DEMOGRAPHIC RESEARCH
A peer-reviewed, open-access journal of population sciences

DEMOGRAPHIC RESEARCH

VOLUME 28, ARTICLE 24, PAGES 681-712
PUBLISHED 3 APRIL 2013
http://www.demographic-research.org/Volumes/Vol28/24/
DOI: 10.4054/DemRes.2013.28.24

Research Article

The sequential propensity household projection model

Tom Wilson

Table of Contents

Demographic Research: Volume 28, Article 24
Research Article

The sequential propensity household projection model

Tom Wilson[1]

Abstract

BACKGROUND

The standard method of projecting living arrangements and households in Australia and New Zealand is the 'propensity model', a type of extended headship rate model. Unfortunately it possesses a number of serious shortcomings, including internal inconsistencies, difficulties in setting living arrangement assumptions, and very limited scenario creation capabilities. Data allowing the application of more sophisticated dynamic household projection models are unavailable in Australia.

OBJECTIVE

The aim was to create a projection model to overcome these shortcomings, whilst minimising input data requirements and costs and retaining the projection outputs users are familiar with.

METHODS

The sequential propensity household projection model is proposed. Living arrangement projections take place in a sequence of calculations, with progressively more detailed living arrangement categories calculated in each step. In doing so the model largely overcomes the three serious deficiencies of the standard propensity model noted above.

PROJECTIONS

The model is illustrated by three scenarios produced for one case-study State, Queensland. They are: a baseline scenario in which all propensities are held constant to demonstrate the effects of population growth and ageing, a housing crisis scenario where housing affordability declines, and a prosperity scenario where families and individuals enjoy greater real incomes. A sensitivity analysis in which assumptions are varied one by one is also presented.

CONCLUSIONS

The sequential propensity model offers a more effective method of producing household and living arrangement projections than the standard propensity model, and is a practical alternative to dynamic projection models for countries and regions where the data and resources to apply such models are unavailable.

[1] Queensland Centre for Population Research, School of Geography, Planning and Environmental Management. The University of Queensland, Brisbane. E-mail: tom.wilson@uq.edu.au.

1. Introduction

How much growth in the number of households will occur over the next 30 years? What family and household types will there be? How many dwellings will have to be built, and of what type, and where? These are the questions asked by policymakers and planners in preparing regional planning strategies, and the basis of many requests made to demographers to produce household projections. There are, of course, many other applications of household projections, including calculating future demand for a whole range of consumer goods and services which are purchased on a household rather than an individual basis, estimating future nursing home and elderly care needs because these vary considerably according to living arrangement (Keilman and Christiansen 2010), projecting future travel behaviour (Prskawetz et al. 2004), and calculating per capita resource consumption and greenhouse gas emissions (Liu et al. 2003).

However, this paper approaches the preparation of household projections with a focus on the needs of State/regional government planning departments. Although the empirical focus of the paper is Australia, it is hoped the methodological aspects will be of wider interest. The point of departure for this research was the question 'Which methods are most suited to the preparation of projections of households by type for Australian States and large sub-state regions?' Preferably, the method would (Bell et al. 1995):

- (i) produce projections using existing Australian Bureau of Statistics (ABS) classifications of living arrangements and household types,
- (ii) not require multidimensional living arrangement-to-living arrangement data (which are not readily available in Australia),
- (iii) incorporate clear connections with demographic processes,
- (iv) be easily linked to the cohort-component population projection systems currently in use by State governments,
- (v) be easily updated,
- (vi) be amenable to scenario formulation,
- (vii) give projections no less accurate than current propensity models, and
- (viii) be within the resource, budget, and timeframe constraints within which State government demography sections must work.

There are potentially many different types of household projection model to choose from (Bell et al. 1995; van Imhoff et al. 1995). The most conceptually advanced methods are macro-scale multi-dimensional models which handle living arrangement-to-living arrangement transitions, and microsimulation models which simulate demographic events on the individual scale. Unfortunately the data, budgets, timeframes, or staff resources available for preparing household projections regularly preclude the use of these model types. In Australia and many other countries there are no readily available data on household transitions, making it difficult for sophisticated models such as LIPRO (van Imhoff and Keilman 1991; NIDI 1999) to be implemented. The multidimensional model PROFAMY (Zeng et al. 1997, 1999; Jiang and O'Neill 2007), whilst possessing many attractive features, would also be difficult to apply. Although the designers of the model emphasise that it "requires only data that are available from conventional demographic data sources" (Zeng et al. 1999 p.62) it is still quite data-hungry. Amongst its input requirements are fertility rates by age, parity, and marital status, marital status transitions by age and sex, and age-sex probabilities of leaving and returning to the parental home; all of which are unfortunately unavailable as conventional demographic data in Australia.

In Australia and New Zealand the propensity model – described in section 2 – has become widely used. It is easily linked to existing cohort-component population projections, does not require multidimensional living arrangement transition data, is reasonably simple to compute, and provides considerable output detail. But it suffers from many practical and theoretical limitations (O'Leary 2000), discussed in the next section. One option would be to switch to an entirely new model, such as McDonald et al.'s (2006) net transition probability model. But rather than throwing out the propensity model entirely, another option is to revise the model, retaining its best features whilst addressing its shortcomings. The latter option is taken here. Thus this paper presents a substantially revised version of the propensity model, termed the sequential propensity household projection model. Revising, rather than abandoning, the propensity model enables existing time series data on living arrangements to be used (often purchased at great cost), maintains some commonality of thinking with the standard propensity model (reducing the amount of training required), and provides the same kind of living arrangement and household outputs which users are familiar with.

A brief note about terminology is useful before proceeding further. It is acknowledged that the terms 'household' and 'family' have a variety of definitions and interpretations (Keilman 1995; Tillman and Nam 2008) and are not really applicable to traditional Aboriginal communities (Morphy 2007). However, throughout the paper ABS definitions and data are used. "A household is defined as one or more persons, at least one of whom is at least 15 years of age, usually resident in the same private dwelling. Under this definition, all occupants of a dwelling form a household" (ABS 2011a). Individuals may only belong to one household. "A family is defined by the ABS as two or more persons, one of whom is at least 15 years of age, who are related by blood, marriage (registered or de facto), adoption, step or fostering, and who are usually resident in the same household. Each separately identified couple relationship, lone parent-child relationship or other blood relationship forms the basis of a family. Some households contain more than one family." (ABS 2011a).

The paper continues as follows. Section 2 describes the standard propensity model, noting its strengths and weaknesses. The following section introduces the new model, and details a ten-step calculation scheme. In the subsequent section three scenarios for the future development of living arrangements and households in the case study State of Queensland are described. These are: a baseline scenario in which all propensities are held constant to demonstrate the effects of population growth and ageing, a housing crisis scenario where housing affordability declines (involving more young adults living with parents, lower fertility, and greater probabilities of living in group and multiple-family households), and a prosperity scenario where families and individuals enjoy greater real incomes (resulting in higher fertility, earlier leaving of the parental home, and lower probabilities of group and multiple-family households being formed). A sensitivity analysis, in which assumptions are varied one at a time, is the subject of section 5. The final section summarises the main findings and suggests avenues for further research.

2. The standard propensity model

The propensity model can be viewed as a type of headship rate model (UN 1973) extended to provide more information about households and avoid the outdated 'head of household' concept (Bell and Cooper 1990, Ironmonger and Lloyd-Smith 1992). Rather than dividing an existing population projection into two categories, heads and non-heads, a propensity model disaggregates a population into many categories. The term 'propensity' (p) refers to the proportion of a population (P) of sex s and age group a in category i:

$$p_{s,a}^{i}(t) = \frac{P_{s,a}^{i}(t)}{P_{s,a}(t)}$$

These categories are commonly household sizes (e.g., Linke 1988; Bell and Cooper 1990) and living arrangements (e.g., ABS 1999). For example, the propensity for a woman aged 30-34 to live with a husband/partner and children is calculated as the number of females aged 30-34 living with a husband/partner and children divided by all females aged 30-34. Living arrangements, family types, and household types typically used in Australian applications of propensity models are listed in Table 1.

Table 1: Living arrangement categories typical in a propensity model and how they map to family and household types

Living arrangement	Family type	Household type
Living with a spouse/partner and child(ren) Child living with two parents (either dependent or non-dependent)	Couple family with children	Couple family with children household
Living with a spouse/partner; no child(ren)	Couple only family	Couple only family household
Single parent Child living with a single parent (either dependent or non-dependent)	Single parent family	Single parent family household
Living with family members (excluding children, partners or parents), e.g. adult siblings	Other Family§	Other Family household
Related individual living with a family	*Any of the above family types*	*Any of the above household types*
Unrelated individual living with a family	*Any of the above family types*	*Any of the above household types*
Any of the above living arrangements	*Any of the above family types*	Multiple-family household
Living alone	n/a	Lone person household
Living in a group household	n/a	Group household
Persons in non-private dwellings*	n/a	n/a

Notes: § An 'Other Family' is defined as "a group of related individuals residing in the same household, who cannot be categorised as belonging to a couple or one parent family" (ABS 2006).
* Non-private dwellings are also known as communal establishments or group quarters.
n/a: not applicable

Whilst propensity models vary in their categories and calculation schemes, the following simplified description of a propensity model is typical of Australian and New Zealand applications (e.g., ABS 2004; Statistics New Zealand 2010). As a first step, age-sex-specific propensities to live in a particular living arrangement are calculated from several past censuses. Second, propensities are extrapolated on the basis of past trends, sometimes linearly, sometimes using non-linear methods, and sometimes using only judgment. Adjustments may have to be made to ensure that propensities sum to unity across all living arrangements. Third, projected propensities are multiplied by age-sex population projections to obtain the projected population by living arrangement. Fourth, projected numbers of families are obtained from the population in family living arrangements. A spouse/partner represents 0.5 of a family whilst a lone parent represents one family. The number of Other Families is obtained by dividing the number of persons in Other Families by the average Other Family size. ABS defines an Other Family as “a group of related individuals residing in the same household, who cannot be categorised as belonging to a couple or one parent family” (ABS 2006) such as two adult siblings living together. Next, the numbers of families are converted to the number of family households to allow for a small number of multiple-family households. Often ratios of family households to families from the most recent census are assumed. Sixth, the numbers of non-family households are calculated. The number of group households equals the number of persons living in a group household divided by the average group household size. The number of lone person households simply equals the number of persons living alone.

The strengths of the standard propensity model include its mathematical simplicity and ease of comprehension and calculation. It has reasonably low data requirements. As a minimum it needs population projections by age and sex, a disaggregation of the population by living arrangement by age and sex from the most recent census, and a few other census-based statistics, such as ratios of households to families. It produces good output detail: projections of persons by living arrangement by age and sex, and the number of households by household type, are obtained. It avoids using the outdated head of household concept. And finally, it incorporates the effects of population age structure change, a feature which is particularly important for ageing populations.

Unfortunately, there are many limitations. Four major problems are highlighted.

(1) It is a static model. It does not imitate the processes of household formation and dissolution, neither does it allow the distribution of the population across relationship and living arrangement statuses to influence fertility, mortality, and migration, as would be the case in a dynamic model. And there are no cohort effects unless propensity assumptions explicitly incorporate them.

(2) There are inconsistencies in the model. Two types are noted here. First, there are inconsistencies within living arrangement projections. For example, when projected separately, the numbers of males and females in (opposite-sex) partnerships have a tendency to differ, a feature known as the two-sex problem (Keilman 1985). Second, living arrangement and population assumptions are not linked (O’Leary 2000). For example, an increasing fertility assumption in the population projection could well be combined with a declining propensity for adults to be parents in the living arrangement projection, which is an unlikely outcome.

(3) From a practical viewpoint, the projection of age-sex-specific living arrangement propensities, whilst not technically taxing, is awkward. And where many hundreds of local areas must be handled, it can also be very time-consuming. In many cases initially projected propensities will not sum across living arrangements to unity, requiring them to be scaled, with the consequence that other propensities will then require adjustment. In addition, even if the analyst has some confidence about the future

direction of demographic and household processes, it is not a simple matter to translate these to future trajectories of propensities.

(4) It is difficult to formulate alternative scenarios linked to processes such as marriage, divorce, de facto partnership formation and dissolution, children leaving home, etc. Many propensities are the net outcome of several demographic processes.

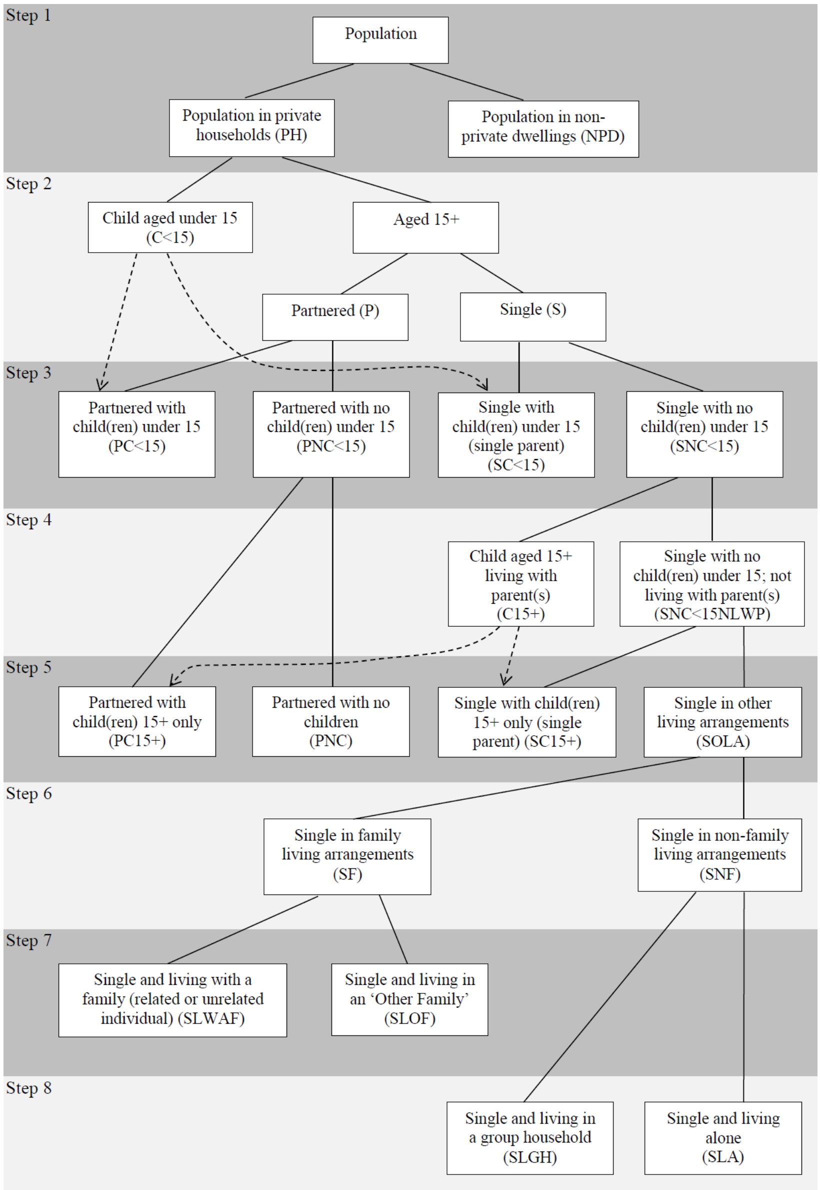
3. The sequential propensity household projection model

3.1 Overview

The sequential propensity household model largely overcomes three of the problems of the standard propensity model listed in the previous section, specifically: inconsistencies between living arrangements and between living arrangement and population projections (limitation 2 in the above list), awkward propensity projections (3) and scenario creation difficulties (4). It achieves this by arranging the living arrangement projections into a tree structure in which progressively more detailed living arrangement categories are calculated in each step, avoiding sex disaggregation, and linking projections of dependent children to those of their parents. The step-by-step feature of the model was inspired by the conditional shares approach taken by Alho and Keilman (2010) in their probabilistic household projection model. Figure 1 outlines the process of projecting the population by living arrangement. The ordering of calculations was largely influenced by the way in which ABS classifies families and households (ABS 2005). ABS determines the family composition of a household on the basis of the following relationships (in order of importance): a couple relationship, a parent-child relationship, the dependency status of any children, and other family relationships. In non-family households the main distinction is between group households and people living alone.

The calculations begin with an exogenously projected population by five-year age group (but without sex disaggregation). In step 1 the population is split into people living in private households and those in non-private dwellings. Children under the age of 15 are then separated from those aged 15 and over. In step 2 a basic distinction is made between those living with a spouse or partner (‘partnered’) and those who are not (‘single’). The extent of partnering in the population is clearly a key influence on the number and type of households, and on the distribution of children between single parent and couple households.

Figure 1: Outline of the sequential propensity household model living arrangement calculations



Step 3 deals with children under the age of 15, dividing both partnered and single individuals into those living with children under 15 and those who are not (though they may still be living with older children). The number of children affects the proportions of adults who are parents (as depicted by the dashed lines in Figure 1), thus allowing changes to fertility and childhood-age migration in the population projections to influence the extent of parenting. Step 4 divides those adults who are single and not living with children into older children (aged 15 and over) living with parents, and single people in other living arrangements. The number of older children influences the proportions of partnered and single adults living with older children (as indicated by the dashed lines between steps 4 and 5).

The model then allocates single persons without children into various living arrangements. In step 6 these individuals are divided into those in family living arrangements and those in non-family living arrangements. Step 7 further distributes those in family living arrangements into individuals living with a family and those living in an Other Family. Single adults in non-family living arrangements are allocated to the categories of living in a group household and living alone in step 8. Two further steps (not shown in Figure 1) then convert persons by living arrangement into numbers of families and households. The precise calculations are set out in section 3.2.

3.2 Ten-step calculation scheme

Step 1: Split the population into private and non-private dwelling residents

The projected population in non-private dwellings equals the resident population multiplied by the probability of living in a non-private dwelling (NPD):

$$P_a^{NPD}(t) = P_a(t)\ \ p_a(NPD, t)$$

where $p_a(NPD, t)$ is the projected probability of living in a non-private dwelling at time t. The private household population (PH) is then calculated as a residual:

$$P_a^{PH}(t) = P_a(t)\ - P_a^{NPD}(t).$$

Step 2: Split the private household adult population into partnered and single adults

The private household adult (aged 15+) population living with a partner (P) is calculated as:

$$P_a^{P}(t) = P_a^{PH}(t)\ \ p_a(P|PH, t)$$

where $p_a(P|PH,t)$ is the projected probability of living with a partner conditional on being part of the private household population. People not living with a partner are, for the purposes of this modelling, labelled as single (S). Their numbers are calculated as:

$$P_a^S(t) = P_a^{PH}(t) - P_a^P(t).$$

Step 3: Split partnered and single adults into those living with and without children under 15

Projections of the adult population living with a partner and children under 15 (PC<15) are derived as the product of the partnered population and the probability of being a parent:

$$P_a^{PC<15}(t) = P_a^P(t)\ p_a(PC < 15|P,t)$$

where $p_a(PC < 15|P,t)$ is the probability of living with a partner and children under 15 conditional on living with a partner. Similarly, projections of the adult population who are single parents with children under 15 (SC<15) are derived as:

$$P_a^{SC<15}(t) = P_a^S(t)\ p_a(SC < 15|S,t)$$

where $p_a(SC < 15|S,t)$ is the probability of being a single parent living with children under 15 conditional on being single. The numbers of partnered and single adults with no children under 15 (NC<15) are calculated as residuals:

$$P_a^{PNC<15}(t) = P_a^P(t) - P_a^{PC<15}(t)$$

and

$$P_a^{SNC<15}(t) = P_a^S(t) - P_a^{SC<15}(t).$$

Unlike earlier steps, however, the probabilities of partnered and single adults being parents are not set in advance, but are obtained during the course of the projections. They consist of base period probabilities adjusted to be consistent with the projected number of children aged under 15. The model therefore permits fertility and migration assumptions, which affect the number of under 15s in the population, to be reflected in adults' living arrangements. To make the necessary adjustments Child/Parent Ratios (CPRs) are calculated, defined as the number of children aged under 15 in private households divided by the number of parents to these children aged 15+. They are similar in concept to the Child/Woman Ratio. Separate ratios for children with two parents (the Child/2 Parent Ratio, C2PR) and one parent (the Child/1 Parent Ratio, C1PR) are required:

$$C2PR(base) = \frac{P_{<15}^{2P}(base)}{P_{15+}^{PC<15}(base)}$$

and

$$C1PR(base) = \frac{P_{<15}^{1P}(base)}{P_{15+}^{SC<15}(base)}$$

where 1P denotes 'children with one parent' and 2P 'children with two parents'.

To maintain consistency with the numbers of children aged under 15 in private households the following identity must hold:

$$\sum_{a=15+}\big(p_a(PC < 15|P)\, P_a^P(t)\big)\ C2PR(t) +$$

$$\sum_{a=15+}\big(p_a(SC < 15|S)\, P_a^S(t)\big)\ C1PR(t)\ =\ P_{<15}^{PH}.$$

That is, the conditional probabilities of partnered and single adults being parents, when multiplied by their respective populations at risk, summed over ages 15+, and then multiplied by their relevant Child/Parent Ratios, must equal the numbers of children under 15 in private households. The populations at risk, $P_a^P(t)$ and $P_a^S(t)$, have already been determined in the previous step. Changes to numbers of children aged under 15 in private households therefore have to result in either changes to parenting probabilities, or changes to Child/Parent Ratios, or both.

A user-defined parameter γ indicates the extent to which changes are made to parenting probabilities. It takes values in the range 0 to 1. If γ is set to 1 then any rises in fertility are wholly accommodated by increasing age-specific parenting probabilities with no changes to Child/Parent Ratios. If, on the other hand, γ is set to zero then parenting probabilities remain constant and all the fertility increase is accommodated by larger average family sizes. It is assumed that single parent and two-parent families are adjusted to the same extent in response to fertility changes. The hypothetical number of under 15s in private households in the absence of changes to parenting probabilities and Child/Parent Ratios is required to adjust the parenting probabilities:

$$P_{<15}^{PH}(hyp,t) =$$

$$\sum_{a=15+}\left(p_a(PC < 15|P,base)\ P_a^P(t)\right) C2PR(base) +$$

$$\sum_{a=15+}\left(p_a(SC < 15|S,base)\ P_a^S(t)\right) C1PR(base).$$

The adjusted parenting probabilities are then calculated as:

$$p_a(PC < 15|P,t) =$$
$$= p_a(PC < 15|P,base)\ \frac{P_{<15}^{PH}(hyp,t) +\ \gamma\left(P_{<15}^{PH}(t) - P_{<15}^{PH}(hyp,t)\right)}{P_{<15}^{PH}(hyp,t)}$$

and

$$p_a(SC < 15|S,t) =$$

$$= p_a(SC < 15|S,base)\ \frac{P_{<15}^{PH}(hyp,t) +\ \gamma\left(P_{<15}^{PH}(t) - P_{<15}^{PH}(hyp,t)\right)}{P_{<15}^{PH}(hyp,t)}.$$

For policy purposes a distinction is then made between male and female single parents. Their numbers are calculated simply by multiplying the number of single persons with children under 15 by a projected sex proportion. For example, the number of female single parents with children under 15 is calculated as:

$$P_{f,a}^{SC<15}(t) = P_a^{SC<15}(t)\ \ p_f(t)$$

where p_f denotes the proportion female.

Step 4: Divide single adults not living with children under 15 into children aged 15+ living with parents and those in other living arrangements

The single adult population not living with any children under 15 is divided into children aged 15+ living with parents (C15+) and single individuals living neither with their parents or children under 15 (SNC<15NLWP). Children aged 15+ living with parents (either a single parent or two parents) are projected as:

$$P_a^{C15+}(t)\ = P_a^{SNC<15}(t)\ p_a(C15 + |SNC < 15, t)$$

The number of single individuals not living with their parents or children under 15 is then:

$$P_a^{SNC<15NLWP}(t) = P_a^{SNC<15}(t) - P_a^{C15+}(t).$$

Step 5: Divide single adults living neither with their parents or children under 15 into single adults living with children aged 15+ only and those in other living arrangements

The number of single parents with children aged 15+ only is calculated as the base year conditional probability multiplied by the scaling factor in square brackets below. This factor alters the base year conditional probability by λ proportion of the projected change in probability of being a child aged 15+ living with parents.

$$P_a^{SC15+}(t) = P_a^{SNC<15NLWP}(t)\ p_a(SC15+|SNC<15NLWP, base)$$
$$\left[1+\lambda\frac{p_a(C15+|SNC<15,t)-p_a(C15+|SNC<15,base)}{p_a(C15+|SNC<15,base)}\right].$$

The value of λ is user-defined and may be between 0 and 1. For example, a value close to zero would describe a situation where an increase in the number of children aged 15+ living with parents leads to a slight increase in the number of adults living with children aged 15+ only. Many households shift from a situation of having one child aged 15+ living at home to two such children (leaving the number of parents with children aged 15+ only unchanged in this situation), whilst a few shift from no children aged 15+ living at home to one (increasing the number of adults with children aged 15+). Overall, there would be a small increase in the numbers of parents with children aged 15+ only. As before, a distinction is made between male and female single parents via a simple sex proportion.

The same equation is used to project the number of partnered individuals living with children aged 15+ only:

$$P_a^{PC15+}(t) = P_a^{PNC<15}(t)\ p_a(PC15+|PNC<15, base)$$
$$\left[1+\lambda\frac{p_a(C15+|SNC<15,t)-p_a(C15+|SNC<15,base)}{p_a(C15+|SNC<15,base)}\right].$$

The number of persons who are single in other living arrangements (SOLA) is calculated as:

$$P_a^{SOLA}(t) = P_a^{SNC<15NLWP}(t) - P_a^{SC15+}(t)$$

and the number of persons who are partnered and not living with children (PNC) is:

$$P_a^{PNC}(t) = P_a^{PNC<15}(t) - P_a^{PC15+}(t).$$

Step 6: Divide adults in other living arrangements into those in family living arrangements and those in non-family living arrangements
The number of persons who are single and in family living arrangements (SF) not previously specified is calculated as:

$$P_a^{SF}(t) = P_a^{SOLA}(t)\ p_a(SF|SOLA,t)$$

whilst those who are single in non-family (SNF) living arrangements are projected as:

$$P_a^{SNF}(t) = P_a^{SOLA}(t) - P_a^{SF}(t).$$

Step 7: Divide adults in family living arrangements into those living with a family and those who are members of an Other Family
The number of persons who are members of an Other Family (e.g. siblings living together) are projected as:

$$P_a^{SLOF}(t) = P_a^{SF}(t)\, p_a(SLOF|SF,t)$$

whilst the number of persons who are single and living with a family (related or unrelated to the family) is calculated as:

$$P_a^{SLWAF}(t) = P_a^{SF}(t) - P_a^{SLOF}(t).$$

Step 8: Divide adults in non-family living arrangements into those living alone and members of group households
The number of people who are single and living in group households (SLGH) is found as:

$$P_a^{SLGH}(t) = P_a^{SNF}(t)\ p_a(SLGH|SNF,t)$$

whilst those who are single and living alone (SLA) are projected as:

$$P_a^{SLA}(t) = P_a^{SNF}(t) - P_a^{SLGH}(t).$$

The projection of persons by living arrangement is now complete. The final two steps convert projections of persons by living arrangement to projections of the number of families and households by type.

Step 9: Calculate the numbers of families by type

The numbers of four types of family are calculated. Table 2 lists the family types and living arrangements of adults who count as family representatives. These representatives are adults who define the type of household: partners, single parents, and members of an Other Family. The numbers of each family are calculated as the number of family representatives divided by the number of representatives per family. The average number of representatives per Other Family is usually taken from a recent census or survey.

Table 2: Family types and living arrangements of family representatives

Family type	Family representatives	No. of representatives per family
Couple family with children	Partnered with child(ren) under 15	2
	Partnered with child(ren) 15+ only	2
Couple without children	Partnered with no children	2
Single parent family	Single mother with child(ren) under 15	1
	Single mother with child(ren) 15+ only	1
	Single father with child(ren) under 15	1
	Single father with child(ren) 15+ only	1
Other Family	Single and living in an Other Family	empirically determined

Step 10: Calculate the numbers of households by type

In this final step projections of seven types of household are produced. Household types, the living arrangements of household representatives, and the average number of household representatives per household are described in Table 3. In calculating the numbers of family households, those which contain two or more families are distinguished from those containing just one family. Household representatives are allocated to single or multiple-family households on the basis of an assumed distribution, often that of a recent census or survey. Table 4 presents proportions for these family household representatives using data calculated for Queensland from the 2006 Census.

The number of single-family couple family with children households is calculated as the number of adults in the living arrangements ‘partnered with child(ren) under 15’ plus those ‘partnered with child(ren) 15+ only’ each multiplied by the proportion in single-family households, with the result divided by the number of representatives per household. For example, if there were 700,000 adults living with a partner and children under 15 and 300,000 living with children aged 15+ then the number of single-family couple family with children households would be:

$$\frac{(0.9773\ \ 700{,}000) + (0.9695\ \ 300{,}000)}{2} = 974{,}988.$$

Table 3: Household types and living arrangements of household representatives

Household type	Household representatives	No. of representatives per household
Family households		
Single-family households		
Couple family with children	Partnered with child(ren) under 15	2
	Partnered with child(ren) 15+ only	2
Couple without children	Partnered with no children	2
Single parent	Single mother with child(ren) under 15	1
	Single mother with child(ren) 15+ only	1
	Single father with child(ren) under 15	1
	Single father with child(ren) 15+ only	1
Other Family	Single and living in an Other Family	empirically determined
Multiple-family households		
Multiple-family	*Any of the above living arrangements*	empirically determined
Non-family households		
Lone person	Single and living alone	1
Group	Single and living in a group household	empirically determined

Table 4: Distribution of household representatives across single and multiple-family households, Queensland, 2006

Family household representatives	Single family	Multiple-family	Total
Partnered with child(ren) under 15	0.9773	0.0227	1.0000
Partnered with child(ren) 15+ only	0.9695	0.0305	1.0000
Partnered without children	0.9643	0.0357	1.0000
Single with child(ren) under 15	0.8901	0.1099	1.0000
Single with child(ren) 15+ only	0.9555	0.0445	1.0000
Member of an Other Family	0.9789	0.0211	1.0000

Source: calculated from ABS 2006 Census.

The numbers of single-family couple without children, single parent family, and Other Family households are calculated in a similar manner. The number of multiple-family households equals the numbers of household representatives in each family type multiplied by the proportions living in multiple-family households divided by the average number of representatives in a multiple-family household.

The numbers of non-family households are calculated more simply. The number of lone person households, by definition, is the number of adults who are ‘single and living alone’. The number of group households equals the number of persons who are ‘single and living in a group household’ divided by the average group household size.

Optional additional step

An additional step can be undertaken for users interested in obtaining projections of a different household concept, that of Minimal Household Units. Proposed by Ermisch and Overton (1985), a Minimal Household Unit (MHU) is the smallest group of persons that could potentially form a separate household. There are four main types:

- MHU1: single adults with no dependent children,
- MHU2: single parent families with dependent children,
- MHU3: couples with no dependent children, and
- MHU4: couples with dependent children.

Once children reach the minimum school leaving age they are considered as forming an MHU1, because potentially they could leave home and support themselves through employment. An MHU is therefore the smallest family decision-making unit possible; the total number of MHUs is the maximum number of households that could potentially be formed. The concept of the MHU divides household formation into demographic/family factors (primarily partnering and childbearing trends) which create MHUs, and largely economic forces which influence whether and how MHUs group together into actual households. For examples of analyses employing the MHU concept see Ermisch and Overton (1985) and Santi (1988).

Numbers of MHUs can be calculated directly from the four categories of living arrangement produced in Step 3. The cut-off age of 15 used here reflects the ABS classification of all children under age 15 as dependent, with those aged 15-24 classified either as dependent or independent according to their circumstances. Age 15 is a little low (and could be refined in a single year of age disaggregation), but is adequate for the purposes of illustration. The number of MHU1s is equal to the number of individuals who are single with no children under 15 (SNC<15), and the number of MHU2s is equal to the number of single parents with children under 15 (SC<15). The number of MHU3s is half the number of persons who are partnered who are not living with children under 15 (PNC<15) and the number of MHU4s is half the number of persons who are partnered with children under 15 (PC<15).

3.3 Strengths and weaknesses

Several advantages of the sequential propensity household model flow from its separation of the calculations into a number of steps. Because each step focuses on one aspect of a person's living arrangements, it brings the propensity assumptions a little closer to the processes which generate them. It also assists with consistency between living arrangements – for example, if a smaller proportion of individuals are partnered, then this will flow through to a larger population being at risk of living alone. In addition, adjustments are made to ensure serious inconsistencies between children and parents are avoided. Changes in partnering are reflected in shifts in the distribution of children under 15 between couple families and single parent families; and the numbers of children aged under 15 are made consistent with the numbers of parents, thus incorporating the effects of fertility and migration change. Furthermore, the lack of sex disaggregation simplifies the calculations and avoids the two-sex problem.

There are also some advantages from a practical perspective. The separation into different steps simplifies assumption-setting and scenario creation. For example, separate assumptions can be made about partnering (step 2), the extent to which older children live at home (step 4), and the degree to which single adults live together in group households (step 8). It also means there are only two propensities per step, thus avoiding having to scale propensities to sum to unity and creating undesirable adjustments to other propensities in the process. This staged nature of the model also means that some age profiles of propensities can be borrowed from elsewhere, a feature which may prove particularly useful in applying the model to smaller regions with unstable propensity age profiles. In addition, data inputs are not nearly so onerous as for dynamic models and require, as a minimum, a population projection by age, plus living arrangement data from the most recent census. Finally, the calculations can be implemented in an Excel spreadsheet quite easily, and without iterative formulae or VBA coding.

However, it is important to note that there are a number of limitations to this model. It is, of course, still a static model. It does not simulate processes of household formation and dissolution. In addition, the feedback mechanism for adjusting the number of parents with children aged 15+ to account for changes to propensities of being a child aged 15+ living at home is approximate. The lack of sex disaggregation (except for single parents) means that sex-specific living arrangements cannot be easily produced, and compositional effects, such as sex-specific life expectancy convergence and its impact on proportions living with a partner at the oldest ages, are omitted. There is also no distinction between children aged 15+ who are dependent on their parents and non-dependent older children looking after frail elderly parents. And, like the standard propensity model, it does not disaggregate household types by household size.

4. Illustrative projections

4.1 Scenarios for the future household demography of Queensland

The State of Queensland is used as a case study to illustrate the scenario formulation features of the sequential propensity model. Three scenarios for the future of Queensland's household demography for the period 2006-2036 have been devised based on different economic contexts. They are:

- A baseline scenario in which all propensities are held constant in order to illustrate the effect of changing population size and age structure.
- A housing stress scenario which describes more difficult economic times for families and individuals. This future of reduced housing affordability is associated with later ages of leaving home, lower partnering amongst young adults, lower fertility, and increased propensities for single people to be in group households, living with a family, and living in multiple-family households.
- A prosperity scenario reflecting greater real household incomes. Partnering amongst young adults and fertility increase and propensities for single people to live in group households are lower and average group household sizes smaller, young adults leave home at younger ages, and there are lower proportions of multiple-family households.

Fertility assumptions are specified in terms of the Total Fertility Rate (TFR), mortality assumptions as life expectancy at birth (e_0), and migration assumptions as net migration totals per annum (though the population projection model uses base period directional migration probabilities scaled to these net totals). To simplify assumption setting, living arrangement assumptions are similarly formulated as summary indices. These indices are age-standardised measures calculated like the Total Fertility Rate: they are the sum of age-specific values multiplied by the width of the age group in years. For example, the total group household index is calculated as:

$$Total\ group\ household\ index\ (t) =\ 5\ \sum_a\ p_a(SLGH|SNF,t).$$

Assumptions are listed in Table 5. Most assumption changes are trended in over the ten-year period 2006-2016, after which they are held constant. It is stressed that these scenarios are illustrative of the model's scenario-setting features only; they are not forecasts. The scale of increased household prosperity and declining housing affordability is left unspecified, and living arrangement responses to these two scenarios are likely to differ to some extent from those assumed in the table.

Table 5: Assumptions for the three scenarios

Scenario	Summary of assumptions
Baseline	TFR: 2006-2011: 2.02; 2011-2036: 1.90.
	e0: 2006-2011: 84.3 (females); 79.7 (males); 2031-2036: 88.6 (females); 85.1 (males).
	Net migration: 2006-2011: 62,500 per annum; 2011-2026: 55,000 per annum.
	All living arrangement propensities: held constant at their 2006 values.
	γ and λ parameters set to 0.5.
	Proportions of household representatives in multiple-family households and household representative rates held constant at their 2006 values.
Housing stress	TFR: 2006-2011: 2.02; 2011-2016: 1.90; 2016-2036: 1.80.
	Over ages 15-29 10% lower partnering than 2006 from 2016.
	Total older child living at home index (C15+): 15% higher than 2006 from 2016.
	Total family living arrangements index (SF): 10% higher than 2006 by 2016.
	Total group household index (SLGH): 10% higher than 2006 from 2016.
	Total living with a family index (SLWAF): 10% higher than 2006 from 2016.
	Average no. of persons in group households: 10% higher than 2006 from 2016.
	Proportions of household representatives in multiple-family households: 20% higher than 2006 from 2016.
	All other assumptions: same as Baseline.
Prosperity	TFR: 2006-2011: 2.02; 2011-2036: 2.00.
	Over ages 15-29 10% higher partnering than 2006 from 2016.
	Total older child living at home index (C15+): 15% lower than 2006 from 2016.
	Total family living arrangements index (SF): 10% lower than 2006 by 2016.
	Total group household index (SLGH): 10% lower than 2006 from 2016.
	Total living with a family index (SLWAF): 10% lower than 2006 from 2016.
	Average no. of persons in group households: 10% lower than 2006 from 2016.
	Proportions of household representatives in multiple-family households: 20% lower than 2006 from 2016.
	All other assumptions: same as Baseline.

4.2 The future household demography of Queensland under three scenarios

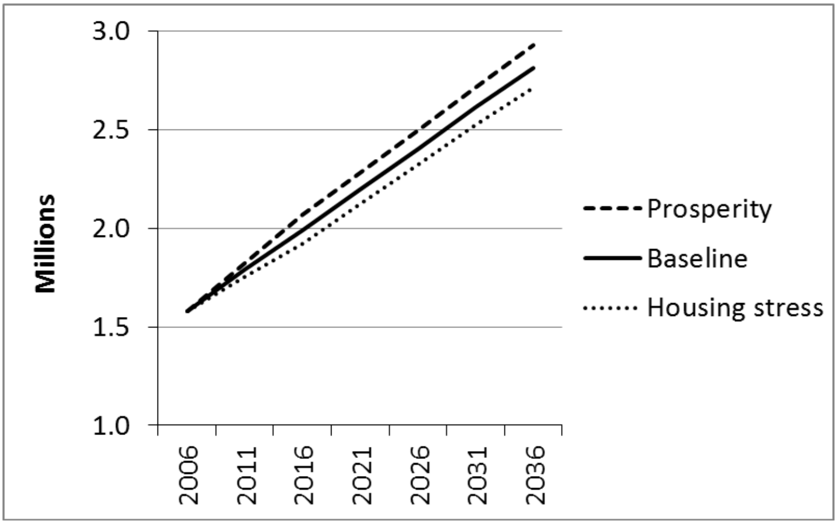
What would happen to the number of households and average household sizes if the three scenarios were to eventuate? Figure 2 illustrates how the total numbers of households would grow (Figure 2a) along with the numbers of family, group, and lone person households (Figure 2b to d). Total numbers of households are projected to reach 2.81 million by 2036 in the baseline scenario, 2.93 million in the prosperity scenario, and 2.72 million in the housing stress scenario. There is little difference in the number of family households between the three projections (Figure 2b). In the prosperity scenario they total only 31,000 more than in the baseline scenario by 2036, and 28,000 lower in the housing stress projection. However, numbers of non-family households vary considerably. By 2036 lone person households number 762,000 (baseline), 706,000 (housing stress), or 828,000 (prosperity). In relative terms group households vary to an even greater extent, totalling 105,000 (baseline), 122,000 (prosperity), or 91,000 (housing stress) by 2036.

Notably, the projected number of minimal household units hardly differs at all between the three scenarios (3.80 million by 2036 in the baseline scenario, 3.80 million in the housing stress scenario, and 3.82 million in the prosperity scenario). This is due to only minor differences in fertility levels, which only begin to make any impact from 15 years into the projection horizon, minor differences in partnering, and the lack of variation in migration and mortality assumptions. Differences in the number of households are almost completely due to the extent to which minimal household units co-reside, whether that be through two or more families sharing a dwelling, older children living at home, group households, Other Family households, or living with a family.

Average household sizes according to the three scenarios are shown in Figure 3. Under the housing stress scenario average household size increases slightly for the first 10 years of the projections (whilst the assumptions are being trended in), whereas the prosperity scenario sees an accelerated drop in average household size. The baseline scenario illustrates the extent of the fall in average household size due to population growth and ageing. Population ageing drives an increase in the proportion of households containing only one person, therefore lowering overall average household size. The housing stress scenario, which includes young people leaving home later, families co-residing more, and group households becoming larger and more common, raises average household size relative to the baseline scenario. Interestingly, results from the 2009-10 ABS Survey of Income and Housing reveal a very slight reversal in the long-run trend of declining average household size, suggesting that Australia’s housing situation is tracking closer to the housing stress scenario (ABS 2011b).

Figure 2: Growth in the number of households by type, Queensland, 2006-2036, according to three scenarios

(a) Total households



(b) All types of family household

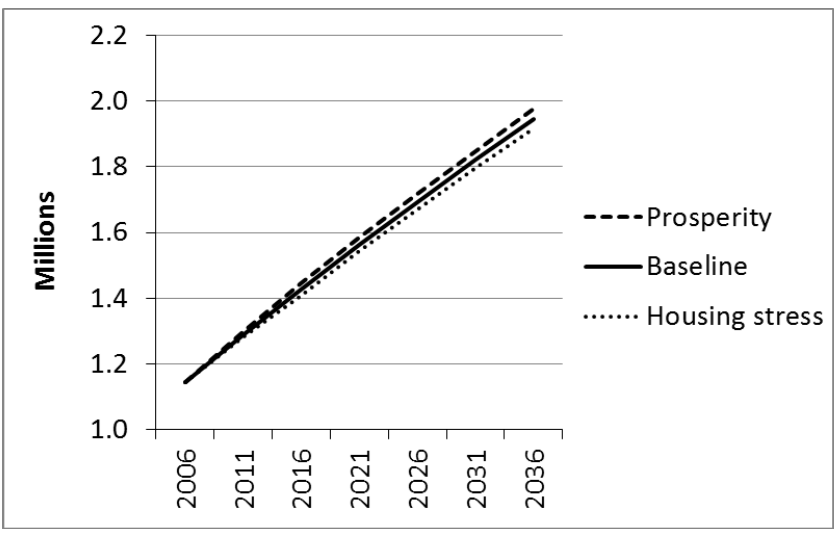
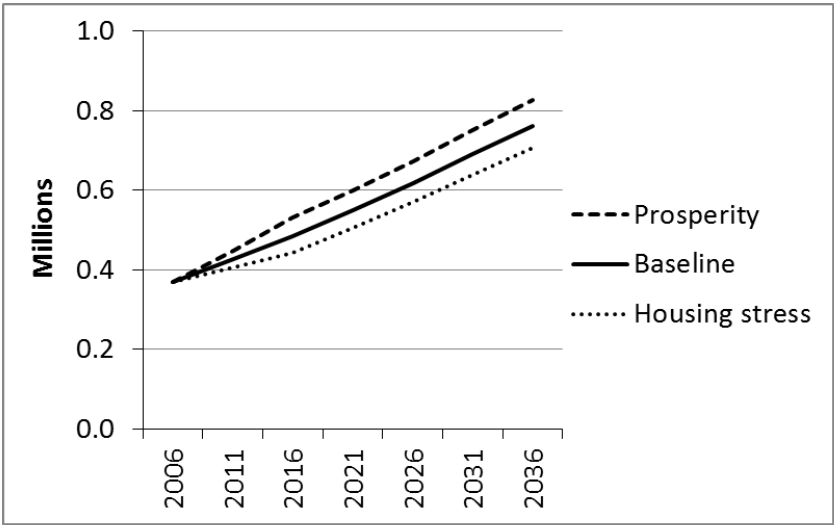


Figure 2: (Continued)

(c) Lone person households



(d) Group households

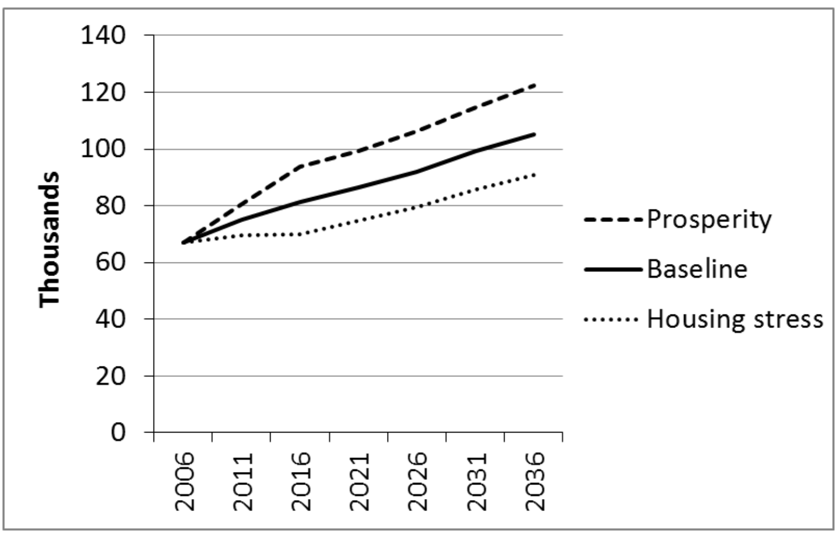
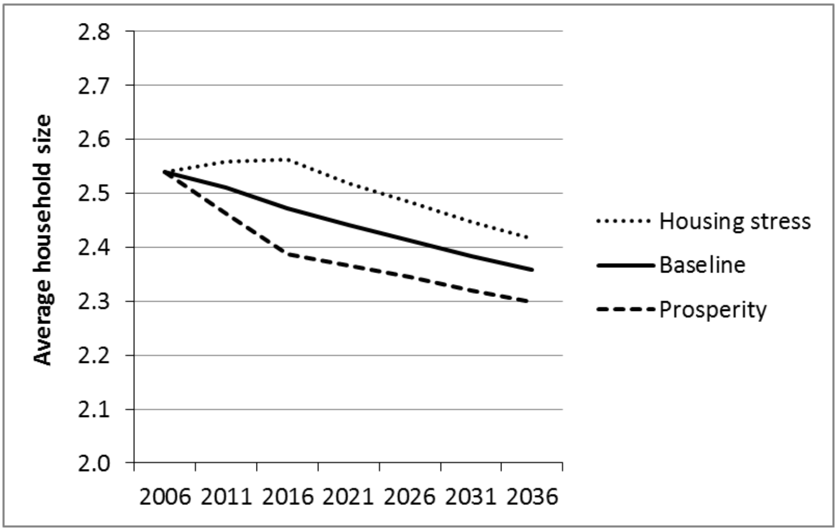


Figure 3: Change in average household size in Queensland, 2006-2036, according to three scenarios



In summary, differences between the scenarios in terms of total numbers of households and average household sizes are not huge, but not insignificant either (for example, compare average household sizes in 2016 in Figure 3). However, for non-family households the differences are quite substantial. The key conclusion here is that assumptions which reflect different and plausible economic contexts do make a difference to household demography. This is in contrast to the impression given by many household projection models which extrapolate historical trends in some form or another and imply that family/demographic factors alone influence household demography.

5. Sensitivity analysis

A sensitivity analysis was undertaken to investigate the relative importance of changes to assumptions on the number and average size of households. Just one assumption from the baseline scenario was changed in each projection variant. The value of the summary index for each variable was set 10% higher or lower than the baseline value from 2011 onwards. So, for example, in the '-10% TFR' projection the Total Fertility Rate was set to 1.71 from 2011 to 2036 with all other assumptions those of the baseline scenario. The '+10% partnered' projection increased the total partnering index by 10% from 2011 onwards, and the '-10% multiple-family' projection decreased the proportions of individuals living in multiple-family households by 10% from 2011. The only exception to this approach was applied to life expectancy at birth because it is calculated differently from all other indices. Both male and female life expectancy at birth trajectories were set to gradually diverge from the main assumption, ending up two years above or below the main assumption by the end of the projection horizon. Different values of γ and λ were not included in this analysis because they only have an impact where the under 15 population changes considerably (due to fertility and migration).

Table 6 presents selected statistics from the sensitivity analysis for 2036, ordered by percentage change in the total number of households relative to the baseline scenario. As the table shows, the variables with the most significant impact on household numbers are the extent of partnering, the level of net migration, and life expectancy at birth. A decline in partnering increases the proportion of adults in the population who are single, and on average single people will form more households than those who are partnered. However, an increase in household numbers from a rise in net migration is primarily due to the size of the population expanding rather than any significant shift in living arrangements – the model assumes immigrants take on the same age-specific propensities as the existing population. The increase in household numbers from a rise in fertility is fairly modest. This is because for half of the 30-year projection horizon any rise in fertility increases only the number of children but not the number of adults forming separate households.

In terms of average household size, the most significant influences are the extent of partnering and the fertility rate. If a greater proportion of the population is partnered then the numbers and percentage of small non-family households are much lower than in the baseline scenario. In the higher partnering projection the number of lone person households is almost 150,000 lower by 2036 (comprising 22% rather than 27% of all households by that date) and the number of group households and Other Family households, whose average sizes are less than the overall average household size, are also less numerous. Thus average household size rises a little. These average household size responses are similar to those reported by Jiang and O'Neill (2007) in a sensitivity test of the multidimensional PROFAMY model applied to the US population. They found that changes to the fertility rate and the general marriage rate (they separated relationship formation into marriage and cohabitation) were the most important in altering average household size.

Table 6: Sensitivity of household projections for Queensland in 2036 to changes in assumptions

Projection variant	No. of households	% increase in no. of households relative to baseline	Average household size	% increase in average household size relative to baseline	No. of lone person households	% increase in no. of lone person households relative to baseline
Baseline	2,812,919	n/a	2.36	n/a	761,343	n/a
-10% partnered	2,890,042	2.7	2.30	-2.7	908,614	19.3
+10% net migration	2,875,871	2.2	2.36	0.2	775,361	1.8
+2 years e(0)	2,852,064	1.4	2.35	-0.5	780,837	2.6
-10% C15+	2,837,582	0.9	2.34	-0.9	778,802	2.3
+10% TFR	2,835,177	0.8	2.40	1.9	762,898	0.2
-10% SF	2,828,475	0.6	2.35	-0.5	776,275	2.0
-10% SLGH	2,826,642	0.5	2.35	-0.5	785,573	3.2
-10% NPD	2,823,359	0.4	2.36	-0.1	766,572	0.7
-10% multiple-family	2,816,653	0.1	2.36	-0.1	761,343	0.0
-10% SLWAF	2,816,285	0.1	2.36	-0.1	761,343	0.0
+10% SLWAF	2,809,552	-0.1	2.36	0.1	761,343	0.0
+10% multiple-family	2,809,185	-0.1	2.36	0.1	761,343	0.0
+10% NPD	2,802,478	-0.4	2.36	0.1	756,114	-0.7
+10% SLGH	2,799,196	-0.5	2.37	0.5	737,113	-3.2
+10% SF	2,797,363	-0.6	2.37	0.6	746,411	-2.0
-10% TFR	2,790,670	-0.8	2.31	-1.9	759,736	-0.2
+10% C15+	2,788,236	-0.9	2.38	0.9	743,947	-2.3
-2 years e(0)	2,771,410	-1.5	2.37	0.5	741,165	-2.7
-10% net migration	2,749,956	-2.2	2.35	-0.2	747,313	-1.8
+10% partnered	2,736,234	-2.7	2.43	2.8	613,505	-19.4

Notes: C15+ = children aged 15+; SF = single in family living arrangements; SLGH = single and living in a group household; NPD = living in a non-private dwelling; SLWAF = single and living with a family.

It should be noted that in any realistic projection scenario the effect of changing assumptions will not necessarily result in the exact same household number and average household size impacts described here. Changes in assumptions early in the calculation scheme will alter the population distribution by living arrangement in later calculations, so that the effect of one assumption change could be a little different depending on the combination of other assumptions. Nonetheless, these tests are useful in indicating that the main focus of assumption setting should be on migration, life expectancy, fertility, partnering, and older children living at home.

6. Conclusions

The sequential propensity household projection model presented in this paper represents an attempt to resolve some of the more serious shortcomings of the standard propensity model. It meets many of the criteria listed in the introduction. Although it does not directly model demographic processes, the step-by-step nature of the sequential propensity model permits the net influences of different processes (partnering, older children leaving home, group living decisions, etc.) to be considered one at a time. Doing so simplifies propensity projections, aids scenario formulation, and permits sensitivity analyses to be conducted. In particular, it allows the formulation of scenarios which reflect worsening or improving housing affordability, something which is difficult to achieve in many household models and for which they have been criticised (Meen and Andrew 2008). Separate consideration of what might be described as demographic/family factors on the one hand and economic/institutional influences also enables projections of Minimal Household Units to be produced. The separation of assumption setting into various steps also allows sensitivity analyses to be performed. The example sensitivity analysis for Queensland revealed partnering, fertility, life expectancy, migration, and the extent to which older children live at home to be the most important variables affecting household projections, and therefore the ones which deserve the most attention in formulating a set of assumptions.

From a practical perspective, the model produces projections based on existing ABS definitions of living arrangements and households, thus avoiding any data conversion or adjustment. And it easily links to existing cohort-component population projections. The model also clearly fits within the resource, budget, and timeframe constraints of State government demographic sections, given the mathematical simplicity, ease of implementation in a spreadsheet, and fairly low input data requirements relative to outputs. Importantly, multidimensional living arrangement-to-living arrangement data, which are currently unavailable in Australia, are not required. Data inputs are sufficiently modest that projections can be easily updated when new census data become available. Indeed, for Australian examples at least, all data can be obtained directly from the ABS website without incurring the costs and delays of having to place special census table requests. In the example projections for Queensland all input data were obtained from the 2006 Census via the online TableBuilder service in under an hour (www.abs.gov.au/TableBuilder). A definitive answer to the question of whether the model can give projections which are no less accurate than those produced by standard propensity models is not yet possible. One would hope that the improved assumption-setting capacity of the new model would lead to more accurate projections.

Having emphasised the strengths of the sequential propensity model, there are nonetheless a number of extensions and enhancements that may be considered.

1. Some users may require living arrangement projections disaggregated by sex. Whilst the lack of sex disaggregation in the new model (except for single parents) represents a large saving on the quantity of input data and avoids the two-sex problem, it would be possible to create a version with a sex breakdown throughout. Alternatively, if users require projections by sex for just one or two living arrangement types then it might be easier to apply a sex breakdown after the projections have been produced in the current model.

2. Although the model produces more output detail that published by the ABS, some users may wish to have projections by both household type and the distribution by household size.

3. Linking the new model to economic models which affect living arrangement propensities may also prove a fruitful avenue for further research.

4. Finally, the new model does not produce projections of the numbers of dwellings required to house the growth in households. Currently in Australia projections of dwellings are usually obtained in a very simple manner from household projections. Often this involves multiplying household projections by a ratio of dwellings to households obtained from the most recent census. Strictly speaking, these are not projections of dwelling need, demand, or supply, but rather a continuation of current realities. A better approach would be to project dwellings by type (perhaps by number of bedrooms) based on the number, type, and occupants of households, and to distinguish between dwellings required for usual residence and those which are secondary/holiday homes. Ideally assumptions would be amenable to changes in individual, family, and national economic circumstances. In such an approach household demography would be better connected to housing demography (Myers 1990).

These extensions remain to be explored in further research. In the meantime, the current sequential propensity model offers a number of practical and conceptual advantages over the standard model. It is hoped, in particular, that it will prove beneficial to government demographers tasked with producing household projections for planning purposes. Although the focus of the paper has been on the preparation of State-level household projections, the model has been designed for implementation at a variety of spatial scales, including large sub-State regions and local government areas; it should also be applicable in other countries with similar census data, such as New Zealand.

7. Acknowledgements

The author is grateful to Martin Bell and Jim Cooper for providing helpful suggestions on modelling and comments on an earlier draft of the paper. Funding for this research was kindly provided by the Government Statistician, Queensland Treasury and Trade.

References

ABS (1999). Household and Family Projections, Australia, 1996 to 2021. Canberra: Australian Bureau of Statistics (ABS). (Catalogue No. 3236.0).

ABS (2004). Household and Family Projections, Australia, 2001 to 2026. Canberra: Australian Bureau of Statistics (ABS). (Catalogue No. 3236.0).

ABS (2005). Family, Household and Income Unit Variables, 2005. Canberra: Australian Bureau of Statistics (ABS). (Catalogue No. 1286.0). http://tiny.cc/a6tiqw.

ABS (2006). Census Dictionary Australia 2006 (Reissue). Canberra: Australian Bureau of Statistics (ABS). (Catalogue No. 2901.0). http://tiny.cc/cq76sw.

ABS (2011a). Census Dictionary, 2011. Canberra: Australian Bureau of Statistics (ABS). (Catalogue No. 2901.0). http://tiny.cc/tzlrz.

ABS (2011b). Housing Occupancy and Costs, 2009-10. Canberra: Australian Bureau of Statistics (ABS). (Catalogue No. 4130.0).

Alho, J. and Keilman, N. (2010). On future household structure. *Journal of the Royal Statistical Society: Series A (Statistics in Society)* 173(1): 117-143. doi:10.1111/j.1467-985X.2009.00605.x.

Bell, M. and Cooper, J. (1990). Household forecasting: Replacing the headship rate model. Paper presented at: The Australian Population Association conference, Melbourne, 18-21 November 1990.

Bell, M., Cooper, J., and Les, M. (1995). *Household and Family Forecasting Models: A Review*. Canberra: Commonwealth Department of Housing and Regional Development.

Ermisch, J. F. and Overton, E. (1985). Minimal household units: A new approach to the analysis of household formation. *Population Studies* 39(1): 33-54. doi:10.1080/0032472031000141266.

Ironmonger, D.S. and Lloyd-Smith, C.W. (1992). Projections of households and household populations by household size propensities. *Journal of the Australian Population Association* 9(2): 153-171.

Jiang, L. and O’Neill, B.C. (2007). Impacts of demographic trends on US household size and structure. *Population and Development Review* 33(3): 567-591. doi:10.1111/j.1728-4457.2007.00186.x.

Keilman, N. (1985). Nuptiality models and the two-sex problem in national population forecasts. *European Journal of Population* 1(2-3): 207-235. doi:10.1007/BF01796933.

Keilman, N. (1995). Household concepts and household definitions in Western Europe: Different levels but similar trends in household developments. In: van Imhoff, E., Kuijsten, A., Hooimeijer, P., and van Wissen, L. (eds). *Household Demography and Household Modeling*. New York: Springer: 111-135. doi:10.1007/978-1-4757-5424-7_5.

Keilman, N. and Christiansen, S. (2010). Norwegian elderly less likely to live alone in the future. *European Journal of Population* 26(1): 47-72. doi:10.1007/s10680-009-9195-9.

Linke, W. (1988). The headship rate approach in modelling households: The case of the Federal Republic of Germany. In: Keilman, N., Kuijsten, A., and Vossen, A. (eds). *Modelling Household Formation and Dissolution*. Oxford: Clarendon Press: 108-122.

Liu, J., Daily, G.C., Ehrlich, P.R., and Luck, G.W. (2003). Effects of household dynamics on resource consumption and biodiversity. *Nature* 421: 530-533. doi:10.1038/nature01359.

McDonald, P., Kippen, R., and Temple, J. (2006). Net transition probabilities: An approach to subnational level projections of households and housing demand based on census data. *Population, Space and Place* 12(6): 479-495. doi:10.1002/psp.424.

Meen, G. and Andrew, M. (2008). Planning for housing in the post-Barker era: Affordability, household formation, and tenure choice. *Oxford Review of Economic Policy* 24(1): 79-98. doi:10.1093/oxrep/grn010.

Morphy, F. (2007). Uncontained subjects: Population and household in remote Aboriginal Australia. *Journal of Population Research* 24(2): 163-184. doi:10.1007/BF03031929.

Myers, D. (1990). Introduction: The emerging concept of housing demography. In: Myers, D. (ed.). *Housing Demography*. Madison: University of Wisconsin Press; 3-31.

NIDI (Netherlands Interdisciplinary Demographic Institute) (1999). LIPRO multistate projection model [electronic resource]. http://tiny.cc/ou76sw.

O'Leary, J. (2000). Household projections for Australia. *Urban Policy and Research* 18(1): 77-89. doi:10.1080/08111140008727825.

Prskawetz, A., Jiang, L., and O'Neill, B.C. (2004). Demographic composition and projections of car use in Austria. *Vienna Yearbook of Population Research* 2004: 175-202. doi:10.1553/populationyearbook2004s175.

Santi, L.L. (1988). The demographic context of recent change in the structure of American households. *Demography* 25(4): 509-519. doi:10.2307/2061318.

Statistics New Zealand (2010). National Family and Household Projections: 2006(base)–2031 update. Wellington: Statistics New Zealand. http://tiny.cc/9fdma.

Tillman, K.H. and Nam, C.B. (2008). Family structure outcomes of alternative family definitions. *Population Research and Policy Review* 27(3): 367-384. doi:10.1007/s11113-007-9067-0.

United Nations (1973). *Manual VII: Methods of Projecting Households and Families*. New York: UN.

van Imhoff, E. and Keilman, N. (1991). LIPRO 2.0: *An Application of a Dynamic Demographic Projection Model to Household Structure in the Netherlands*. Amsterdam: Swets and Zeitlinger.

van Imhoff, E., Kuijsten, A., Hooimeijer, P. and van Wissen, L. (eds). (1995). *Household Demography and Household Modeling*. New York: Plenum Press.

Zeng, Y., Vaupel, J.W. and Zhenglian, W. (1997). A multi-dimensional model for projecting family households – with an illustrative application. *Mathematical Population Studies* 6(3): 187-216.

Zeng, Y., Vaupel, J.W., and Zhenglian, W. (1999). Household projection using conventional demographic data. In: Lutz, W., Vaupel, J.W., and Ahlburg, D.A. (eds). *Frontiers of Population Forecasting. Supplement to Population and Development Review Volume 24*. New York: Population Council: 59-87.