.28	-0.66
15	-0.18	-0.49	-0.50	-0.29	-0.35	-0.14	-0.36	-0.40
Width of 80% Δr distribution (%)								
5	0.43	0.66	0.97	0.54	1.45	1.02	1.78	1.58
10	0.33	0.99	0.76	0.78	0.94	0.87	1.46	1.45
15	0.30	0.71	0.42	0.57	1.01	0.47	1.48	1.17

Source: author's calculations using ABS projections and ERP data

* Negative values of Δr indicate under-projections of growth; positive values indicate over-projections.

The upper and lower bounds of the distribution spanning the middle 80% of the Δr distribution are given in the third and fourth panels of the table. For example, it is shown that over the first five years of the projections 80% of annual average growth rate errors for New South Wales fell within the range 0.28% below the actual annual average growth rate to 0.15% above it. At the other end of the scale is the Northern Territory, where 80% of annual average growth rate projections over the first five years ranged from 0.68% below the actual growth rate to 1.86% above it. The width of 80% Δr intervals is given in the bottom panel of Table 3.

3.3. Error in projecting age-specific populations

For many projection users it is not total population which is of primary concern, but projections of policy-relevant age groups, such as school-age children and the very elderly. This sub-section reports on the accuracy of projections by five year age group from the 1984-based projections onwards (five year age detail was not published for earlier projection rounds). Figure 2 presents Median Absolute Percentage Errors by State/Territory and age group after 0, 5, 10 and 15 year projection durations.

For most States and Territories projections for 0-4 year olds were, on average, less accurate than those for older children. This concurs with evidence from other subnational and national studies (e.g.

Keilman 1997, Smith & Tayman 2003). The finding is not surprising given that projections for these infants suffer from both error in projections of births and error in projections of demographic processes once they enter the population.

Errors were often larger than average at ages 25-34, reflecting relatively high migration rates at the young adult stage of the life course. This is particularly the case for the Australian Capital Territory and is almost certainly due to rates of interstate migration being very high and fluctuating (ABS 2011), and hence difficult to forecast. Although smaller in magnitude, errors at these ages are relatively high for South Australia and Tasmania at projection durations of 10 and 15 years. These findings contrast somewhat with forecast error patterns for national populations where the absolute error pattern by age tends to be u-shaped due to the dominance of fertility and mortality errors (e.g. Keilman 2005 Shaw 2007).

At the older working ages and younger elderly ages errors generally proved to be smaller. Projections should be more accurate at these ages because these stages of the life course are not usually subject to high rates of mortality or long-distance migration. Projections should therefore be closely related to the numbers living in each State and Territory 5, 10 or 15 years earlier. At the highest ages average errors tend to increase a little, especially for the Northern Territory and Australian Capital Territory. The Northern Territory is particularly affected by jump-off errors at these ages, whilst both territories have probably also suffered from errors in projected mortality, and also migration given the migratory nature of these populations.

In Figure 3 the focus switches from average errors to their distribution. It shows the distribution of Percentage Errors by age group for 10 year projection durations, illustrating both the median and upper and lower bounds of the middle 80% of errors. Although the number of projection rounds is quite small (between 10 and 12), resulting in a fair degree of random fluctuation, a number of patterns can be seen. The largest median PEs and widest ranges can be seen in the Northern Territory elderly populations and the ACT young adult populations. In most States and Territories the elderly population is under-projected, reflecting repeated under-projections of life expectancy (Wilson 2007). The exception to this is Queensland where under-projections of life expectancy were probably offset by over-projections of net migration gains. Unlike many other studies, there is no universal pattern of over-projections at the youngest ages.
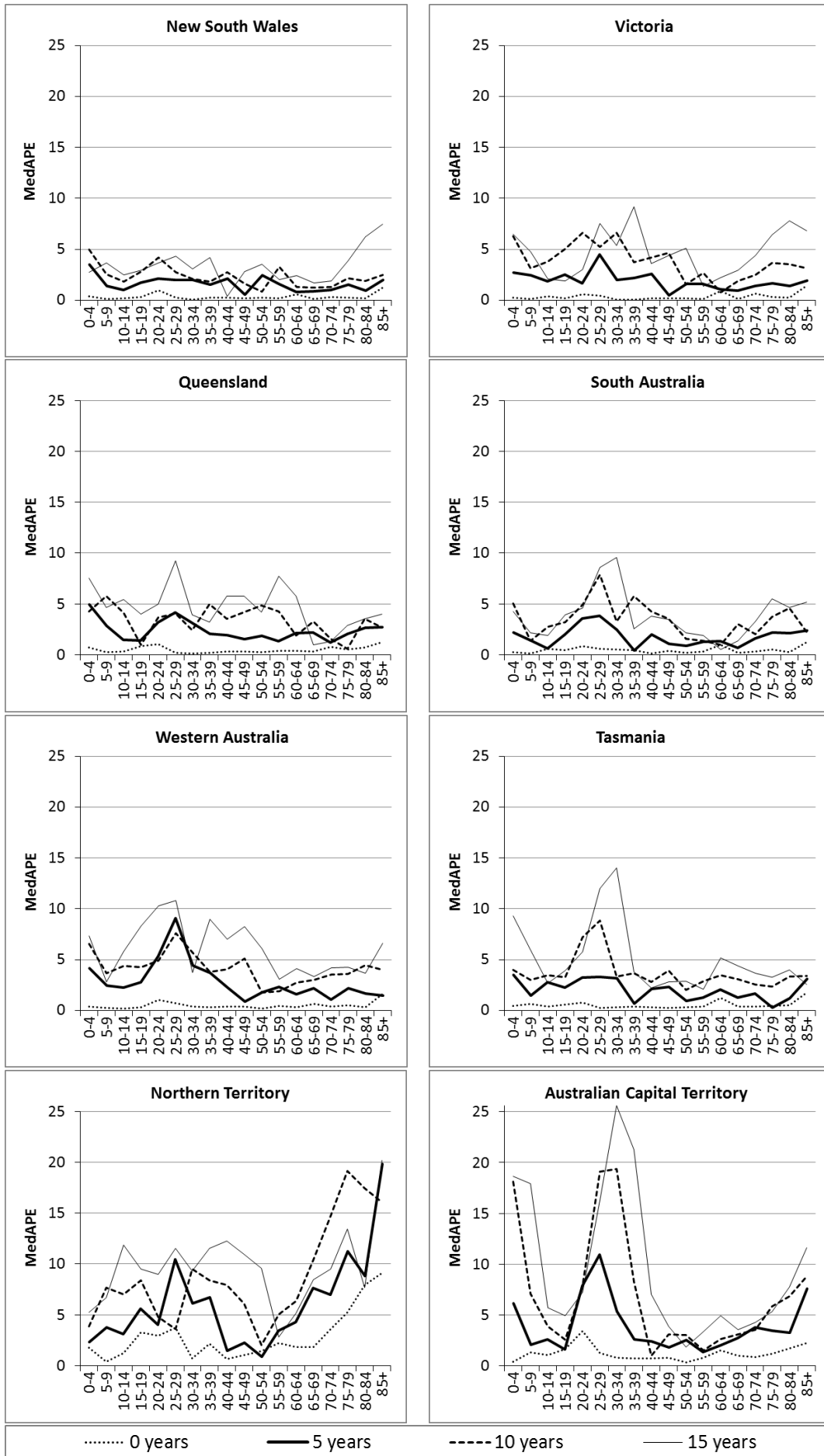
Figure 2: Median Absolute Percentage Errors of ABS projections by State/Territory and age group for 0, 5, 10 and 15 year projection durations

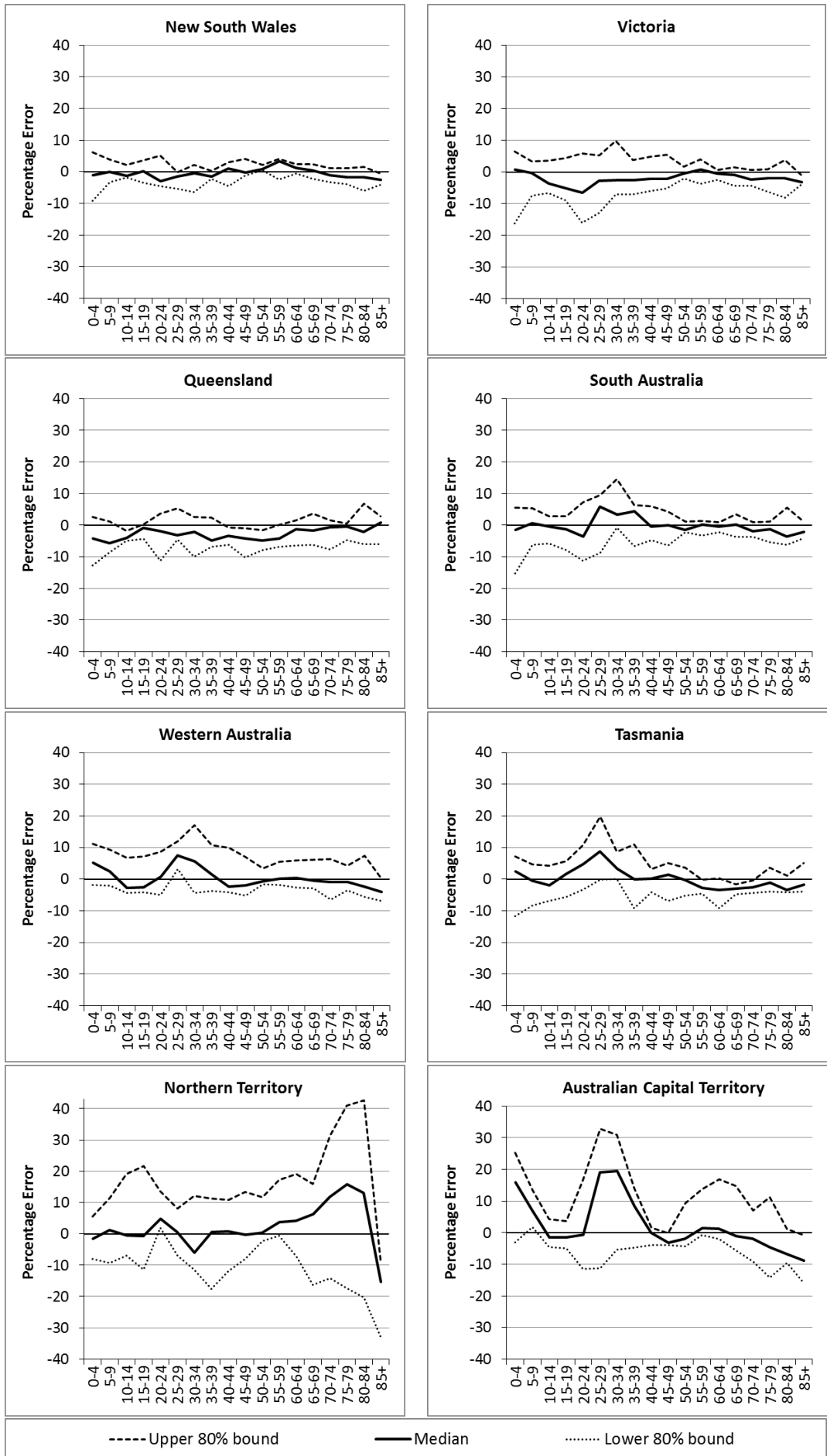Source: author's calculations using ABS projections and ERP data

Figure 3: Distribution of Percentage Errors of ABS projections by State/Territory and age group for 10 year projection durations

Source: author's calculations using ABS projections and ERP data

3.4. Error in projecting total populations compared to naïve projections

Absolute Percentage Errors of naïve projections created from linear extrapolation were compared with those of the ABS projection series listed in Table 1. How well did the ABS projections perform? Table 5 answers this question by presenting Percentage Better statistics: the percentage of ABS projections which were better in terms of Absolute Percentage Error than linear extrapolation. Numbers highlighted in grey indicate where linear extrapolations tended to provide more accurate projections of total population.

On the basis of Table 5, ABS projections of Tasmania's population have proved the most successful of all the States and Territories. ABS projections for this State have been more accurate than those of linear extrapolation for the majority of projection rounds and for every projection duration shown in the table. Interestingly, although the two territories have been forecast the least accurately in terms of total populations and population growth, the majority of ABS projections have proved more accurate than linear extrapolations. In other words, the ABS projections have added value beyond simple extrapolations. Conversely, whilst ABS projections of South Australia's total population have proved reasonably accurate (Figure 1; Table 2), for the majority of projection rounds, better forecasts of total population would have been obtained from linear extrapolation. This reflects the long-run stability of the trend in total population numbers in South Australia.

Table 5: Percentage of ABS State and Territory projections of total population which were more accurate than those created by linear extrapolation, by projection duration

Projection duration (years)	NSW	Vic	Qld	SA	WA	Tas	NT	ACT
1	81	89	71	58	59	71	58	82
2	81	94	59	42	59	71	68	76
3	63	83	53	37	53	71	68	76
4	56	78	53	42	41	76	74	76
5	44	78	59	37	41	76	74	76
6	33	65	44	33	38	88	72	63
7	27	59	44	33	56	69	72	56
8	36	50	53	35	53	73	76	60
9	36	44	47	29	60	80	76	67
10	54	47	43	31	64	79	69	57
11	62	47	43	31	64	71	75	57
12	62	47	43	19	64	71	63	57
13	50	33	46	23	62	69	60	62
14	58	33	46	31	54	54	60	62
15	64	36	50	50	50	58	64	67

Source: author's calculations using ABS projections and ERP data
Note: numbers highlighted in grey illustrate circumstances where linear extrapolations would have provided more accurate projections of total population for the majority of projection rounds.

3.5. Changes in accuracy over time

Have ABS projections of State and Territory total populations become more accurate over time? Table 6 presents average errors of the projections at 5 and 10 year durations by jump-off year. The values are means of State and Territory projections for each jump-off year. MAPE is shown in the table because of its common usage, but it has the disadvantage of giving equal weighting to each Percentage Error. Thus, the higher Percentage Errors for the Northern territory and Australian Capital Territory are given as much weight as the smaller errors for New South Wales, which has twelve times as many people as these two Territories combined. Because of the considerable variation in

population sizes across the States and Territories WMAPE, the sum of population-weighted Absolute Percentage Errors, is also shown.

From the MAPE values for 5 year projection durations it is difficult to discern any clear trend in forecast accuracy. MAPEs lie between 1.2% and 2.4% for all years except for the 2004-based projection. The larger error for this projection round is mostly due to a huge, but temporary, increase in net overseas migration to Australia between 2006 and 2009 (ABS 2011). According to WMAPE there appears to be a slightly clearer trend of improving accuracy up to the 1999-based round before the recent net overseas migration rise resulted in large errors for the 2004-based round. At 10 year projection durations there is no obvious trend in accuracy over time.

However, examining an error measure such as MAPE or WMAPE is only one way of assessing the performance of projections over time. A fuller picture would take into account variations in forecasting difficulty. Some projections may have proved to be highly accurate only because demographic trends fortuitously turned out to be stable for a number of years, not because it was based on any great foresight about future trends. One approach to evaluating accuracy whilst accounting for forecasting difficulty is to measure how much more accurate ABS projections proved to be against the linear extrapolations reported in the previous subsection. To provide an answer, the Proportionate Reduction in Error (PRE) of WMAPE was calculated for each jump-off year at 5 and 10 year projection durations (Table 6). The PRE describes the percentage reduction in WMAPE achieved by the ABS projections over linear extrapolation. As the table shows, there is no clear improvement in accuracy over time. Similar conclusions have been made in other studies. For example, in his evaluation of national population forecasts of 14 European countries Keilman (2008) discovered no improvements in forecast accuracy for these countries over the last 25 years.

Table 6: Average errors of ABS State and Territory projections of total population at 5 and 10 year projection durations by jump-off year

Jump-off year	5 year projection duration			10 year projection duration		
	MAPE (%)	WMAPE (%)	PRE in WMAPE (%)	MAPE (%)	WMAPE (%)	PRE in WMAPE (%)
1978	1.86	1.94	-11.6	3.08	3.30	-8.2
1981	1.61	1.24	32.4	3.07	1.59	61.2
1984	2.01	2.00	-0.6	3.88	2.60	-4.3
1987	2.36	1.21	7.3	4.78	3.17	-105.2
1989	1.84	1.66	-32.7	3.92	2.48	-34.8
1993	1.73	0.99	34.9	2.50	1.90	-6.0
1995	1.47	1.22	-29.7	1.63	1.23	1.1
1997	1.35	1.20	4.6	3.93	3.52	-58.3
1999	1.37	0.92	17.2	5.02	1.98	-11.7
2002	2.21	1.67	33.5	n/a	n/a	n/a
2004	3.38	3.24	-0.3	n/a	n/a	n/a
2006	1.20	1.33	61.1	n/a	n/a	n/a

Source: author's calculations using ABS projection, ERP data and linear extrapolations

4. Empirical prediction intervals for current projections of total population

New sets of population projections are usefully accompanied by information on the likely error (or uncertainty) of those projections. Over the last two decades an increasing number of demographers have represented demographic uncertainty in the form of probabilistic population projections (e.g. Keilman et al. 2002; Lutz et al. 2004; Bell et al. 2011). However, the application of probabilistic methods at subnational scales faces a number of challenges: the bulk of probabilistic methodology has been developed for national scale projections, the data requirements for subnational probabilistic models are considerable, and the preparation of such projections is complex and time-consuming.

An alternative is to create prediction intervals based on the distribution of past errors (e.g. Keyfitz 1981; Stoto 1983; Rayer et al. 2009; Smith and Rayer 2010). An evaluation of as many past projections as possible is conducted, the distribution of forecast errors is determined, and then those distributions are applied in some way to current forecasts. Such an approach is dependent on the assumption that future errors will, at least approximately, resemble those of the past. Of course, no guarantee of this outcome can be given, though several studies have found a fair degree of stability in errors over time (e.g. Smith and Sincich 1988; Rayer et al. 2009). Key advantages of empirically-derived prediction intervals over probabilistic methods include their simplicity and the speed with which they can be produced.

For this paper empirically-based prediction intervals were calculated and applied to the most recent set of ABS State and Territory Series B population projections, the 2006-based set (ABS 2008). Series B is generally interpreted as a forecast. Given the lack of a clear trend in changes to forecast accuracy over time, the errors of all projection series listed in Table 1 were used in the creation of prediction intervals. However, because the 2006 ERPs are final census-based population estimates and not subject to any further revision there is, by definition, no jump-off error. Thus, instead of basing the prediction intervals on the past distributions of Absolute Percentage Errors, Absolute *Corrected* Percentage Errors (ACPE) were used. Following the practice of Lutz et al. (2004) 80% prediction intervals were calculated. In addition, because of the common research finding "there is no way to know in advance whether a particular forecast … will be too high or too low" (Tayman 2011 p 782) predictive distributions were assumed to be symmetrical. Furthermore, rather than combining error observations across all States and Territories and disaggregating by population size and/or base period growth rate, each State and Territory was handled separately. As shown earlier, population size alone is not a sufficiently reliable predictor of forecast error distributions for Australian States and Territories; the population dynamics of each State/Territory is also important. Finally, it is acknowledged that some errors used to calculate the predictive distributions are based on forecasts and ERPs for the period 2006 to 2011. If this method was being applied during the preparation of 2006-based projections then of course errors for these recent years would not be available; for the purposes of illustration in this paper their inclusion is unimportant.

The predictive distributions for the 2006-based ABS Series B projections were calculated as follows.
(1) Values describing the width of the inner 80% of the distribution of Absolute Corrected Percentage Errors were obtained for each State and Territory for projection durations of 0 to 10 years. Values for longer durations were not used because of the small number of observations.
(2) The observed 80% ACPE intervals by projection duration were smoothed by fitting straight lines to smooth out random variation due to small sample sizes. Intercepts were forced through zero to signify no jump-off error. As an example, Figure 4 shows an actual and smoothed 80% ACPE interval for Tasmania.

(3) Prediction intervals were created for the current ABS projections. Populations at the upper bound of the 80% prediction interval were calculated as:

$$P^{upper}(t) = P^{ABS}(t) + (smoothed\ 80\%\ ACPE(t)/100)\ P^{ABS}(t)$$

where P^{ABS} denotes the ABS Series B projection and t the projection duration in years. Populations describing the lower bound were found as:

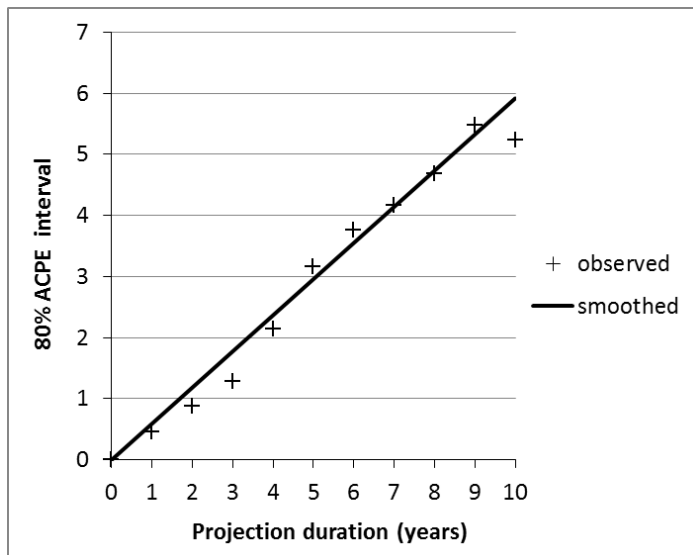$$P^{lower}(t) = P^{ABS}(t) - (smoothed\ 80\%\ ACPE(t)/100)\ P^{ABS}(t).$$

Figure 4: Observed and smoothed 80% ACPE intervals for Tasmania
Source: author's calculations based ABS projections and ERP data

Figure 5 illustrates the ABS Series B 2006-based projections along with 80% prediction intervals shown as grey bands. Given that these intervals were created from projection durations of up to 10 years only, they are best applied only for the first ten years of the 2006-based projections. However, error distributions for total population often expand in a linear manner with time so it seems reasonable to extend the 80% intervals a little further into the future.

How much forecast uncertainty do these 80% intervals suggest? Taking Queensland as an example, by 2026 the empirical prediction intervals suggest an 80% chance of the State's population lying within ±12.3% of the ABS Series B projection of 6.04 million, which equates to the range 5.29-6.79 million. New South Wales enjoys the greatest forecast certainty, with its 2026 population being forecast within 8.02 and 8.77 million (±4.5%). Relative uncertainty is greatest for the Northern Territory. By 2026 the 80% interval spans 216,000 to 354,000, ±17.9% of the ABS Series B projection of 285,000.

Because these projections were produced a few years ago, it possible to undertake a short-run test of the prediction intervals by plotting Estimated Resident Populations from 2006 to 2011 (shown in Figure Y as the dashed lines). These are not finalised ERPs because they are rolled forward from the 2006 census and have not yet been adjusted to align with 2011 census results. As the graphs show, for all States and Territories ERPs lie within the 80% prediction intervals with the one exception of New South Wales where the estimated population lies just above the 80% upper bound. This finding does not necessarily invalidate the approach, however. Some populations will turn out to lie outside the prediction intervals – they are *80%* intervals after all – and the New South Wales populations only just exceed the interval.
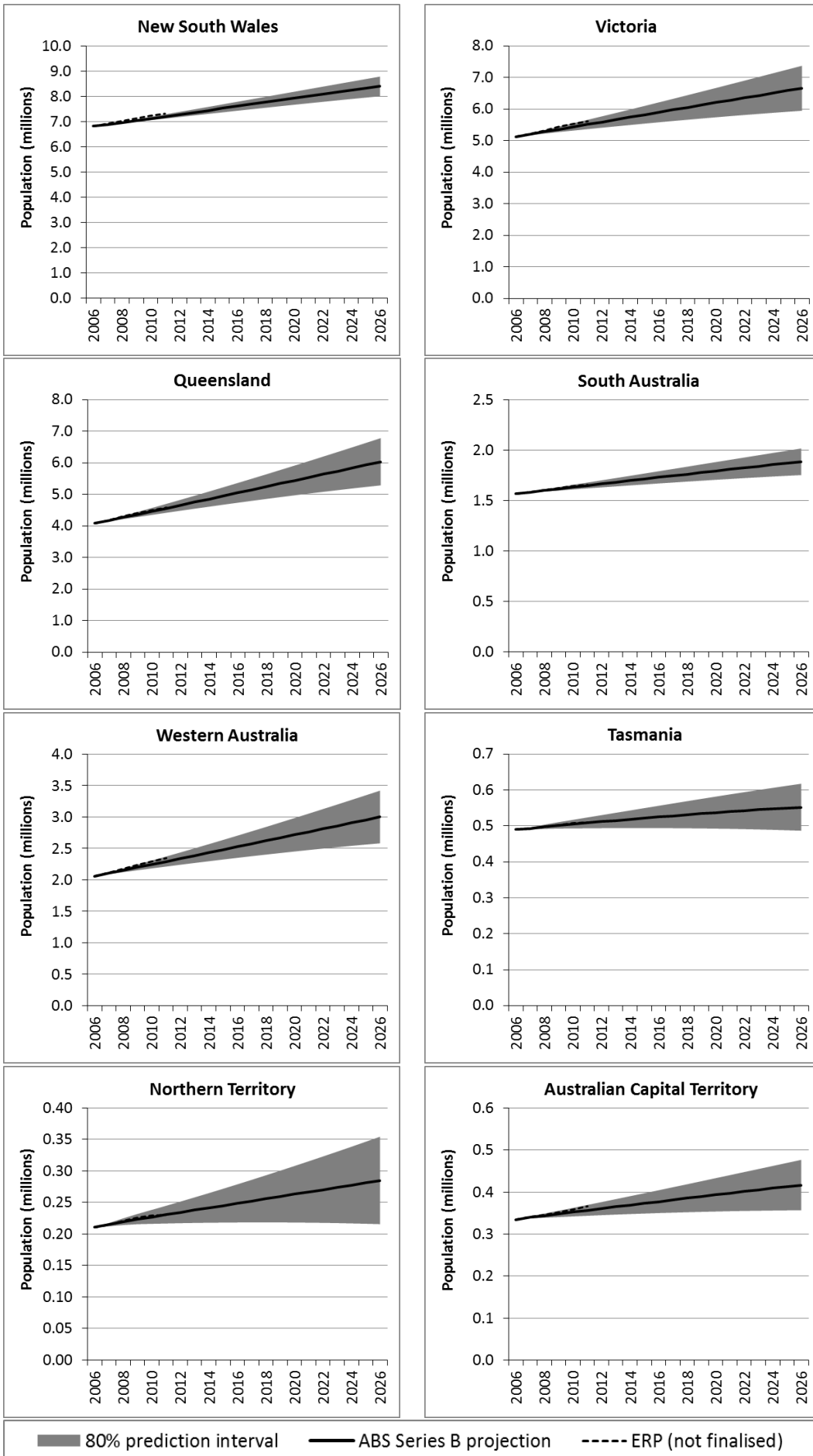
Figure 5: ABS Series B projections of total State and Territory populations with empirically-based 80% prediction intervals, 2006-26

Source: ABS 2006-based projections from ABS (2008); prediction intervals calculated by the author.

5. Summary and conclusions

This paper has evaluated the forecast accuracy of twelve sets of ABS State and Territory population projections, covering the 1978- to the 2006-based rounds. The key findings can be summarised as follows:

- Errors in forecasting total population were generally modest for the States, with Absolute Percentage Errors averaging around 1-3% at projection durations of 10 years, but quite large for the two Territories, at roughly 6% after 10 years.
- New South Wales and South Australia experienced the least bias in their projections of total population; Queensland was generally under-projected; and the two Territories were over-projected at projection durations of 10 years or more.
- There was an approximately linear relationship between average error and projection duration, and between the 80% distribution of errors and projection duration.
- Projections of age-specific populations were generally less accurate for 0-4 year olds than older children, often quite inaccurate at the peak migration ages, and in some cases quite inaccurate at the very oldest ages.
- ABS projections of total population were more accurate than linear extrapolations in the majority of projections for Tasmania, the Northern Territory and the ACT; for South Australia linear extrapolation tended to be more accurate; for the other States the findings were mixed.
- There was no clear evidence of ABS projections of total population becoming more accurate over time.
- Past distributions of Absolute Percentage Errors were used as the basis for creating 80% empirical prediction intervals applied to the 2006-based ABS projections. For all States and Territories, bar one, 2006-11 ERPs fell within the 80% intervals.

Does this analysis reveal anything which could improve the accuracy of ABS State and Territory population projections in the future? Minor improvements may result from using only census-year final ERPs as the jump-off points for projections. Because these ERPs are not subject to any further revision there cannot be any jump-off year error – a type of error which particularly affected projections for the Northern Territory.

Aside from that, this author's view is that any significant improvements in accuracy are unlikely to be realised unless robust methods of forecasting turning points and cyclical patterns in migration and fertility are discovered. Undoubtedly this is a major challenge. Nonetheless, the new type of Total Fertility Rate and projection method devised by McDonald and Kippen (2011) offers some promise in this regard. The approach of these authors involves calculating a Total Fertility Rate standardised for parity and duration since last birth. McDonald and Kippen demonstrated how short-term projections of age-parity-duration-specific fertility rates from 2000 to 2005 successfully predicted the actual upturn in the Australian TFR. Research to ascertain whether this method is equally successful at the State and Territory scale would be extremely valuable.

Regular national-level overseas migration forecasts have recently been initiated by the Department of Immigration and Citizenship (DIAC 2011). These are short-term forecasts looking a few years ahead, and are based on recent offshore visa grants, probabilities of individuals with particular visas becoming international migrants, forecasts of visas being issued, as well as forecasts of non-viased migration streams, such as those involving Australian and New Zealand citizens. It is too early to determine whether these forecasts will prove more accurate than past ABS overseas migration projections, but the disaggregation by visa/ category appears promising. Again, extension to the State and Territory scale might prove valuable.

As for the successful prediction interstate migration, the challenges seem greater. Although interstate migration is known to be affected by spatial variations in employment and housing costs, lifestyle, climate and environment, and family networks (Bell 1996; Hugo et al. 2005) our understanding remains partial. The forecasting of predictor variables in any model of interstate migration would not be easy. Clearly this is an area requiring much more research effort.

Whatever improvements are made to forecast methods, and hopefully accuracy, in the future, errors will still unfortunately occur. If it is not possible for demographers to produce probabilistic population forecasts, a simpler alternative is to create empirical prediction intervals from past errors, as demonstrated in section 4 of the paper.

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