Overcoming data issues to project interregional migration flows amongst Australia's Indigenous population[1]

James Raymer[2], Nicolas Biddle[3] and Paul Campbell[4]

21 April 2015 (**Draft**)

ABSTRACT

In this paper, a model is developed to project the interregional migration flows for the Aboriginal and Torres Strait Islander (Indigenous) populations in Australia at the state and territory level by age and sex. Migration flow data, obtained from the three most recent Australian quinary censuses (2001, 2006 and 2011), are first assessed and analysed in comparison with the patterns of the corresponding non-Indigenous population. Log-linear models are used to identify the key structures and patterns over time. A model is then developed to project the migration flows by origin, destination, age and sex forward in five-year increments to 2031. This includes incorporating techniques to overcome the small number cell issues associated with the very small population size of the Indigenous population. The results of this research provide (i) insights into the different migration patterns of an important but disadvantaged minority population in Australia and (ii) inputs for a dynamic multiregional model of Indigenous population change.

[1] Paper prepared for the 2015 Annual Meeting of the Population Association of America, San Diego. Research funded by the Australian Research Council as part of the Linkage Project on 'Improved Indigenous Population Projections for Policy and Planning' (LP130100735).

[2] Australian Demographic and Social Research Institute, Research School of Social Sciences, College of Arts and Social Sciences, Australian National University, email: james.raymer@anu.edu.au.

[3] Centre for Aboriginal Economic Policy Research and Australian Centre for Applied Social Research Methods, Research School of Social Sciences, College of Arts and Social Sciences, Australian National University email: nicholas.biddle@anu.edu.au.

[4] Centre for Aboriginal Economic Policy Research, Research School of Social Sciences, College of Arts and Social Sciences, Australian National University and Australian Bureau of Statistics, email: paul.campbell@anu.edu.au.

1. INTRODUCTION

There was a 21 per cent increase in the number of people counted as being Australian Aboriginal and Torres Strait Islander (Indigenous) between the 2006 and 2011 Censuses. Understanding this growth and the factors that contribute towards differences across space are important for a number of reasons (Biddle 2012). Indigenous Australians are relatively disadvantaged. They are concentrated in particular areas and in particular age groups. They have certain native-title rights not held by other groups. And they are the focus of many government policies and targets. In order to develop policies for improving the social and economic conditions of this population, it is necessary to first consider how the underlying demographic (and identification) factors are changing over time. This paper focuses on just one of the demographic components: internal migration.

In addition to being useful for planning purposes, internal migration can be used an indicator of a population's wellbeing and its social interactions with other populations distributed across space. To understand the needs of Australia's indigenous populations, policy makers need a sense for how they are interconnected with other populations, and how these connections differ by age, sex and over time. Estimates of future internal migration are required for making accurate population projections, and for policy development and planning. Thus, the aims of this study are to understand how the internal migration patterns of Australia's Indigenous population have changed in the recent past and how they are likely to evolve in the near future. In addressing these aims, we focus on three research questions. How stable are Indigenous migration flows over time? What are the key differences between patterns of Indigenous and non-Indigenous migration? What are the most important migration structures that can be used for both estimation and projection?

The approach taken in this study focuses on analysing and projecting the origin-destination flows of migration and extends the multiplicative component approach developed by Raymer et al. (2006) for projecting interregional migration in Italy. This approach is different from the net migration approach taken by the Australian Bureau of Statistics (ABS) and other recent population projections of the Indigenous population (Australian Bureau of Statistics 2014; Biddle 2013). While

simpler to include in demographic accounting models, projections of net migration totals are not as reliable and often result in biased projections (Rogers 1990). Thus, by focusing on the underlying structures of migration flows, we argue that more reliable projection models are produced for both internal migration and the subsequent population totals.

2. BACKGROUND

The Indigenous population of Australia is a diverse and culturally distinctive population that has existed in Australia for over 40 thousand years (Taylor 1997, 2003). It is also a minority population that is socially and economically disadvantaged in comparison to the majority population including those who have lived in Australia for many generations, as well as more recent migrant cohorts. Understanding the cultural differences, regional diversity and the different demographic structures and behaviours of the Indigenous population, as distinct from non-Indigenous population groups, are required for planning for the needs and aspirations of the Indigenous population.

The Indigenous population has experienced rapid population change since they were first fully incorporated in Australian population estimates (from the 1971 Census onwards). There are a number of Indigenous Australians who are missed from the Census counts entirely, as well as a large number whose Indigenous status is not stated. Not long after the 2006 Census, the ABS attempted to adjust for this undercount and estimated that there were around 517 thousand Indigenous Australians living in Australia, representing about 2.5 per cent of the overall Australian population. The Bureau's estimates from the 2011 Census are around 670 thousand Indigenous Australians, or approximately 3.0 per cent of the total Australian population. This is a very rapid population increase over just a five-year period, but fits with the long term trend in the count. There are six potential reasons for this rapid increase:

1. Indigenous Australians are concentrated in the main childbearing years (at least relative to the non-Indigenous population);

2. Indigenous females continue to have a greater number of children than non-Indigenous females, especially when they are relatively young;
3. In urban areas, there is a high partnering rate between Indigenous males and non-Indigenous females with the children of these partnerships tending to be identified as Indigenous;
4. The Australian Bureau of Statistics may be getting better at counting Indigenous Australians in the Census;
5. The Australian Bureau of Statistics may have historically underestimated the number of Indigenous people who were missed by the census in previous years; and
6. There may have been a non-negligible number of people who previously did not identify as being Indigenous in the census but now feel more comfortable in doing so.

Indigenous populations are not distributed uniformly across the eight States and Territories. Those with the largest population counts in 2011 were New South Wales (173 thousand), Queensland (156 thousand), Western Australia (70 thousand) and Northern Territory (57 thousand). The area with the largest percentage Indigenous was the Northern Territory at at 27 per cent of the total population. Population growth also varied across jurisdictions with much faster growth in the south and east of the country and slower growth in less urbanised areas. Part of this variation in growth is due to the above six factors, but also due to migration between jurisdictions.

Indigenous population projections are needed for planning for population growth or decline and the provision of services. Allocation of Commonwealth revenue to States and Territories is based in part on the share of the populations estimated to be Indigenous, and hence estimates and projections at the jurisdictional level and ideally below is also required. Normally, population projections for Indigenous populations are carried out similarly to population projections for the total population. The main difference is uncertainty around the quality of the data upon which to base the population projections. To offset the deficient data, strong assumptions regarding the demographic components have been required. Some, though not all, projection models also include

adjustments to incorporate changes to the way in which individuals self-identify or are identified. For the past couple of decades this has tended to
result in larger Indigenous populations than could be explained by natural increase and net migration, though the size of this unexplained growth has varied over the intercensal periods.

The demographic accounting equation commonly used for producing Indigenous population projections starts with base population (usually obtained from a Census year and adjusted for census undercount) and adds births, deaths and net internal migration. Net overseas migration is often ignored due to the very small numbers, though they need to be included if parallel projections of the non-Indigenous population are undertaken. Assumptions are made about the future trajectories of births, deaths and net internal migration. In addition to identification change, the net migration component tends to be the most difficult demographic component to project. First, there are insufficient theories to drive the assumptions (Bijak 2010). Second, historical net migration patterns do not always exhibit patterns that are stable or smooth. In this paper, we focus on the matrix of flows between origins and destinations with the argument that these patterns are more stable over time and can be considered more reliable for developing projection assumptions.

3. DATA AND METHODOLOGY

The analyses in this paper are designed to help researchers to better understand the internal migration dynamics of the Indigenous population in relation to the non-Indigenous population. Reliable internal migration projections are also required for the Indigenous population projection model we are developing. The population projection model we envision is a multiregional population projection model (Rogers 1995) that allows subpopulations to interact through internal migration. This model utilises age- and destination-specific out-migration probabilities applied to the state and territory populations at risk of migrating.

3.1 Data

The data collected for this study were obtained from the 2001[5], 2006 and 2011 Australian censuses and include following characteristics:

- Self-reported Indigenous status at time of each census;
- State or territory of current residence by state or territory of residence five years ago;
- Five-year age groups (5-9, 10-14, …, 85+ years) at time of census (2006 and 2011 only); and
- Sex (2006 and 2011 only).

There were 17,557 Indigenous persons that crossed one of the eight main states or territories during the 1996-2001 period. This number increased to 18,777 persons during the 2001-2006 period and then again to 21,283 persons during the 2006-2011 period. The corresponding numbers of non-Indigenous migrants actually decreased 753,285 persons from the 2001-2006 period to 747,425 persons during the 2006-2011 period. The share of Indigenous migration out of total migration increased from 2.4 percent during 2001-2006 to 2.8 percent during 2006-2011, which corresponded to the increase in the Indigenous share of the population (i.e., 2.2 percent to 2.5, respectively). Note, these numbers exclude the persons who did not state their status.

In our study, we analyse the migration between eight states or territories. These include the six states of New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA), Western Australia (WA) and Tasmania (TAS), and the two territories of Northern Territory (NT) and Australian Capital Territory (ACT). In 2011, the share of the Indigenous population persons residing in New South Wales was roughly the same as the non-Indigenous population at 30 percent versus 33 percent, respectively. The same was found for South Australia (6 percent versus 8 percent), Western Australia (13 percent versus 10 percent), Tasmania (4 percent versus 2 percent) and ACT (1 percent vs 2 percent). However, large differences were found in the population shares residing in Victoria

[5] Source: Australian Bureau of Statistics (2003, p. 57)

with 7 percent versus 25 percent, respectively, and the Northern Territories with 12 percent versus 1 percent, respectively.

3.2 Analytical framework

Counts of migration flows may be considered from a categorical data analysis framework. The basic categories are origin (O), destination (D), age (A) and sex (S). Migration flow tables typically include two or more of these categories. These tables can also be decomposed into various hierarchical structures, not all of which are necessary for understanding or accurate prediction. If certain (important) structures are unavailable, they can be imputed or 'borrowed' from auxiliary data sources. This general modelling framework comes from a sequence of papers on the age and spatial structures of internal migration, and how they can be represented by a multiplicative modelling framework (Willekens 1983; Rogers et al. 2002, 2003; Raymer et al., 2006; Raymer and Rogers, 2007; Raymer 2010).

To begin, consider migration from origin i to destination j, denoted by n_{ij}. These counts can be organised in a two-way table, such as in Table 1 for migration between four hypothetical regions. For analyses of these tables, it is important to make a distinction between cell counts (n_{ij}) and marginal totals, that is the total number of out-migrants from each region (n_{i+}), the total number of in-migrants to each region (n_{+j}) and the overall level of migration (n_{++}). Note, within area movements ($i = j$) are excluded from the analyses.

Table 1. Notation for an origin-by-destination migration flow table

Region	Region of Destination				
of Origin	1	2	3	4	Total
1	0	n_{12}	n_{13}	n_{14}	n_{1+}
2	n_{21}	0	n_{23}	n_{24}	n_{2+}
3	n_{31}	n_{32}	0	n_{34}	n_{3+}
4	n_{41}	n_{42}	n_{43}	0	n_{4+}
Total	n_{+1}	n_{+2}	n_{+3}	n_{+4}	n_{++}

For describing and analysing migration flow patterns over time, the flows can be decomposed into multiplicative components:

$$n_{ij} = (T)(O_i)(D_j)(OD_{ij}) \ , \qquad (1)$$

where T is the total number of migrants (i.e., n_{++}), O_i is the proportion of all migrants leaving from area i (i.e., n_{i+} / n_{++}) and D_j is the proportion of all migrants moving to *area j* (i.e., n_{+j} / n_{++}). The interaction component OD_{ij} is defined as $n_{ij} / ((T)(O_i)(D_j))$ or the ratio of observed migration to expected migration (for the case of no interaction). This general type of model is called a multiplicative component model and may be extended to include other categories, such as age or sex.

For illustration of the multiplicative components and their interpretation, the 2006-2011 Indigenous and non-Indigenous migration flows amongst the eight states or territories in Australia have been set out in Table 2. Consider Indigenous migration from the Northern Territories to South Australia ($n_{NT, SA}$) for both Indigenous and non-Indigenous persons. For Indigenous migration, there were 552 persons who made this move. For non-Indigenous migration, there were 4,518 persons. What made up the difference? Was it because the overall level of interstate migration is much higher for the majority non-Indigenous population? Was it because more non-Indigenous migrants were leaving the Northern Territories or more migrants going to South Australia? Or was it because of the interaction (or connectivity) between the Northern Territories and South Australia? The calculation of multiplicative components can help us answer these questions.

Table 2. Interstate migration in Australia by Indigenous status, 2006-2011

	Destination								
Origin	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	Total
A. Indigenous									
NSW	0	1,150	3,644	269	478	165	270	583	6,559
VIC	737	0	580	203	254	119	124	41	2,058
QLD	2,436	692	0	298	685	278	658	175	5,222
SA	226	229	274	0	220	51	267	17	1,284
WA	317	326	508	221	0	96	430	41	1,939
TAS	149	175	281	47	125	0	35	18	830
NT	275	262	951	552	456	63	0	60	2,619
ACT	448	54	193	22	9	5	41	0	772
Total	4,588	2,888	6,431	1,612	2,227	777	1,825	935	21,283
B. Non-Indigenous									
NSW	0	52,700	106,243	11,954	21,455	6,494	6,604	26,217	231,667
VIC	41,329	0	44,146	13,148	19,118	6,790	5,478	6,111	136,120
QLD	67,320	38,074	0	9,779	18,753	8,386	8,009	6,214	156,535
SA	10,971	15,676	15,274	0	7,554	2,039	3,856	2,176	57,546
WA	13,714	18,070	17,865	5,356	0	4,291	3,282	1,914	64,492
TAS	5,136	7,979	7,590	1,678	3,552	0	766	841	27,542
NT	5,245	4,897	11,377	4,816	4,449	868	0	1,030	32,682
ACT	21,596	6,396	8,125	1,480	1,801	634	809	0	40,841
Total	165,311	143,792	210,620	48,211	76,682	29,502	28,804	44,503	747,425

In Table 3, the multiplicative components for the flows set out in Table 2 are presented. For example, the multiplicative components for Indigenous and non-Indigenous migration from the Northern Territories to South Australia are equal to:

$$n^{I}_{NT,SA} = (T)(O_{NT})(D_{SA})(OD_{NT,SA}) = (21,283)(0.123)(0.076)(2.783) \text{ and}$$

$$n^{NI}_{NT,SA} = (T)(O_{NT})(D_{SA})(OD_{NT,SA}) = (747,425)(0.044)(0.065)(2.285),$$

where *I* = Indigenous and *NI* = non-Indigenous. From these calculations, it is clear that most of the difference was attributed to the overall level, offset somewhat by the much higher proportion of Indigenous migrants leaving the Northern Territories. The proportion of migration to South Australia was, more or less, the same for both groups, as was the high level of interaction (i.e., more than twice expected) between the two areas.

Table 3. Multiplicative components of interstate migration in Australia by Indigenous status, 2006-2011

	O_i	D_j	$OD_{i,NSW}$	$OD_{i,VIC}$	$OD_{i,QLD}$	$OD_{i,SA}$	$OD_{i,WA}$	$OD_{i,TAS}$	$OD_{i,NT}$	$OD_{i,ACT}$
A. Indigenous, T = 21,283										
NSW	0.308	0.216	0.000	1.292	1.839	0.541	0.696	0.689	0.480	2.023
VIC	0.097	0.136	1.661	0.000	0.933	1.302	1.180	1.584	0.703	0.453
QLD	0.245	0.302	2.164	0.977	0.000	0.753	1.254	1.458	1.469	0.763
SA	0.060	0.076	0.816	1.314	0.706	0.000	1.637	1.088	2.425	0.301
WA	0.091	0.105	0.758	1.239	0.867	1.505	0.000	1.356	2.586	0.481
TAS	0.039	0.037	0.833	1.554	1.120	0.748	1.439	0.000	0.492	0.494
NT	0.123	0.086	0.487	0.737	1.202	2.783	1.664	0.659	0.000	0.521
ACT	0.036	0.044	2.692	0.515	0.827	0.376	0.111	0.177	0.619	0.000
B. Non-Indigenous, T = 747,425										
NSW	0.310	0.221	0.000	1.182	1.627	0.800	0.903	0.710	0.740	1.901
VIC	0.182	0.192	1.373	0.000	1.151	1.497	1.369	1.264	1.044	0.754
QLD	0.209	0.282	1.944	1.264	0.000	0.969	1.168	1.357	1.328	0.667
SA	0.077	0.065	0.862	1.416	0.942	0.000	1.279	0.898	1.739	0.635
WA	0.086	0.103	0.961	1.456	0.983	1.288	0.000	1.686	1.321	0.498
TAS	0.037	0.039	0.843	1.506	0.978	0.945	1.257	0.000	0.722	0.513
NT	0.044	0.039	0.726	0.779	1.235	2.285	1.327	0.673	0.000	0.529
ACT	0.055	0.060	2.391	0.814	0.706	0.562	0.430	0.393	0.514	0.000

Next, consider the representation of age-specific migration patterns between these regions. The multiplicative component model for this table is specified as:

$$n_{ijx} = (T)(O_i)(D_j)(A_x)(OD_{ij})(OA_{ix})(DA_{jx})(ODA_{ijx}), \quad (2)$$

where A_x is the proportion of all migrants in age group x. This model is more complicated because there are now three two-way interaction components and a single three-way interaction component between the origin, destination, and age variables. However, the interpretations of the parameters remain relatively simple and the calculations follow the same format as presented for the two-way table. That is, the interaction components represent ratios of observed flows or marginal totals to expected ones. For example, the destination-age interaction (DA_{jx}) component is calculated as n_{+jx} /

$((T)(D_j)(A_x))$ and represents the ratios of observed age patterns of in-migration to each region divided by the expected age pattern of in-migration.

The multiplicative component model for describing and analysing tables of migration flows can be expressed as a saturated log-linear (statistical) model:

$$\ln(n_{ijx}) = \lambda + \lambda_i^O + \lambda_j^D + \lambda_x^A + \lambda_{ij}^{OD} + \lambda_{ix}^{OA} + \lambda_{jx}^{DA} + \lambda_{ijx}^{ODA} \quad , \tag{3}$$

where the λs are simply the natural logarithms of the variables appearing in Equation 2. The saturated model is expressed as (*ODA*), using the notation set out in Agresti (2013: 345). The parameters of the log-linear model can be analysed using standard statistical techniques for categorical data analysis to identify key structures in the data. For examples of log-linear models applied to age-specific patterns of migration, see Willekens (1994), Raymer and Rogers (2007) and Van Wissen et al. (2008).

Reduced forms of the model set out in Equation 3 are called unsaturated models. For example, the model that only includes the main effects of origin, destination, and age is specified as

$$\ln\left(\hat{n}_{ijx}\right) = \lambda + \lambda_i^O + \lambda_j^D + \lambda_x^A \quad . \tag{4}$$

This model assumes independence between each of the categories of origin, destination, and age and is designated (O, D, A). A model that includes the interaction between origin and destination plus all of the main effects is designated as (OD, A) and is denoted as:

$$\ln\left(\hat{n}_{ijx}\right) = \lambda + \lambda_i^O + \lambda_j^D + \lambda_x^A + \lambda_{ij}^{OD} \quad . \tag{5}$$

Such notations are used because these models are hierarchical, that is, for two-way interaction terms, the main effect parameters must be included, and for three-way interaction terms, all the main effects and two-way interactions must be included. Note, throughout this paper, we exclude the n_{ii} values, i.e., the non-migrants or 'stayers', from the analyses.

To remove non-migrant elements from the analysis, structural zeros can be inserted by using an offset containing zeros in the diagonal elements and ones in the off-diagonal elements (Willekens 1983). An offset can also be used to incorporate auxiliary information in the off-diagonal elements of

the table to improve the estimation procedure. Auxiliary information can be obtained, for example, from a recent census or survey table of migration flows. For instance, consider the following log-linear-with-offset model:

$$\ln\left(\hat{n}_{ijx}\right) = \lambda + \lambda_i^O + \lambda_j^D + \lambda_x^A + \ln\left(n_{ijx}^*\right) , \qquad (6)$$

where the offset is denoted by n_{ijx}^*. In this case the values contained in the offset are forced to fit the marginal totals represented by the overall level and the main effects of origin, destination and age.

In summary, the multiplicative component model and analogous log-linear model provide powerful instruments for the study of complex data structures. The parameters of the model clarify and simplify the estimation of migration flows. And when particular interaction effects cannot be derived from available data, they often may be calculated using other comparable data sets (e.g., interaction data from historical periods or from other populations). Since Snickars and Weibull (1977) found that migration tables of the past provide much better estimates of current accessibility than any distance measure, historical data are often used to capture the spatial patterns of migration.

4. INDIGENOUS MIGRATION

In this section, we first compare the structures of the 2006-2011 interstate migration of Indigenous persons with the corresponding patterns of non-Indigenous persons. We then examine how Indigenous migration has changed over the past three censuses. Finally, we use log-linear models to identify the key structures contained in the 2006-2011 origin-destination-age-sex (ODAS) table of migration flows.

4.1 Indigenous versus non-Indigenous migration

In Table 2, the interstate migration flows for the 2006-2011 Indigenous and non-Indigenous populations are presented. As mentioned previously, the non-Indigenous population is much larger, representing 97.2 percent of all interstate migration. For both population groups, the top ranked out-migration flows came from New South Wales followed by Queensland. The third-ranked flow for Indigenous migration came from the Northern Territories, whereas for the non-Indigenous population, it was Victoria. For in-migration there was more consistency in the ranking with the top four flows in the same order. The fifth-ranked flow for the Indigenous population was Northern Territories, whereas for the non-Indigenous population, it was South Australia. Finally, in terms of origin-destination flows, the New South Wales to Queensland flow was the largest, and the Australian Capital Territory to Tasmania flow was the smallest --- for both populations.

While the levels of migration provide us with information about the relative movements, they do not inform us about the underlying structures of migration. The multiplicative components presented in Table 3 are useful for comparing the origin main effect (O_i), destination main effect (D_j) and origin-destination interaction (OD_{ij}) structures of Indigenous and non-Indigenous migration. Here, we see that the main differences in the main effect structures are driven by three areas: Victoria, Northern Territories and Australian Capital Territory. The origin-destination interaction structures between Indigenous and non-Indigenous migration were fairly consistent for 45 of the 56 flows in the table. The main differences were found in the flows from and to the Northern Territories and Australian Capital Territory (e.g., , South Australia to Queensland (0.71 versus 0.94), and New South Wales to South Australia (0.54 versus 0.80). In nearly all of these cases, the Indigenous origin-destination ratio was further from the reference (i.e., 1.00) than the corresponding non-Indigenous ratio.

4.2 Indigenous migration over time: 1996-2001, 2001-2006 and 2006-2011

The multiplicative components calculated for the 1996-2001 and 2001-2006 interstate migration flows of Indigenous persons are presented in Table 4. The comparison of these components in relation to the 2006-2011 Indigenous patterns in Table 3A shows remarkable stability over time. The overall level increased by 7 percent between the 1996-2001 and 2001-2006 periods and 13 percent between the 2001-2006 and 2006-2011 periods. The relative shares of out-migration (O_i) and in-migration (D_j), however, remained the mostly the same. The biggest changes occurred in the migration from New South Wales during 2001-2006 and Queensland during 2006-2011 (relative shares increased by 1.5 percent in both cases) and to Western Australia during 2006-2011 (relative share increased by 1.7 percent). There were also hardly any major changes to the OD_{ij} interaction terms over time. The exceptions were *Victoria* to Tasmania (2.26, 2.26, 1.58) and Australian Capital Territory (0.40, 0.20, 0.45), *South Australia* to Western Australia (2.25, 1.51, 1.64) and Australian Capital Territory (0.45, 0.46, 0.30), *Northern Territories* to Western Australia (2.12, 2.30, 1.66) and Tasmania (0.12, 0.37, 0.66), and *Australian Capital Territory* to Victoria (0.41, 0.75, 0.52), Western Australia (0.52, 0.39, 0.11) and Tasmania (0.38, 0.47, 0.18).

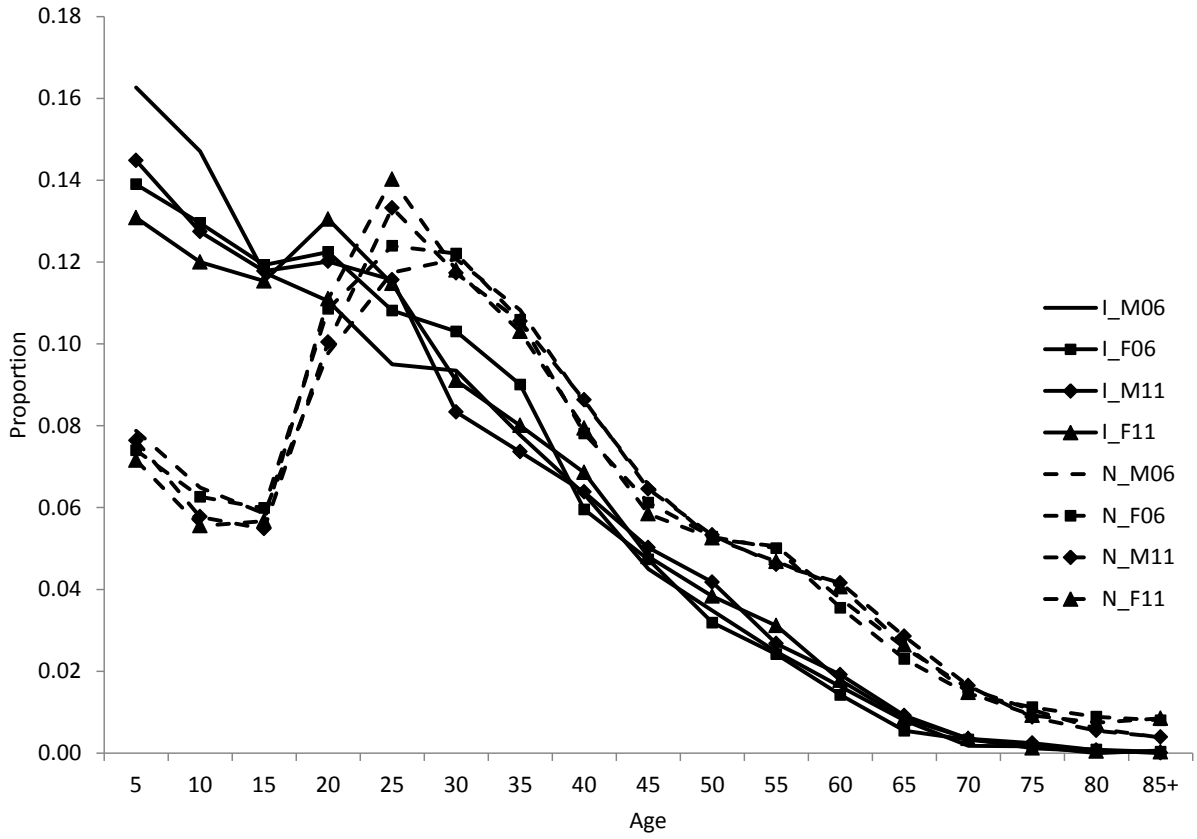
Table 4. Multiplicative components of interstate Indigenous migration in Australia, 1996-2001 and 2001-2006

	O_i	D_j	$OD_{i,NSW}$	$OD_{i,VIC}$	$OD_{i,QLD}$	$OD_{i,SA}$	$OD_{i,WA}$	$OD_{i,TAS}$	$OD_{i,NT}$	$OD_{i,ACT}$
A. 1996-2001, T = 17,557										
NSW	0.303	0.207	0.000	1.337	1.844	0.646	0.599	0.755	0.368	1.934
VIC	0.091	0.124	1.631	0.000	1.049	1.457	0.823	2.264	0.495	0.399
QLD	0.226	0.310	2.322	0.997	0.000	0.623	1.023	1.295	1.595	0.954
SA	0.073	0.086	0.792	1.506	0.575	0.000	2.251	0.967	2.035	0.451
WA	0.093	0.095	0.667	0.832	0.677	1.921	0.000	1.836	3.038	0.444
TAS	0.050	0.028	0.795	2.033	0.988	0.824	1.410	0.000	0.496	0.441
NT	0.122	0.102	0.453	0.527	1.299	2.420	2.105	0.116	0.000	0.539
ACT	0.042	0.047	2.626	0.411	0.795	0.389	0.521	0.379	0.645	0.000
B. 2001-2006, T = 18,777										
NSW	0.318	0.207	0.000	1.295	1.854	0.587	0.641	0.811	0.349	1.957
VIC	0.097	0.125	1.710	0.000	0.905	1.256	1.170	2.260	0.550	0.196
QLD	0.230	0.318	2.356	1.032	0.000	0.802	1.044	1.167	1.423	0.911
SA	0.068	0.084	0.765	1.376	0.616	0.000	1.509	1.158	2.773	0.461
WA	0.092	0.087	0.662	0.866	0.743	1.753	0.000	1.258	3.052	0.399
TAS	0.041	0.039	0.772	1.995	1.044	0.859	1.366	0.000	0.457	0.533
NT	0.118	0.100	0.511	0.587	1.184	2.494	2.300	0.373	0.000	0.505
ACT	0.038	0.039	2.352	0.745	0.834	0.489	0.389	0.474	0.607	0.000

4.3 Indigenous age-sex structures of migration

We found no major differences between males and females in the patterns of migration for both Indigenous and non-Indigenous populations. However, there were major differences found in the age profiles as shown in Figure 1. The explanations for the unusual shape of the Indigenous migration age profile can be explained by four factors. First, the Indigenous population exhibits higher fertility, which would result in higher numbers of children migrating. Second, the age profile includes births to non-Indigenous parent, which would increase the number of children relative to young adults. Third, it is thought the Indigenous population have different life course events and responses in comparison to the non-Indigenous population. These include different responses to the common migration triggers, such as leaving the parental home, entering employment or tertiary education, partnership or marriage and having children. Finally, the migration age profiles of the

Indigenous population are affected by identification change, which can occur at any age but more likely during the child age groups.



Notes: I_M06 = Indigenous males 2001-2006; I_F06 = Indigenous females 2001-2006; I_M11 = Indigenous males 2006-2011; I_F11 = Indigenous females 2006-2011; N_M06 = Non-Indigenous males 2001-2006; N_F06 = Non-Indigenous females 2001-2006; N_M11 = Non-Indigenous males 2006-2011; N_F11 = Non-Indigenous females 2006-2011; Age measured at the time of each census.

Figure 1. Proportions of male and female Indigenous and non-Indigenous interstate migration by age, 2001-2006 and 2006-2011

To identify the key structures in the origin by destination by age by sex patterns of migration, several unsaturated log-linear models were fitted to the 2006-2011 data. Supporting other log-linear analyses of interregional migration, we found the two-way interaction model that includes the main effects and two-way interactions between origin and destination, origin and age, destination and age and age and sex, i.e., the [OD, OA, DA, AS] model, to fit the best with the least amount of complexity. Although there were no strong two-way or higher interactions including the

variable sex, we include an AS term as there can be differences in the oldest age groups where elderly migration is dominated by the larger female population who tend to live longer than the male population.

Table 5. Unsaturated log-linear model fits for Indigenous migration by origin, destination, age and sex, 2006-2011

Model	Likelihood Ratio Statistic, G^2	df	G^2 / df
(ODA, ODS, DAS)	1,145	768	1.49
(ODA, ODS)	1,284	880	1.46
(ODA, DAS)	1,215	809	1.50
(ODS, DAS)	2,233	1,424	1.57
(ODA)	1,356	921	1.47
(ODS)	2,372	1,536	1.54
(OAS)	2,271	1,465	1.55
(DAS)	2,303	1,465	1.57
(OD, OA, OS, DA, DS, AS)	2,443	1,577	1.55
(OD, OA, DA, AS)	2,466	1,591	1.55
(OD, OA, DA)	2,505	1,607	1.56
(OD, AS)	3,129	1,815	1.72
(OD)	3,168	1,831	1.73

Identification of the [OD, OA, DA, AS] model is important for both estimation and projection. It implies that one only requires four two-way tables of migration for accurate estimation: origin by destination, origin by age, destination by age and age by sex. This makes the estimation process much simpler than attempting to estimate all the structures or flows contained in the four-way table, especially when there exists many cells with small numerical or zero values as there are with the data used in this analysis.

5. PROJECTION OF 2016 AND 2021 FLOWS

5.1 Testing a main effects log-linear model with Census data as an offset

The analyses in the previous section informed us that there were strong regularities in the migration patterns of the Indigenous population over time. To form a projection model, one should make best use of the available data where possible. In this case, census migration flows tables could be used as a base for projection, where migration flow are adjusted to account for differences in the overall levels and proportions of migration by origin, destination, age and sex. This model can be specified as a log-linear with offset model:

$$\log\left(\mu_{ijxy}\right) = \lambda + \lambda_i^O + \lambda_j^D + \lambda_x^A + \lambda_y^S + \log\left(n_{ijxy}\right) \qquad (7)$$

where μ represents the estimated count of migration, λ denotes the parameters of the log-linear model and n_{ijxy} represent the most recent census migration flow table.

The log-linear with offset model presented above (Equation 7) was tested on the census data collected for this paper, namely the 2001-2006 Indigenous migration flows by origin, destination, age and sex were used to predict the 2006-2011 flows with the assumption that the overall level (i.e., 21,283) and main effects (O_i, D_j, A_x and S_y) were known. This might appear to be strong assumption but, as discussed in Section 4.2, the O_i and D_j components hardly changed and the A_x components are largely the same (see Figure 2). The 2006-2011 A_x component exhibited slightly lower shares of migration in the 5-9, 10-14 and 30-34 age groups and slightly higher shares in the 20-24 and 25-29 age groups. With regard to the S_y component over time, the overall proportion of female migrants decreased very slightly from 51.8 percent during the 2001-2006 period to 51.6 percent during the 2006-2001 period. Finally, the overall level component (T) increased from 17.6 thousand to 21.3 thousand between 1996-2001 and 2006-2011. For the 2001-2006 migration period, Indigenous migrants represented 2.43 percent of the total interstate migrants. This number increased to 2.77 percent during the 2006-2011 period.

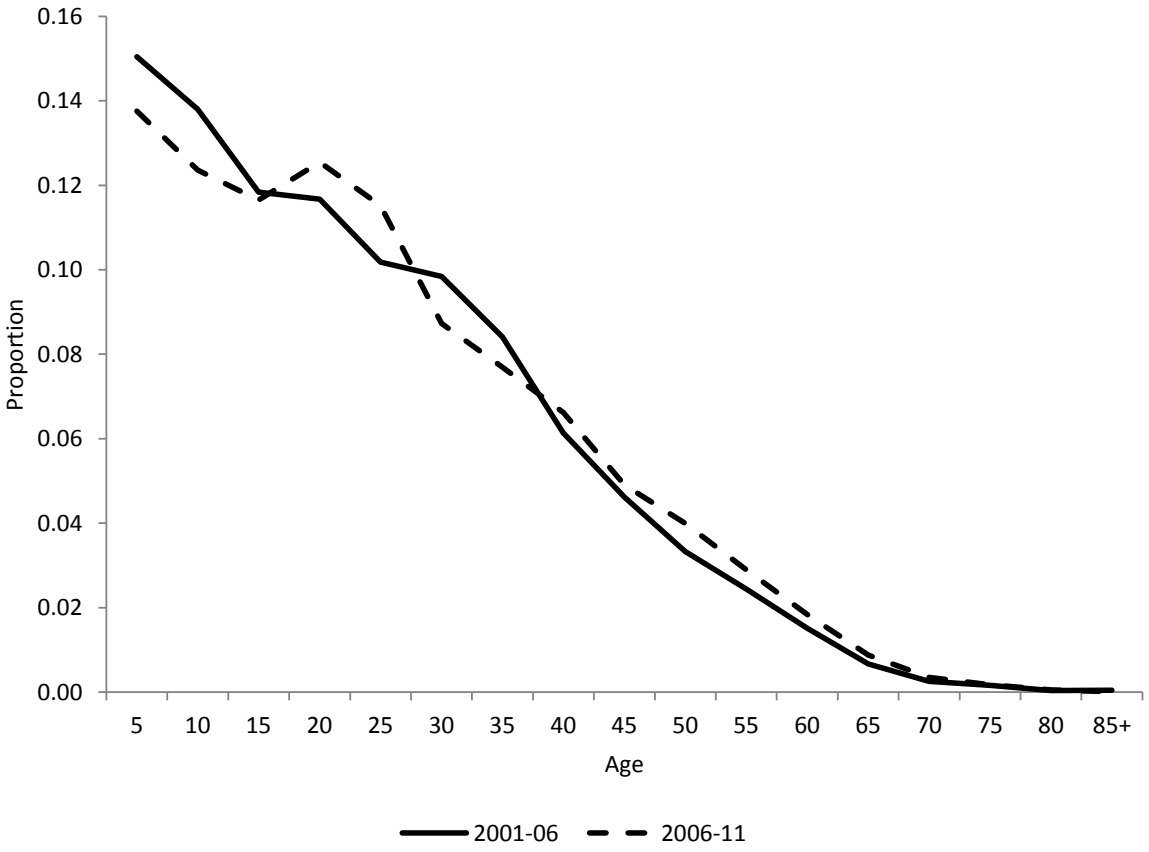


Figure 2. Proportions of Indigenous interstate migration by age, 2001-2006 and 2006-2011

Selected results from the log-linear with offset model applied to project the observed 2006-2011 period of migration are presented in Figure 3 for age-specific Indigenous male migration from New South Wales to Victoria, Queensland, South Australia, Western Australia, Northern Territory and Australian Central Territory. Here, we can see that the overall levels and spatial patterns are captured fairly well but there are substantial differences in the observed and projected age profiles of migration. These differences are larger for smaller flows. These irregularities do not appear to be systematic and are largely a consequence of the small indigenous population. In the next subsection, we overcome this problem by projecting 2011-2016 and 2016-2021 patterns using the [OD, OA, DA, AS] multiplicative model with smoothed OA, DA and AS structures. This allows us to avoid the problem of projecting the randomness contained in the census offset data (i.e., 2001-2006) as illustrated in this subsection.

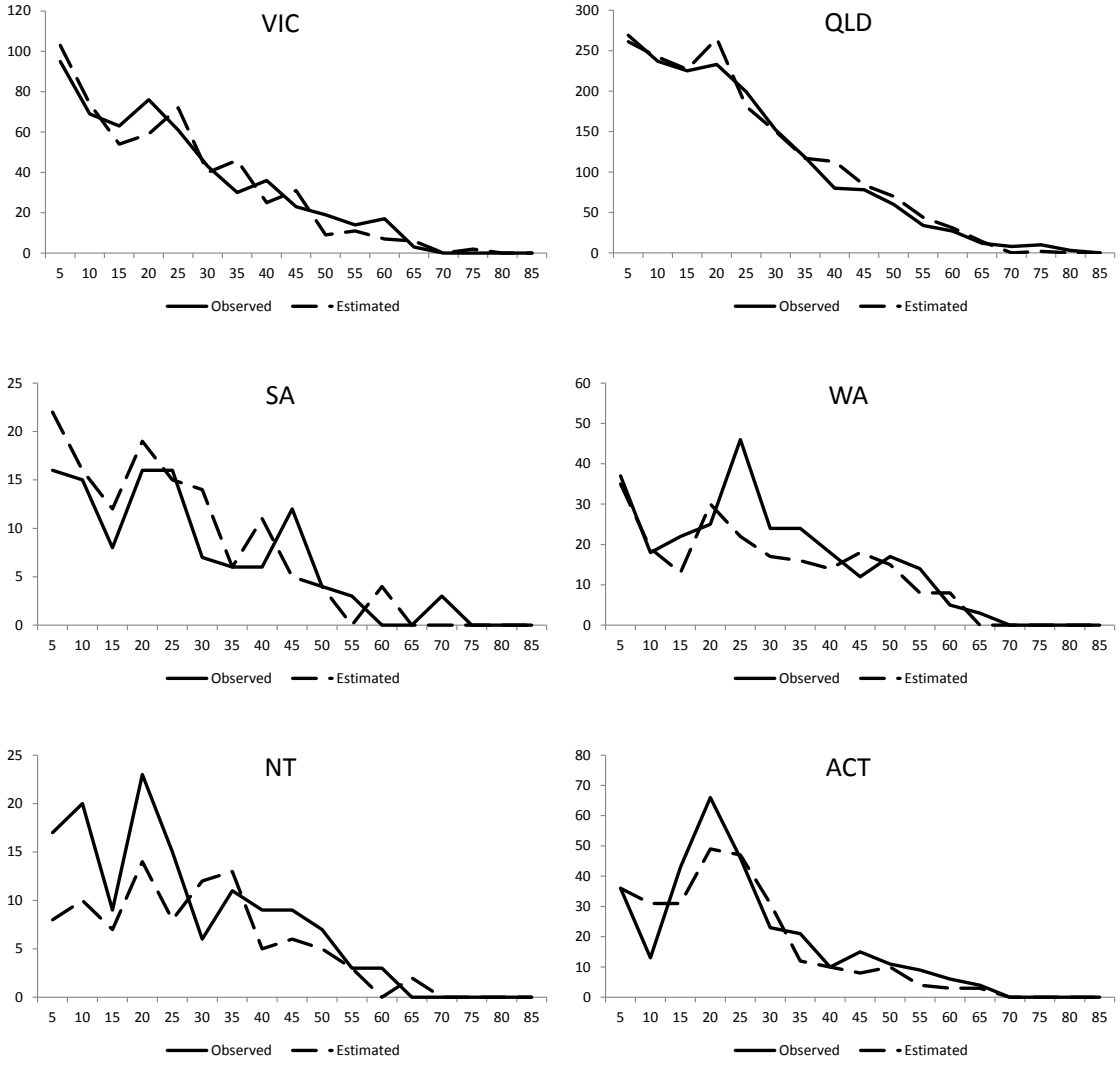


Figure 3. Projections of 2006-2011 age-specific Indigenous male migration from New South Wales to Victoria (VIC), Queensland (QLD), South Australia (SA), Western Australia (WA), Northern Territory (NT) and Australian Central Territory (ACT): Main effects log-linear model with 2001-2006 offset

5.2 Projecting the 2011-2016 and 2016-2021 flows

To avoid the irregular data problem shown in the previous subsection, we decided to use the multiplicative component model to project the age and sex patterns of Indigenous interstate migration in Australia. The projection is based on the [OD, OA, DA, AS] unsaturated model specification that was found in Section 4.3 to capture the observed data well.

The projections of the origin by destination by age by sex tables of migration flows are based on estimated changes to the overall level, main effect and the OD, OA, DA and AS two-way interaction multiplicative components. The projection model is specified as

$$\mu_{ijxy}^{t+5} = \left(T^{t+5}\right)\left(O_i^{t+5}\right)\left(D_j^{t+5}\right)\left(A_x^{t+5}\right)\left(S_y^{t+5}\right)\left(OD_{ij}^{t+5}\right)\left(OA_{ix}\right)\left(DA_{jx}\right)\left(AS_{xy}\right), \quad (9)$$

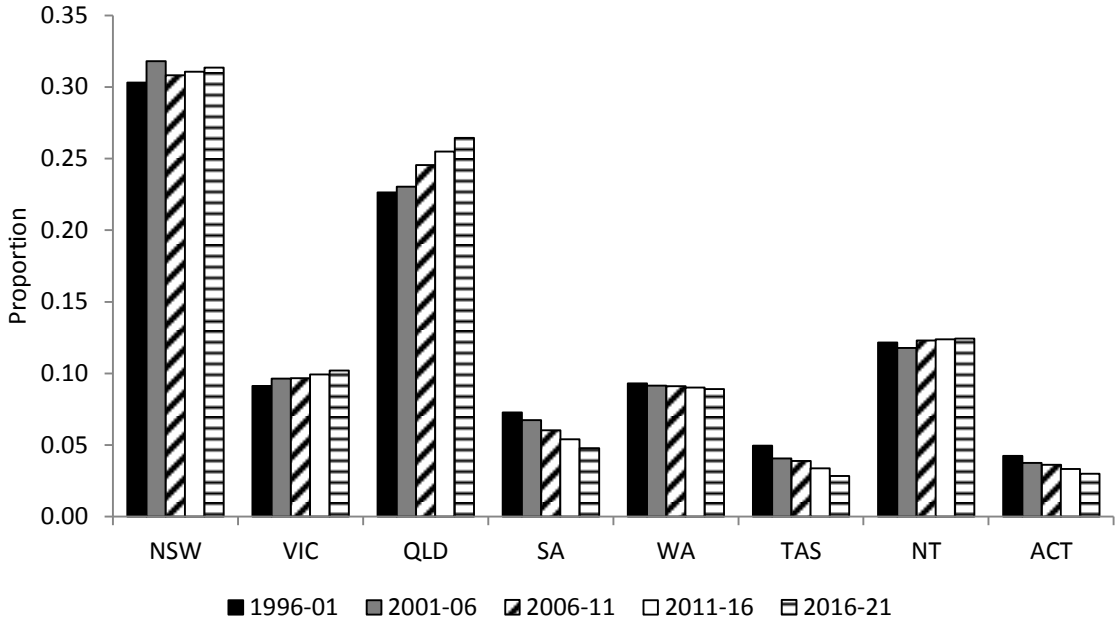
where *t* denotes time period. For the overall level, main effect and origin-destination interaction components, we extrapolate the patterns forward by applying the following formula, specified for the overall level component:

$$T^{t+5} = T^{t} + \frac{\left(T^{t-5} - T^{t-10}\right) + \left(T^{t} - T^{t-5}\right)}{2}. \quad (10)$$

The extrapolation formula assumes future changes are based on the average change that occurred during the previous two time periods.

Applying the formula in Equation 10, our projections assume that the overall level component will increase from 21,283 Indigenous migrants observed during the 2006-2011 period to 23,146 migrants during the 2011-2016 period and to 25,009 migrants during the 2016-2021 period. The projected O_i and D_j components are presented in Figure 4. Here, we see that the relative shares of out-migration are expected to steadily increase from Queensland and steadily decrease from South Australia, Tasmania and Australian Capital Territory with more modest changes occurring in the remaining states or territories. For the relative shares of in-migration, we expect increases to occur in New South Wales, Victoria, Western Australia and Tasmania and decreases in Queensland, South Australia and Northern Territories. Our projections of the age main effect component are presented in Figure 5, where we find the proportions in the 5-14 year old age groups are expected to decrease with slight increases in the 20-24 year old age groups and 45-74 year old age groups. Finally, the projected proportions of female migration are expected to slightly decrease from 51.6 percent in 2006-2011 to 51.2 percent in 2016-2021 with corresponding increases in the shares of male migration. Note, the projections for both the age and sex main effect components were based on the two most recent census periods due to data availability.

A. Proportion of migration from each state or territory, O_i



B. Proportion of migration to each state or territory, D_j

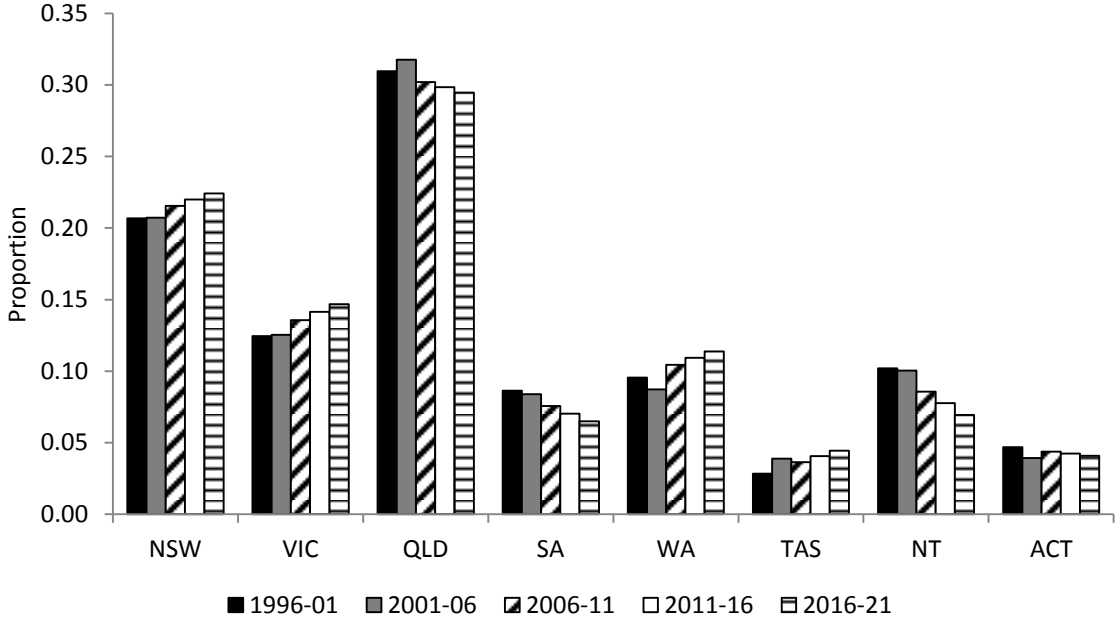


Figure 4. Observed and projected proportions of in-migration and out-migration by state or territory in Australia: 1996-2001 to 2016-2021

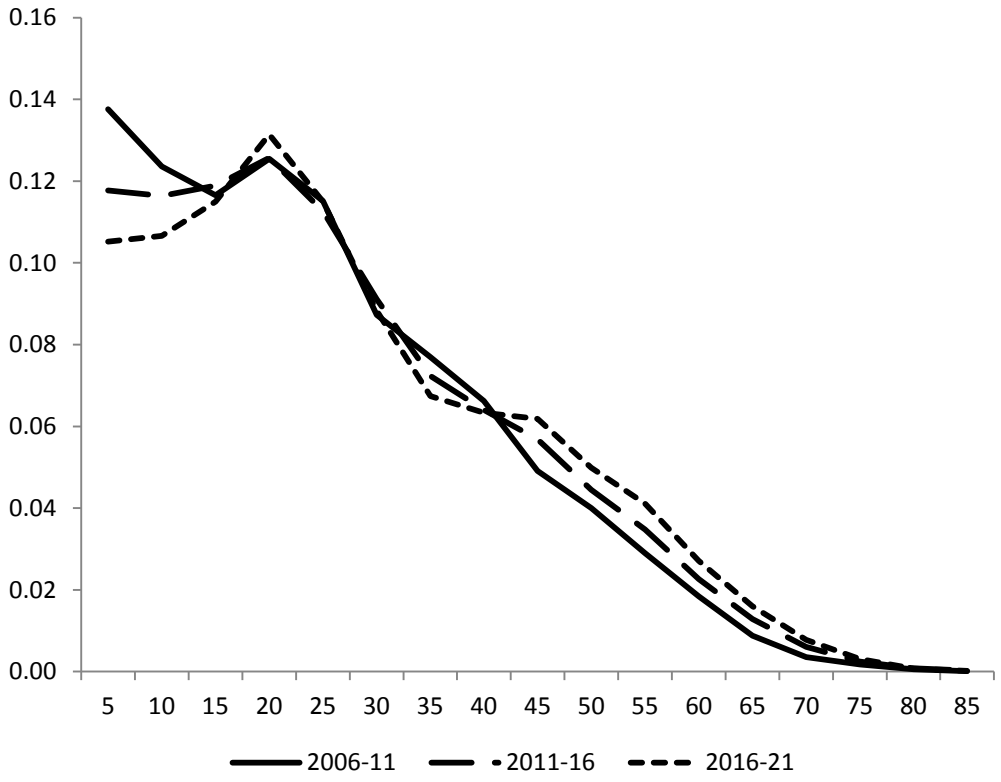
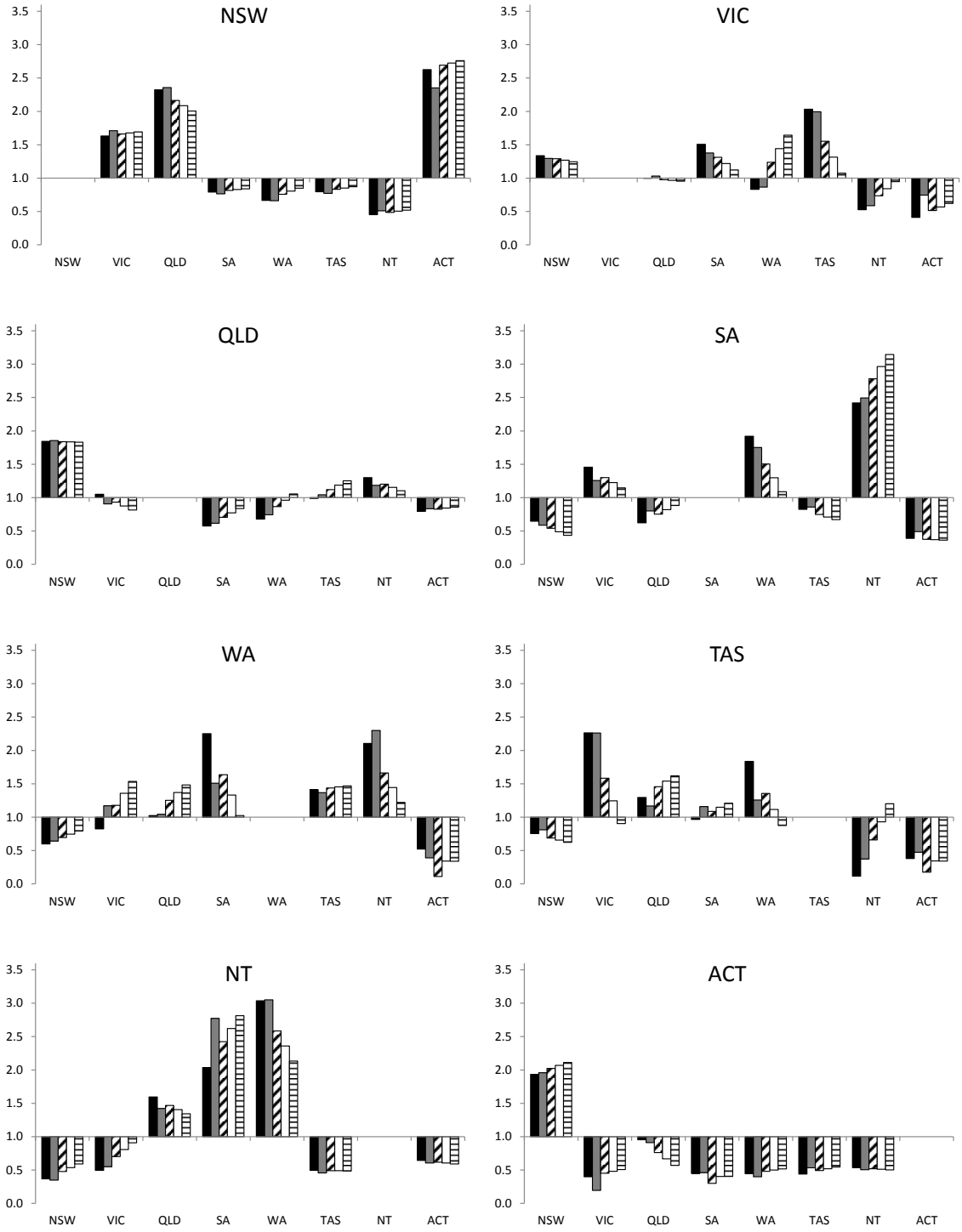


Figure 5. Observed and projected proportions of Indigenous interstate migration by age: 2006-2011 to 2016-2021

The observed and projected changes to the OD_{ij} multiplicative components are presented in Figure 6. The projections are based on the extrapolation formula presented in Equation 10, except for three flows from (i) South Australia to the Australian Capital Territory, (ii) Australian Capital Territory to Western Australia, and (iii) Australian Capital Territory to Tasmania, where the average observed ratios were used instead and held constant for both projection periods. This was done to avoid negative or close to zero ratios.



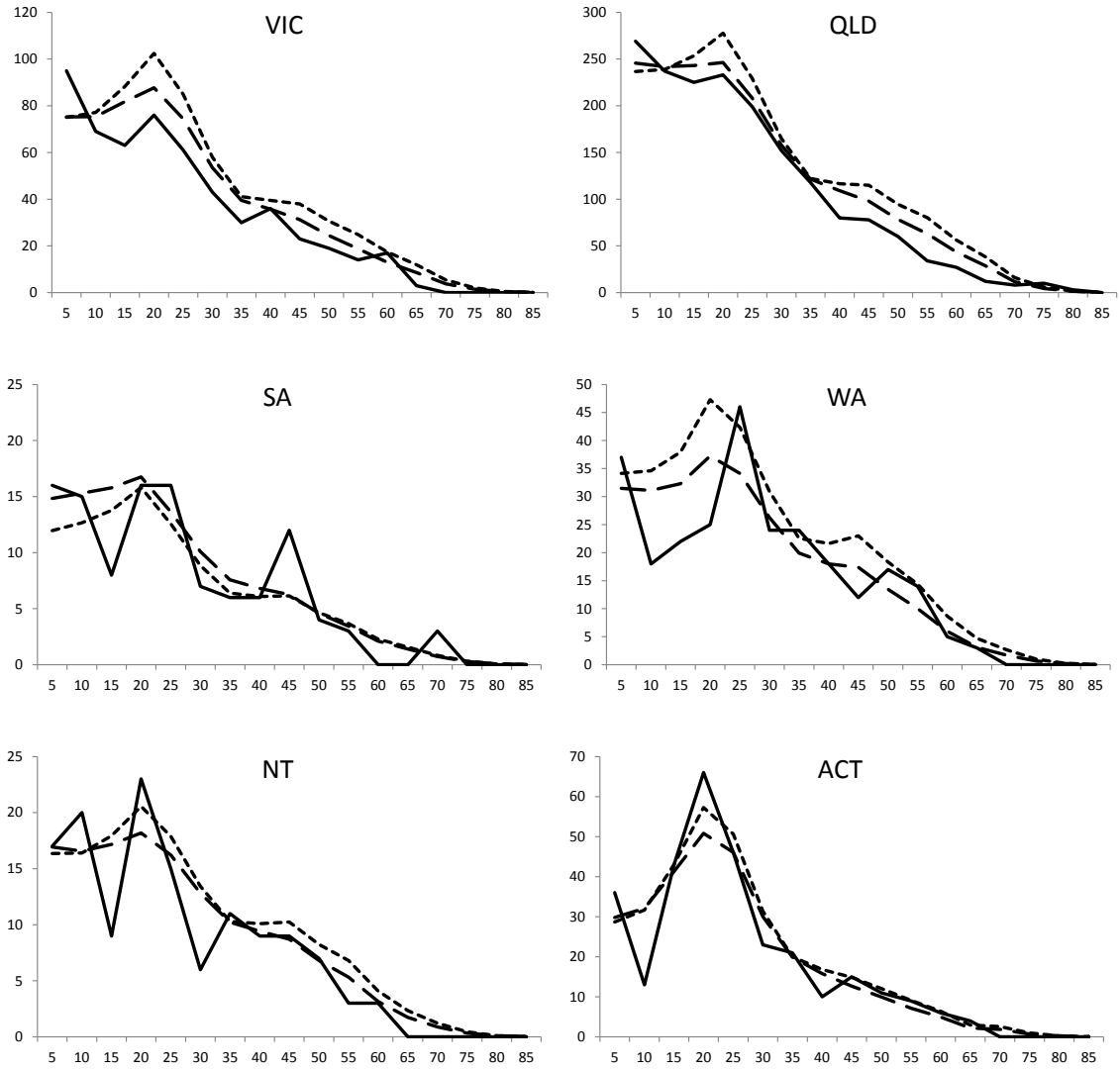
Note: x-axis = state or territory of origin.

Figure 6. Observed and projected origin-destination interaction components (OD_{ij}) by state or territory of destination: 1996-2001 to 2016-2021

Finally, for the OA_{ix}, DA_{jx} and AS_{xy} components, there were no obvious trends exhibited over time but they did exhibit substantial irregularities across age groups. To prevent these irregularities

from influencing the migration flow projections, the OA_{ix}, DA_{jx} and AS_{xy} components were smoothed both by averaging across ages (moving average across three age groups) and over the two observed periods of time. These smoothed components (not shown) were kept fixed for both projection periods.

In Figure 7, we present a selection of the projection results corresponding to those presented in Figure 3. The smoothed projections allow us to overcome the highly irregular data observed in base census data, especially for small flows, such as New South Wales to South Australia. They also reflect projected changes to the overall level, main effect components and OD interaction component. Finally, since the model produces the full matrix of migration flows by age and sex, we can produce any projected migration statistics required as inputs into population projections.



Note: x-axis = age.

Figure 7. Projections of 2011-2016 and 2016-2021 age-specific Indigenous male migration from New South Wales to Victoria (VIC), Queensland (QLD), South Australia (SA), Western Australia (WA), Northern Territory (NT) and Australian Central Territory (ACT): (OD, OA, DA, AS) multiplicative component model

Finally, we present the observed and projected net migration totals for the Indigenous population in Figure 8. Here we find that net migration for New South Wales will continue to be negative at around 2000 persons per five-year period. Net migration will increase in Victoria, South Australia, Western Australia, Tasmania and Australian Capital Territory. Queensland will experience steady decreases in net migration, while the negative net migration in the Northern Territories will become even greater.

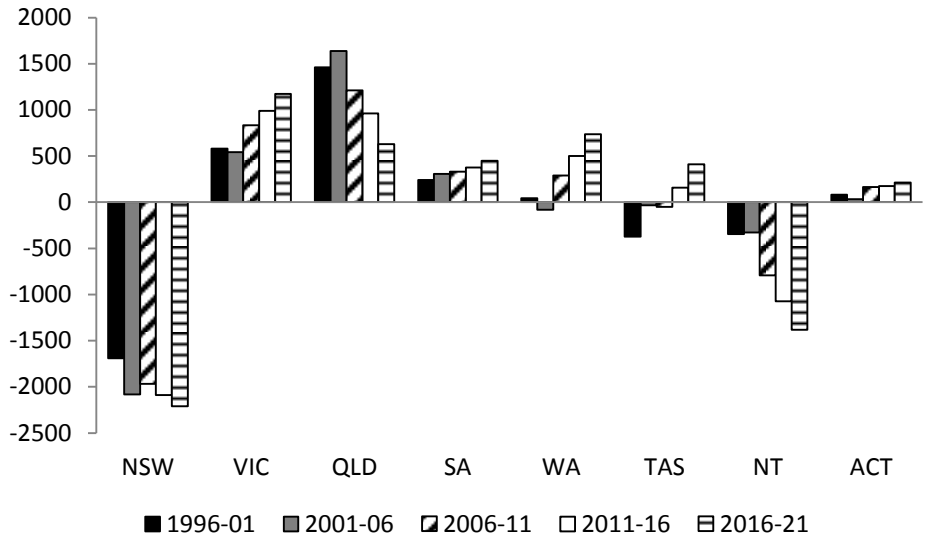


Figure 7. Observed and projected Indigenous net migration in Australia by state or territory, 1996-2001 to 2016-2021

6. SUMMARY AND DISCUSSION

In this paper, we have analysed the internal migration patterns of Indigenous persons over three time periods (i.e., 1996-2001, 2001-2006 and 2006-2011) and have compared these patterns with the corresponding non-Indigenous patterns. This information was used to develop a projection model for Indigenous migration by origin, destination, age and sex.

We found the spatial patterns of Indigenous migration were distinct from the non-Indigenous patterns but, within each group, the internal migration patterns are remarkably stable over time. This information is useful for understanding the patterns and developing projection models for internal migration. The two-way interaction model (OD, OA, DA, AS) was found to provide a good representation of the full ODAS table and provided a base for making projections of future interstate migration patterns. Using historical census data as a base, we were able to produce reasonable short-term migration projections based on futures estimates of the key underlying migration structures.

The analysis has provided some new insights into the evolution of recent patterns of age-specific interstate migration exhibited by the Indigenous population in Australia. In the near future,

the interstate migration flows are likely to reflect a continuation of past trends found in the age , sex and spatial structures. These include the high proportions of migration from New South Wales and Queensland reflecting relative population size and the preference for Queensland as the top destination as with other interstate migrants. The Northern Territories will be interesting to watch as currently there are greater shares of migrants leaving this area than going to it. This may have reflected policy settings over the period (including the Northern Territory Emergency Response, or Intervention), though this would need to be tested with other techniques and more disaggregated data.

The techniques used in this paper overcome some of the data limitations of the Indigenous population in the Census – namely the small absolute number of migration flows between certain jurisdictions. We are still, however, reliant on accurate underlying Census data with robust information on place of usual residence on the night of the Census and usual residence five years earlier. One of the consequences of modelling a highly mobile population and one with relatively low levels of English language ability and general literacy, however, is the uncertainty around usual residence status (Morphy 2007; Biddle and Prout 2009).

In conclusion, migration is generally viewed as a complex phenomenon that is difficult to model or incorporate into population projection models (Smith, Tayman and Swanson 2001). This analysis has demonstrated that complex patterns can be reliably predicted if one focuses on the underlying structures rather than net migration totals or the flows themselves. More research is needed to explain and model the different shapes of age-specific Indigenous migration and how they change over time. In particular, we need to understand the relationship between migration and identification change and how this differs across ages and spatial units.

REFERENCES

Agresti A (2013) *Categorical data analysis*, Third edition. Wiley, Hoboken.

Australian Bureau of Statistics (2003) Census of population and housing: Population growth and distribution, Australia, 2001. Australian Bureau of Statistics, Canberra.

Australian Bureau of Statistics (2013) Census of population and housing: Understanding the increase in Aboriginal and Torres Strait Islander counts, 2006-2011. Cat. No. 2077.0, Australian Bureau of Statistics, Canberra.

Australian Bureau of Statistics (2014) Estimates and projections, Aboriginal and Torres Strait Islander Australians: 2001-2026. Cat. No. 3238.0, Australian Bureau of Statistics, Canberra.

Biddle N (2012) Population and age structure. Paper 5, CAEPR Indigenous Population Project 2011 Census Papers, Centre for Aboriginal and Economic Policy Research, The Australian National University, Canberra.

Biddle N (2013) Population Projections. Paper 14, CAEPR Indigenous Population Project 2011 Census Papers, Centre for Aboriginal Economic Policy Research, The Australian National University, Canberra.

Biddle N and Prout S (2009) The geography and demography of Indigenous temporary mobility: An analysis of the 2006 Census snapshot. *Journal of Population Research* 26(4):305-326.

Bijak J (2010) *Forecasting international migration in Europe: A Bayesian view*. Springer, Dordrecht.

Department of Immigration and Border Protection (2014) *The people of Australia: Statistics from the 2011 Census*. Department of Immigration and Border Protection, Canberra.

Morphy F (2007) Agency, contingency and census process: Observations of the 2006 Indigenous Enumeration Strategy in remote Aboriginal Australia. Research Monograph No. 28, Centre for Aboriginal Economic Policy Research, ANU E Press, The Australian National University, Canberra.

Raymer J (2010) A general framework for estimating population movements. In *Demographic aspects of migration*, Salzmann T, Edmonston B and Raymer J, eds., pp. 73-96.

Raymer J, Bonaguidi A, and Valentini A (2006) Describing and projecting the age and spatial structures of interregional migration in Italy. *Population, Space and Place* 12(5):371-388.

Raymer J and Rogers A (2007) Using age and spatial flow structures in the indirect estimation of migration streams. *Demography* 44(2): 199-223.

Rogers A (1990) Requiem for the net migrant. *Geographical Analysis* 22:283-300.

Rogers A (1995) *Multiregional demography: Principles, methods and extensions*. Wiley, Chichester.

Rogers A, Willekens FJ, Little JS and Raymer J (2002) Describing migration spatial structure. *Papers in Regional Science* 81: 29-48.

Rogers A, Willekens FJ and Raymer J (2003): Imposing age and spatial structures on inadequate migration-flow datasets. *The Professional Geographer* 55(1): 56-69.

Snickars F and Weibull JW (1977) A minimum information principle: Theory and practice. *Regional Science and Urban Economics* 7(1-2):137-168.

Taylor J (1997) The contemporary demography of Indigenous Australians. *Journal of the Australian Population Association* 14(1):77-114.

Taylor J (2003) Indigenous Australians: The first transformation. In *The transformation of Australia's population: 1970-2030*, Khoo S-E and McDonald P, eds., pp. 17-39. University of New South Wales Press, Sydney.

Van Wissen L, Van der Gaag N, Rees P and Stillwell J (2008): In search of a modelling strategy for projecting internal migration in European countries. In *Migration and human capital*, Poot J, Waldorf B and Van Wissen L, eds., pp. 49-74. Edward Elgar, Cheltenham.

Willekens F (1983) Log-linear modelling of spatial interaction. *Papers of the Regional Science Association* 52: 187-205.

Willekens F (1994) Monitoring international migration flows in Europe: Towards a statistical data base combining data from different sources. *European Journal of Population* 10:1-42.