Problems and Prospects for Dynamic Microsimulation: A Review and Lessons for APPSIM

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Abstract

This paper has been prepared as the first in a series of papers associated with the development of the Australian Population and Policy Simulation Model (APPSIM). The APPSIM dynamic population microsimulation model is being developed as part of an Australian Research Council (ARC) Linkage grant (LP0562493), and will be used by Commonwealth Government policy makers and other analysts to assess the social and fiscal policy implications of Australia’s ageing population. This paper reviews progress nationally and internationally on the construction of dynamic population microsimulation models and considers the lessons that might be taken from that earlier experience for the construction of the APPSIM model.
Author note

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1 Introduction

1.1 Background

In the 1990s, NATSEM at the University of Canberra constructed the first Australian dynamic population microsimulation model, DYNAMOD. The behavioural equations within that model were based on the relatively inadequate longitudinal data that were available at the time — and the behaviour of Australians has in any event changed greatly over the 15 years that have since elapsed. Today, the new HILDA longitudinal data offer the prospect of constructing more reliable and up-to-date estimates of Australian behaviour — in such areas as labour market participation, family formation and dissolution, participation in education, and so on.1 A second factor prompting the development of a new dynamic microsimulation model for Australia has been the growing concern about the likely future fiscal and social consequences of population ageing.

In Australia, the Commonwealth Government’s initial assessment of these issues was contained in the 2002 Intergenerational Report. This Report suggested that under current projections of fertility rates, labour force participation rates and so on — and assuming that current policy settings remained unchanged — there would be a shortfall between Commonwealth government revenue and outlays of five per cent of Gross Domestic Product by 2042. In today’s dollars, this would translate into a budget deficit of about Aust$40 billion. The report concluded that resolving this budget shortfall would require either higher taxes upon future generations or reductions in spending programs (or some combination of these) (Treasury 2002, p. 6).

This initial analysis for the Commonwealth budget was subsequently extended to examine the implications of population ageing for State and Territory governments. The Productivity Commission report concluded that the fiscal gap for all levels of government would reach 6.4 per cent of GDP by 2044-45 (2005). While escalating health, aged care and pension costs were seen as playing an important role in creating this fiscal gap, the impact of population ageing on labour supply and economic growth was also expected to be significant. Because people aged 55 and over have lower labour force participation rates than those who are younger — and, when they work, are more likely to work part-time rather than full-time — population ageing reduces both labour force and economic growth rates.

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1 For the latest details on HILDA, see http://melbourneinstitute.com/hilda/.
This concern with the fiscal and other pressures created by population ageing has led many other OECD countries to develop the sophisticated modelling infrastructure needed to comprehensively evaluate and plan for the long-term impact of population ageing and to assess the likely future magnitude of those pressures and the impact of possible policy changes. Policy makers are questioning whether the generous pay-as-you-go pension schemes that exist in many of these countries will be affordable in the future. Can the future health and aged care needs of the baby boomers be met without draconian increases in the tax burdens of the generations that follow the baby boomers? Will population ageing reduce economic growth to such an extent that it will threaten future growth in tax revenues? Are the labour supply and retirement decisions of the baby boomers being unduly influenced by provisions within tax and cash transfer programs that now seem outdated, such as financial incentives for early retirement? As the OECD’s chief economist observes: ‘to cope with mounting financial pressures, governments have to make hard choices’ (Cotis 2003).

The construction of a second generation Australian dynamic microsimulation model – the Australian Population and Policy Simulation Model (APPSIM) - will provide policy makers working within our research partners’ and other organisations involved in public policy with the necessary tools to assess, plan and manage the current and future distributional consequences of social and fiscal policy changes developed to address Australia’s ageing population.

1.2 Types of microsimulation models

Microsimulation is a technique used to model complex real life events by simulating the actions of and/or impact of policy change on the individual units (micro units) that make up the system where the events occur. Microsimulation is a valuable policy tool used by decision makers to analyse the distributional and aggregate effects of both existing and proposed social and economic policies at a micro level.

Static microsimulation models

Static microsimulation models, that simulate the immediate or ‘morning after’ distributional impact upon households of possible changes in tax and transfer policy, are now extremely widely used in OECD countries. These impacts at the micro level are also summed to show the impact of the possible policy change upon aggregate tax revenues or upon government outlays. In Europe, for example, Sutherland has played a key role in the development of EUROMOD, which simulates the tax and transfer systems of each EU country (Sutherland 2007; Immervol et al. 2006); in the US the TRIM model continues to flourish (O’Hare 2000, http://trim.urban.org);
Statistics Canada continues to develop the publicly available SPSD/M model (Murphy 2000); while, in Australia, NATSEM’s publicly available STINMOD model is used for a wide variety of policy analyses (Lloyd 2007; Toohey and Beer 2004; Harding et al. 2006).

Traditionally, these static models have usually been ‘arithmetical’ calculators, where the models ‘simulate the change in the real disposable income of individuals or households due to a change in the rules for calculating tax or benefit payments under the assumption that individual behaviour is unchanged’ (Bourguignon and Spadaro 2006, p. 6). However, if the changes in government policy are sufficiently great, then they can be expected to have effects on labour supply (and thus on wages and aggregate employment) and/or on the prices facing consumers (and thus on demand for particular types of goods and services and subsequently on industry). In the past decade or so, greater efforts have been made to take into account these general equilibrium effects, by trying to link sectoral models to a household micro-database. As Bourguignon and Spardaro note, to date such efforts have limited ‘themselves to a subset of markets, most often the labour market’ (2006, p. 5) — with the Melbourne Institute, for example, having constructed the MITTS static microsimulation model, which simulates behavioural labour supply responses to policy change (Buddelmeyer et al. 2006).

Despite their undoubted advantages, static microsimulation models usually illustrate the impact of policy change only for today's world, perhaps at most looking four or five years into the future through the application of standard static ageing techniques (Harding 1996, p. 3). (The behavioural variants of these models typically abstract from the likely time path of changes in behaviour that in the real world could take years to unfold.) But a large number of issues of concern to policy makers today involve looking at the impact of policy change in future decades or over the lifetime. For these purposes, dynamic microsimulation models provide the better modelling tool.

**Dynamic microsimulation models**

Dynamic microsimulation models were the brainchild of Guy Orcutt who, frustrated by the macroeconomic models of the day, proposed a new type of model consisting of interacting, decision-making entities such as individuals, families and firms (1957). Dynamic models try to move individuals forward through time, by ‘updating each attribute for each micro-unit for each time interval’ (Caldwell 1990, p. 5). Thus, the individuals within the original microdata or base file are progressively moved forward through time by making major life events - such as death, marriage, divorce, fertility, education, labour force participation etc. - happen to each individual, in accord with the probabilities of such events happening to real people within a
particular country. Thus, within a dynamic microsimulation model, the characteristics of each individual are recalculated for each time period.

Following the typology developed by Harding (1993a), there are two major types of dynamic microsimulation models. **Dynamic cohort** models usually age only one or a series of cohorts, rather than an entire population. Typically, one cohort is aged from birth to death, so that the entire lifecycle is simulated. For some applications, such models are more cost-efficient than ageing an entire population. Such models have been used to analyse lifetime income distribution and redistribution, lifetime rates of return to education, repayment patterns for student income-contingent loans, and the impact of proposals for including homemakers in the Canada Pension Plan (Wolfson 1988; Harding 1993a, 1993b, 1995; Falkingham and Hills 1995; Hain and Helberger 1986; Falkingham and Harding 1996; O’Donoghue 2002; Baldini 2001). A variant on the more usual theme is the LifePaths model constructed by Statistics Canada, which processes a series of cohorts through their lifetimes and in which the cohorts can be placed ‘side by side’ to produce a cross-sectional snapshot (Gribble et al. 2003).

**Dynamic population** microsimulation models involve ageing a sample of an entire population. They typically begin with a comprehensive cross-section snapshot of the population at a particular point in time (such as a census) or, in some cases, with longitudinal administrative data. To date, such dynamic models have been used for such purposes as the analysis of retirement incomes, future health status, the long-term impact of social security amendments, and the lifetime redistributive impact of the social security system (e.g. Nelissen 1996; Bonnet and Mahieu 2000; Hancock 2000; Favreault and Caldwell 2000; plus see O’Donoghue 2001 for an extremely useful summary of dynamic modelling research and Harding and Gupta 2007a for a host of recent examples of the use of dynamic microsimulation in pension policy development). As APPSIM is a dynamic population microsimulation model, these are the types of models of most relevance to our project.

After the formulation of the original idea by Orcutt (1957), he and a team of three graduate students built the first realisation of the model (Orcutt et al. 1961) and then in the 1970s the second realisation, the DYNASIM model, was constructed at the Urban Institute (Orcutt et al. 1976). However, in the 1980s, dynamic microsimulation languished (Caldwell 1996). In the 1990s, while static microsimulation flourished due to the great improvements in microdata availability and quality, the quantum advances in computer software and hardware and the growing complexity of government programs (Harding and Gupta 2007b), dynamic microsimulation grew more slowly.

However, principally during the past 10 years, a number of important new dynamic population microsimulation models have been constructed, primarily because of the
growing concern about population ageing. The construction of a dynamic microsimulation model, as Caldwell has pointed out (2006), is a costly and complex task that requires both substantial funding and a team effort — an effort that the Nordic countries appear to have been particularly successful at during the 1990s and this decade.

As Bourguignon and Spadaro helpfully note, until recently most dynamic microsimulation models have been ‘dynamic arithmetical’ models (2006, p. 32), in the sense that they have not allowed for changes within the model in the behaviour of individuals initiated by government tax-transfer policy change. In addition, they have often not allowed for possible macro-economic effects in response to government policy changes. Thus, traditionally, dynamic microsimulation models have often been ‘dynamic’ in the sense that the characteristics of individuals have been updated in each time period (e.g. a woman having a baby might be simulated to leave the labour force), rather than being dynamic in allowing feedback effects in behaviour from government policy change and macro-economic change. As with static modelling, advances are now being made on both of these fronts (Aaberge et al. 2007; Frederiksen et al. 2007).

The following section reviews the progress of six dynamic population models and the lessons that might be learnt from their experience for APPSIM.

2 Review of selected dynamic population models

Table 1 below summarises the characteristics of six dynamic population microsimulation models.

2.1 DYNASIM3

*DYNASIM3* is a dynamic microsimulation model designed to analyse the long-run distributional consequences of retirement and ageing issues.² Starting with a representative sample of individuals and families, the model “ages” the data year by year, simulating such demographic events as births, deaths, marriages and divorces, and such economic events as labour force participation, earnings, hours of work,

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² This material is extracted from the very helpful documentation provided by Favreault and Smith (2004).
Table 1: Summary of six dynamic population microsimulation models

<table>
<thead>
<tr>
<th>Name of model (Country)</th>
<th>Nature of initial database</th>
<th>Continuous or discrete time</th>
<th>Closed or open model</th>
<th>Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>DYNASIM3 (US, completed 2004)</td>
<td>1990-1993 Survey of Income and Program Participation (SIPP) panels (100,000 people)</td>
<td>Discrete (one year steps)</td>
<td>Closed</td>
<td>Yes</td>
</tr>
<tr>
<td>DYNACAN (Canada, 1994 onwards)</td>
<td>Heavily modified version of 1971 Census microdata file (200,000 individuals)</td>
<td>Discrete (one year steps)</td>
<td>Closed</td>
<td>Yes</td>
</tr>
<tr>
<td>MOSART (Norway, 1988 onwards)</td>
<td>12 per cent random sample of population administrative data from 1993 (about 480,000 individuals)</td>
<td>Discrete (one year steps)</td>
<td>Closed</td>
<td>Yes</td>
</tr>
<tr>
<td>SESIM (Sweden, 1997 onwards)</td>
<td>LINDA longitudinal database, created from administrative data, typical sample about 1% of population (about 110,000 individuals)</td>
<td>Discrete (one year steps)</td>
<td>Closed</td>
<td>Yes</td>
</tr>
<tr>
<td>SAGE (UK, 1999 onwards)</td>
<td>0.1% of 1991 Census sample (about 54,000 individuals)</td>
<td>Discrete (one year steps)</td>
<td>Closed (for partnership &amp; parenthood – Open for some extra-family members)</td>
<td>No*</td>
</tr>
<tr>
<td>DYNAMOD (Australia, 1992 onwards)</td>
<td>1/1000 sample from the 1986 Census (150,000 individuals)</td>
<td>Combination (‘continuous’ monthly time unit for most demographic/labour force events, discrete one year units for education and earnings)</td>
<td>Closed</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Automatic alignment of demographic and labour force projections with official sources is not undertaken, but the output has been benchmarked against these projections and the results are satisfactory.
disability onset, and retirement. The model simulates Social Security coverage and benefits, as well as pension coverage and participation, and benefit payments and pension assets. It also simulates home and financial assets, health status, living arrangements, and income from non-spouse family members (co-residents). In addition, it calculates SSI eligibility, participation, and benefits.

DYNASIM has a long history at the Urban Institute. It was originally developed there in the 1970s. A revised version of the model, DYNASIM2, was built in the early 1980s, specifically to analyse retirement income issues (for an overview of the model’s earlier development see Zedlewski 1990). DYNASIM3 represents a major update of the model. It includes a more recent starting sample and recent information on demographics and family economics. DYNASIM3 also includes new household saving and private pension coverage modules, and Social Security and Supplemental Security Income (SSI) calculators. The model does not simulate income taxes, health benefits, or entry to aged care.

The DYNASIM3 model has been used recently to simulate how potential changes to Social Security will affect the future retirement benefits of at-risk populations, such as elderly widows and widowers, and certain divorcees and spouses (Favreault and Sammartino 2002; Favreault et al. 2002). The Institute has also used it to explore annuitisation effects under a Social Security system with personal accounts (Uccello et al. 2003), potential retirement consequences of rapid work effort growth among low-wage, single mothers in the late 1990s (Johnson et al. 2003), and the implications of recent earnings inequality patterns for future retirement income (Smith 2003).

The DYNASIM3 model includes three sectors: demographics, economics, and taxes and benefits (see Figure 1 for an overview). The computer implementation of DYNASIM3 follows the structure of its predecessor and includes two separate microsimulation models, the Family and Earnings History (FEH) model and the Jobs and Benefits (JBH) model. The FEH sector is written in FORTRAN, while the rest of the model is written in SAS. The FEH part of the model takes about 40 minutes of elapsed time for a full population run through to 2050 (that is, 57 projection years). The SAS component takes ‘closer to a whole evening’ to run (personal communication with Ann Harding by Melissa Favreault, 23/9/06).

The FEH model processes the full sample once for each year of simulation, simulating demographic and annual labour force behaviour for each individual in the input file. The output from the FEH model is a set of longitudinal demographic and labour force histories that provide the input for the JBH model. The JBH model processes each sample member through the entire simulation period, simulating an entire lifetime history of job tenure, industry of employment, private pension coverage, retirement, Social Security benefits, and private pension benefits. This structure is particularly interesting given the earlier discussion in Section 1, as it
means that changes in Social Security benefits or pension provisions do not affect previously simulated demographic or economic outcomes. To international observers, a first lesson from the DYNASIM approach is that there is clearly a trade-off here between simplicity and the ability to model behavioural responses.

Figure 1: Overview of the structure of DYNASIM3

<table>
<thead>
<tr>
<th>Demographic sector</th>
<th>Economic sector</th>
<th>Taxes and benefits sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population growth</td>
<td>Earnings</td>
<td>Benefits</td>
</tr>
<tr>
<td>Birth</td>
<td>Labour force participation</td>
<td>Pension benefits</td>
</tr>
<tr>
<td>Death</td>
<td>Hours of work</td>
<td>OASI</td>
</tr>
<tr>
<td>Immigration</td>
<td>Wages</td>
<td>DI</td>
</tr>
<tr>
<td></td>
<td>OASI take-up</td>
<td>SSI</td>
</tr>
<tr>
<td>Family formation</td>
<td>Jobs and employee benefits</td>
<td>Personal saving accounts</td>
</tr>
<tr>
<td>Marriage</td>
<td>Job change</td>
<td>Taxes</td>
</tr>
<tr>
<td>Mate matching</td>
<td>Pension coverage</td>
<td>Payroll taxes</td>
</tr>
<tr>
<td>Divorce</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaving home</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education and health</td>
<td>Asset accumulation</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>Saving/consumption</td>
<td></td>
</tr>
<tr>
<td>Disability status</td>
<td>Housing savings</td>
<td></td>
</tr>
<tr>
<td>DI take-up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institutionalization</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Favreault and Smith (2004, p. 4).

A second interesting lesson that international researchers might draw from the DYNASIM3 example is the importance of government interest (and thus funding) for the long-term maintenance of dynamic microsimulation models. While DYNASIM3 was constructed with funds from the Mellon Institute and investment from the Urban Institute itself, parts of the new model drew heavily on the experience gained and code developed by the researchers when designing the Social Security Administration’s ‘Model of Income in the Near Term’ (the MINT model) (Favreault and Smith 2004, p. 1).

A third lesson from the DYNASIM experience, according to the excellent review of models by Zaidi and Rake, is that ‘the subdivision of the model into smaller modules is important. This aspect of dynamic microsimulation … helps to make the working of the model more systematic and makes it easier to check problems at different stages in the running of the model’ (2001, p. 8).
Melissa Favreault also kindly provided some additional feedback on lessons learned that others could benefit from. She noted that one technical enhancement used in DYNASIM is to add functions that calculate the means of the explanatory variables (at the time that they enter an equation) for every prediction equation in the dynamic model. Developers can then compare these means to those from the equation estimation samples, to see to what extent changes in predictions are generated by changes in the regressors. This has emerged as an invaluable tool for validation and debugging of DYNASIM (personal communication with Ann Harding, 23/9/06).

2.2 DYNACAN

DYNACAN development began in 1994, using Steven Caldwell’s CORSIM model as a template. After some very limited policy application in 1996 and 1997, DYNACAN became part of the formal process for assessing the impacts of prospective changes to the Canada Pension Plan (CPP), Canada’s contributory, earnings-based public pension plan.³

DYNACAN’s primary objective lies with ascertaining the detailed, distributional policy impacts of prospective changes to the CPP, presented within the context of the broader retirement income system. The model simulates, on an annual basis, the evolution of the Canadian population from 1971 as far into the future as the year 2100. However, it concentrates on the roughly three-quarters of the population participating in the Canada Pension Plan. (The province of Quebec administers its own, very similar, plan for the other quarter of the population.) The synthetic individuals are born, age, immigrate or emigrate, leave home, work, marry, divorce, become disabled or recover, retire, and eventually die. DYNACAN simulates a variety of characteristics for these individuals, concentrating on annual CPP contributions and benefits, and the variables, particularly earnings, necessary to calculate them. The Office of the Chief Actuary initially developed DYNACAN at the request of the government department that then administered the Canada Pension Plan. In early 1999, the DYNACAN project was formally transferred to the department that was the primary user of DYNACAN’s results. It is currently housed in Social Development Canada (SDC), the department that has the primary responsibility for CPP policy.

DYNACAN uses, as its starting point, a heavily modified version of the public use microdata file for the 1971 Canadian Census, roughly a 1 per cent sample of the Canadian population. Case weights are equal for all individuals in the initial sample. They remain constant throughout the run, and are identical to the case weights assigned to individuals on birth or immigration.

³ The following material relies heavily on Morrison (2007a).
DYNACAN’s individuals evolve through time primarily via annual events whose probabilities are governed by equations, constrained by alignment to yield desired (historical or assumed future) collective rates. The alignment targets include rates for mortality, fertility, migration, marriage and divorce propensities, etc. An aggressive program of model validation tracks the extent to which, over the historical period, DYNACAN’s synthetic individuals and families resemble, distributionally, their real world counterparts. The validation effort extends, in a cross-model validation sense, to comparing various DYNACAN projections for the future with their counterparts from other models, particularly the Chief Actuary’s ACTUCAN model.

DYNACAN is written in C and the demographic projection portion of a run plus the simulation of ‘current’ base CPP world and an ‘alternative’ CPP world takes less than two hours for a 90 year projection. The extraction of a complex slate of more than 800 SAS tables and graphics that form the standard outputs for the analysis of a policy option takes another hour.

To an external observer, DYNACAN appears to have benefited from the on-going funding and stability of being located inside government and with its modelling projections being a vital part of policy development associated with the Canada Pension Plan. There has been sufficient funding to allow the team to make significant methodological advances and to take part in technology transfer through international gatherings (Neufeld 2000; Morrison 2000; Chenard 2000).

A second interesting lesson for international researchers is the adaptation of the CORSIM methodology and code. CORSIM was constructed by Steven Caldwell in response to the perceived high costs of earlier dynamic models in the US — and represented the first attempt to build a PC-based dynamic microsimulation model with a strong emphasis on portability (Caldwell 1996). The CORSIM methodology has not only been utilised by Canada, but also by Sweden through the SVERIGE model and by POLISIM in the US Social Security Administration (McKay 2003). However, since 2000 CORSIM itself appears not to have been subject to further development – and this provides us with a further lesson about the difficulties of keeping a dynamic model alive when only one or two academics are heavily involved with it (rather than a team of researchers within an institution).

A third feature of interest is the relatively narrow scope of DYNACAN. Attempts are currently being made to add income tax and private pensions to the model (Morrison 2006a, 2007b) but, for example, it does not attempt to simulate health services use or aged care.

Rick Morrison, who has been involved with DYNACAN since its inception, was kind enough to provide his reflections on the lessons learnt in a personal communication with Ann Harding (19/9/06). He noted that the DYNACAN team had consulted closely with their clients, ensuring that they understood exactly what the client
wanted. He felt that the importance of programmers had often been underrated — and that having experienced senior systems analysts and programmers, and providing for continuity for when they left, was critical to success. While noting the ongoing tensions created by time pressures, he felt that documentation was vitally important, including for satisfying the auditors, and providing continuity against the inevitable staff turnover.

Morrison stressed the importance of building on an existing platform (the CORSIM model) rather than starting from scratch, along with the co-operation and collaboration with Stephen Caldwell, as being two of the key ingredients for success. He also noted that considerable effort had been devoted to presenting results to DYNACAN’s clients, with the new Results Browser providing a good indication of this focus (2006b). Finally, he emphasised the significance of validation, observing that they had tried to build into the code facilities that would help in the detection of errors. For example, the model automatically lists the biggest winners and losers from a policy change. Often if there are errors in the code, they’re likely to generate big winners and losers and so this can help in identifying and correcting such errors. And when (as is typical) the gains and losses turn out to be legitimate, then the DYNACAN team learn a lot about the sometimes unanticipated intricacies of how the CPP programmes work.

2.3 MOSART

Statistics Norway started development of the MOSART model in 1988. The first version of MOSART was completed in 1990 and included demographic events, education and labour force processes. The second version of the model, completed in 1993, extended the model by adding public pension benefits and labour market earnings. Work on the third and current version started in 1995, by further extending the model with household formation and a simple representation of other sources of income, taxation, savings and wealth. This version has not been fully documented yet publicly. In addition to the use of the model in research projects in Statistics Norway, the Ministry of Finance and the Ministry of Labour and Social Inclusion are the main users. Specifically, MOSART has been, and is, extensively used in the process of reforming the Norwegian public pension system.

MOSART is a dynamic microsimulation model which starts with a representative cross-section of the Norwegian population and simulates the further life course for each individual in this initial population. The transition probabilities depend on individual characteristics and are estimated from observed transitions in a recent period. Events included in the simulation are migration, deaths, births, household

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4 The following material relies heavily on Fredriksen and Stølen (2007).
formation, educational activities, retirement, labour force participation and income and wealth. Public pension benefits are calculated from the simulated labour market earnings and other characteristics included in the simulation. The pensions covered by the model include old age pensions, disability pensions, survival pensions and early retirement benefits.

MOSART projects the Norwegian population and its characteristics for the coming decades. The modelling of demographic events and the underlying demographic assumptions of the model are to a large degree based on the public population projections from Statistics Norway. Before running the model, the model user must make assumptions on how the behaviour underlying each event will develop in the future. The usual approach is to define a base line scenario based on the conditions in the most recent year with available statistics and, with a few exceptions, let the transition probabilities stay at this level. One interpretation is that the base line scenario shows the development ahead if ‘everything continues as today’. Policies or other circumstances leading to shifts in the underlying assumptions can be analysed by comparing two or more projections.

The current version of MOSART starts with 12 separate one per cent random samples of the population in Norway from 1993. Each one per cent sample comprises 40 000 persons with actual information on marriage, birth histories, educational level and activities, pension status and pension entitlements in the National Insurance Scheme. In addition to being the starting point of the simulation, the initial population is also used to estimate the transition probabilities. At present the model is calibrated to annual data from 2001. When calibrating to new annual data it is assumed in the model that the effects from different explanatory variables (gender, age, education etc.) on the transition probabilities are the same as estimated from the initial population, and that the adjustment factors capture the interesting part of time variation.

The MOSART model is run from a Unix platform, and the simulation part of the model is written in Simula, an object-oriented language developed in Norway in the 1960s. As Simula is not compatible with Statistics Norway’s new digital computers, it is still run on old Sun Sparc servers. These computers take some 3 to 6 hours to complete a standard simulation with 1 per cent of the population until 2100. With an ordinary up-to-date server, it would probably be possible to run the model well within one hour, so rewriting the model in a modern object-oriented language is on the future work agenda (and apparently has recently been completed – Knudsen 2006).
Figure 2: Overview of MOSART

<table>
<thead>
<tr>
<th>Sequence of major simulation items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Add new immigrants</td>
</tr>
<tr>
<td>2. Emigration</td>
</tr>
<tr>
<td>3. Deaths</td>
</tr>
<tr>
<td>4. Household formation (except deaths and births)</td>
</tr>
<tr>
<td>- Out of old age care institutions</td>
</tr>
<tr>
<td>- Into old age care institutions</td>
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<tr>
<td>- Children leaving home</td>
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<tr>
<td>- Adults living in other households without family relations</td>
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<tr>
<td>- Cohabitation and marriage, including matching of spouses</td>
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<tr>
<td>- Divorce</td>
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<tr>
<td>5. Births</td>
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<td>6. Educational activities and accomplishments</td>
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<tr>
<td>7. Social security</td>
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<tr>
<td>- Disability and rehabilitation schemes</td>
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<tr>
<td>- Other non-public pension schemes</td>
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<tr>
<td>- Early retirement (AFP)</td>
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<tr>
<td>- Retirement</td>
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<tr>
<td>8. Labour supply projection (labour force participation rates and average working hours)</td>
</tr>
<tr>
<td>9. Labour market earnings (as an individual characteristic, and consistent with the projected labour supply in (8)).</td>
</tr>
<tr>
<td>10. Public pension benefits, other incomes, taxation and savings</td>
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</tbody>
</table>

Source: Personal communication between Nils Martin Stølen and Ann Harding (20/9/06).

The output from a simulation consists of extensive self-documentation (making the user able to find errors in the results afterwards), a set of standard tables produced by the simulation programme with aggregated figures covering most frequently asked questions and, finally, an option to produce a model population consisting of an ASCII-file with one record per selected person per selected year with selected variables. Special tables may be produced from this file with a suitable table production programme, usually SAS.

The user interface of the MOSART model is very simple and consists of a few shell scripts handling the set up of new simulations and the execution of necessary computer programmes. Every new simulation is given a separate directory with the directory name also being the identification (the name) of the simulation. Each simulation directory includes six small text-files with names of input files and values for other external parameters, and all simulation results are stored in this directory.
To an international observer, dynamic microsimulation appears to have flourished in Norway during the past decade. While the sensitive nature of the merged administrative data which underlies the model means that it is not accessible to those outside government, the model has been extensively used within government – particularly for looking at the consequences of population ageing for the Norwegian social insurance schemes. The MOSART dynamic microsimulation model has been playing an active role in policy formulation in Norway, by shedding light on the effects of different reforms discussed by the recent Norwegian Pension Commission (NOU 2004).

In addition, work within Statistics Norway is at the international forefront in at least two areas of macro-micro linkage. One recent application has linked the MOSART microsimulation model to a large scale dynamic Computable General Equilibrium (CGE) model, with the macroeconomic development of the Norwegian economy until 2050 under different public pension systems being projected. The two models are run iteratively to obtain consistency. To the direct (or first round effects) estimated from the microsimulation model have been added the equilibrium adjustments calculated from the CGE model arising from changes in government expenditures, labour supply incentives and private savings induced by the pension reforms (Fredriksen et al. 2007). A second application has linked a Norwegian CGE model with a detailed microeconometric labour supply model. Aaberge et al (2007) are critical of the standard procedure underlying long run CGE-studies of ageing — of letting a few representative agents determine the aggregate labour supply responses — and have instead developed a micro-econometric model of labour supply for a large representative sample of households.

These initiatives suggest that the combination of a very high priority policy area (namely, the sustainability of the pension system), allied with excellent microdata and on-going government support have allowed dynamic microsimulation to blossom within Norway.

2.4 SESIM

The SESIM model developed at the Swedish Ministry of Finance provides another example of how dynamic microsimulation has flourished over the past decade or so within the Nordic countries. The Swedish approach has involved close cooperation with researchers at Swedish universities. The work started in 1997 as a tool to evaluate the Swedish education financing system. Since 2000, the focus has shifted from education to forecasts and analysis of the new Swedish old-age pension system and the effects of the ageing population on public finances. While SESIM has now

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5 This section relies heavily on Sundberg (2007) and Flood (2007).
been developed into a general microsimulation model that can be used for a broad set of analyses, the most important purpose remains analysis of the financial sustainability of the pension system.

SESIM can be characterised as a mainstream dynamic microsimulation model in the sense that the variables (events) are updated in a sequence, and the period between the updating processes is a year. The start year is 1999 and the initial sample of the Swedish population is approximately 110,000 individuals. SESIM has a recursive structure consisting of a set of modules executed in a predetermined order. The unit of simulation is the individual, but the household also plays a significant role. Figure 3 summarises the structure of SESIM and shows how it has been extended in recent years to include wealth, non-cash benefits, health status and aged care. It is thus now a very broad model.

The primary database for SESIM, both for estimation of the requisite transitional probabilities and construction of the base population is the Statistics Sweden longitudinal database LINDA. This database is created from administrative registers and covers about 3.5 percent of the Swedish population (some 308,000 individuals). The selected individuals are followed backwards and forwards and all relevant information is collected. Some information (for instance, pension rights), can be traced back as far as 1960. Thus, this is a panel data set, since the same individuals are followed over time.

As LINDA is completely created from administrative registers, no interviews are needed and therefore a major advantage is that there are no problems of attrition bias. The database is created by merging a large number of registers, and includes data about income and wealth, earnings, pension rights, sickness and unemployment benefit, schooling etc. The base population used in SESIM is usually formed by a random draw of about 110,000 individuals from LINDA.

To make SESIM useful within the Ministry of Finance environment, it is necessary to make it simple to implement exogenous assumptions and forecasts. The model has therefore been designed to make it easy to use different exogenous demographic and macroeconomic assumptions (e.g. from the Ministry of Finance or Statistics Sweden). For implementation of demographic and labour market assumptions, alignment techniques are used.

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6 The sector is required e.g. for calculations of second pillar occupational pensions. There is also a module for endogenous old-age retirement decisions.
The SESIM model is programmed in Visual Basic 6.0, with Microsoft Excel and Access used for handling of macroeconomic and demographic assumptions and parameters. A typical run of 100,000 individuals and a 50 year long simulation takes about 30 minutes to execute on a modern standard PC. The program can be controlled in three ways: from the ‘user interface’, from the ‘Excel report generator’ or in batch mode. Normally the ‘user interface’ is used in the early stage of development, and the ‘Excel report generator’ is used to produce standard outputs as graphs and tables. More extensive analysis of the results is performed in standard statistical packages like SAS or R. It’s easy to implement different macroeconomic
assumptions in SESIM, but more time-consuming to change population scenarios. If the files with demographic and macroeconomic assumptions are in place and relevant reports available, it is easier to make several model simulations in batch mode. When the model is run repeatedly (e.g. to assess the sampling variance) it is also more appropriate to use the batch mode.

From an international perspective, SESIM provides another example of the powerful dynamic microsimulation models that can be created when modellers are lucky enough to have access to comprehensive longitudinal administrative data. This removes the need for the additional work that has to be undertaken in other countries to set up the requisite base files and data (particularly for the simulation of pensions).

The model has been used regularly in evaluating the financial sustainability of the new Swedish pension system and, as with Norway, the existence of such a significant public policy issue has helped to sustain funding for the model within the government.

A third relevant lesson from the Swedish experience is the close collaboration between government departments and academics, with Professors Anders Klevmarken and Lennart Flood (at Uppsala and Göteborg Universities respectively) both having played a significant role in SESIM’s development and on-going use.

Unusually, the model is in principle open source. The code is freely available at www.sesim.org. However, because of the official data secrets legislation, no individual base data and ‘histories’ are provided.

2.5 SAGE

The ESRC Research Group ‘Simulating Social Policy for an Ageing Society’ (SAGE) was established in November 1999 with funding from the UK Economic and Social Research Council. One of the core activities of the Group was the construction and use of a dynamic microsimulation model to provide projections to inform the development of social policy in Britain for the twenty-first century, focusing on the implications of population ageing for pensions and issues regarding health and long-term care needs. The model generates projections of the likely future socio-economic characteristics of the older population, including their financial resources, health and dependency, and family circumstances. This provides important information for policy makers regarding the likely demand for health and social care, the supply of

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7 This section relies heavily on material in Evandrou et al (2007) and on the many excellent papers available from www.lse.ac.uk/depts/sage.
informal carers and the degree to which older people will be able to resource their own retirement.

The SAGE model is a partially closed, discrete time, time-based dynamic microsimulation model. It is a full population model, and covers demographic processes, education, labour market participation, earnings, pension accumulation, and health and disability. The SAGE model takes a cross-section of the British population drawn from the 1991 census and projects them forwards through time to 2031, with each individual experiencing the risk of dying, forming a partnership, having children, obtaining educational qualifications, working, contributing to a pension (both state and private), experiencing ill health and disability and providing informal care. Using simulation techniques, the model builds a complete picture of the life histories of the model individuals, providing a picture of the likely pension entitlements, health and health care needs of the older population in 2031. The model can then be used to assess the impact of different policy options within the fields of pension provision and long term care.

The base data for the model was drawn from the Samples of Anonymised Records (SARs) from the 1991 Census of Great Britain. The base data have been supplemented with additional information taken from a variety of sources. In particular, summary information on work and caring histories and pension accumulation was matched on the base data from the 1994 Family and Working Lives Survey. This means that the base population start with some history, rather than being a pure cross-section (see SAGE Technical Note 8).

The SAGE population is closed with respect to partnership and parenthood, and a partnership market is implemented for marital and cohabiting relationships. However, for extra-family members open relationships are possible, with a limited number of characteristics of secondary individuals being modelled as attributes of the primary individual.

The SAGE model uses time-based processing with a discrete time frame. The entire population is processed simultaneously, allowing matching between sample individuals, and state changes are computed at fixed time intervals using transition probabilities. The different model processes take place in a fixed order within an annual cycle, and each transition may depend only on the outcomes of transitions in the previous cycle, or transitions that have occurred earlier in the same cycle. This means that the ordering of the transitions in the cycle needs to be carefully considered. As the model population is based on a nationally representative sample of the national population, no re-weighting of cases is required.

The SAGE model program has been developed using the Borland C++ compiler, command-line version 5, for Windows 32 operating systems. The program utilises Object-Oriented Programming to produce a very flexible implementation that
maximises separation between content and implementation. An important feature is a simple scripting language that enables transition rules to be declared and modified without the need for specialist programming skills (further details are available in SAGE Technical Note 3). A variety of other software, particularly Excel and STATA, contribute to the extraction and presentation of the model’s results.

The running time depends on the number and complexity of events included, the frequency of output, and the speed of the output media. A full simulation of all events from 1991 to 2031, with output of results on an annual basis, takes under 420 seconds. There is currently a simple user interface that allows the user to set the start and end year of the simulation, the population size and the output interval. There is no interactivity in the actual simulation itself, which is run in batch mode and relies upon thousands of parameters. However, the script and rules files are easily accessible and it is possible to change key parameters (such as the rate of earnings growth or the real interest rate) without specialised programming skills.

The main aim in developing the model was to provide projections of the future characteristics of older people in Britain and to inform the development of alternative policy options within pensions and long-term care. To date, the model has been used to examine the labour market trajectories and pension accumulation patterns of different birth cohorts amongst the British population. It has also been used to investigate the distributional impact of changes in the operation of the British pension system. An unusual feature of the SAGE model is that it also incorporates health and disability status. Thus, an additional application of the model is the investigation of the likely future demand for long-term care and how this is related to the ability to pay for such care.

The SAGE project offers a number of lessons to international observers. Some of the important lessons that the SAGE group felt that they had learned were very helpfully summarised in a presentation in December 2003 (Scott et al. 2003), by which time the project was nearing the end of its five year course. The first lesson was ‘keep it simple but credible’, with the authors noting that: ‘simplicity is necessary in order to obtain a model that starts functioning within the lifetime of an initial programme of work’ (2003, p. 19).

The second lesson was ‘keep it simple but flexible’. Thus, Scott et al write that ‘the primary goal of modelling work should be the construction of a model that provides at least initial answers to analytical questions of interest. However, the model should have the capacity to provide ‘more complex’ answers as additional modules are developed and refined’ (2003, p. 19). This suggests a phased program of research, where an initial working version of a dynamic model is constructed and then efforts are later made to improve or elaborate upon certain processes within the model.
The SAGE team pointed again to the critical importance of documentation, but noted the tension created by the time costs and resources required to document properly.

They also noted again the significant benefits to be derived from collaboration, observing how helpful their collaboration with the PENSIM2 team within the UK Department of Work and Pensions had been.

Finally, they elaborated on the advantages and disadvantages of constructing a dynamic microsimulation model within academia, noting the superior resources and access to administrative data available within government — versus the ability within academia to examine issues not on the agenda of any political party and to model wider societal processes.

Professors Falkingham and Evandrou are partner investigators on the APPSIM project and they kindly provided some personal reflections on the lessons that could be taken from the SAGE experience for APPSIM. They indicated that: ‘overall project management was critical to the task of building a fully functioning dynamic model within the timeframes and funding levels typically achieved via academic grants. Academics often underestimate the resources required to build a dynamic microsimulation model, both in terms of time and money. The funds required are typically at the upper limit of the research grants available from funding agencies and there is a temptation to reduce the resources requested to fit within funding limits. It is important to be realistic in what can be achieved within the project funds and time.’

‘The amount of effort put into the various modules needs to be proportionate to their importance in determining outcomes. For example, within the SAGE module, the labour market and earnings modules were the most time consuming, taking over a year to complete, but the investment was worthwhile as these modules are also the most important; earlier work history is critical in determining income in later life.’

‘Academic research teams are typically smaller than those in government and the concentration of specialised knowledge means that the teams are particularly vulnerable to staff turnover. Detailed documentation of both the substantive research underlying the transition probabilities and the modules themselves can ameliorate this but does not solve the problem. Close liaison with Government departments and other users is important and can facilitate access to data and knowledge transfer. However there is also the risk that highly trained staff may be poached to work on Government models!’ (personal communication with Ann Harding, 18/9/06).
2.6 DYNAMOD

DYNAMOD is a dynamic microsimulation model of the Australian population developed during the 1990s at the National Centre for Social and Economic Modelling (NATSEM). It is similar to other international microsimulation models in that it has a base population representative of the population; uses functions to model change; and has a set of alignment modules that ensure the output matches external reference data. However, the methods used to model probability and align the data are unusual.

In the early (1992) stages of the development of DYNAMOD, the decision was taken to move away from the traditional approach to dynamic microsimulation and to include some innovative, albeit untested, new methodologies. Noteworthy aspects of the design for DYNAMOD included the use of survival functions; the division of the model into simulation and analysis modules; and the inclusion of an integrated macroeconomic model. Aspects of the modelling within DYNAMOD were regarded within the international modelling community as being at the cutting edge (Spielauer 2002, p. 21), including the use of continuous rather than discrete time intervals within the model, through the use of survival functions (Antcliff 1993).

An overambitious development schedule resulted in faltering progress and culminated in a major break in the project when in late 1994/early 1995 the entire DYNAMOD team of four researchers resigned. An internal review began in March 1995 and three major changes were identified for implementation - the internal macroeconomic model was to be abandoned in favour of a simpler and more controlled micro-macro link; the use of survival functions was to be restricted and more reliance was to be put on the more traditional transition probability approach; and a more flexible model structure was to be implemented. Following the review, development recommenced and DYNAMOD-2 was delivered at the end of 1997 to the Department of Employment, Education and Training.

The current DYNAMOD model is version 3. A number of major changes occurred between version 2 and version 3. The model was redeveloped and transported from the Unix to the Windows/DOS environment. This reduced processing times and provided access to a vastly improved development environment. Alignment of demographics and labour force transitions was improved in version 3 and household wealth, superannuation, taxation and government transfer modules were added. Finally better accounting of labour force participation and earnings was implemented. The model has since been used operationally and a number of papers

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8 The section relies heavily on Kelly (2007) and on the many DYNAMOD technical papers available from www.natsem.canberra.edu.au.
based on simulated outcomes from DYNAMOD have contributed to debate on social policy in Australia (for example Kelly 2001, 2002; Kelly et al. 2002).

DYNAMOD-3 runs on a PC, contains around 40,000 lines of code and is written in the programming language C. It is able to project the characteristics of the Australian population up to the year 2050. It starts with a base population of 150,000 people (a one per cent sample from the 1986 Census) who are representative of the Australian population and then simulates events that will occur in their lives - births, deaths, migration, education, leaving home, forming couples, divorcing, being employed, earning money, accumulating and drawing down household assets, paying taxes, receiving government benefits, becoming disabled and recovering from a disability.

The simulation model has the same structure as other microsimulation models – an initial base population, a simulation cycle and an output. Within the simulation cycle is a set of functions for calculating the probability of events occurring. The simulation uses two methods to replicate events that happen during people’s lives. The first – transition probabilities – is the one normally used and makes use of the simulation clock. This clock steps through time (in DYNAMOD the steps can be as small as one month). At the start of each increment, the chance of a person transitioning from one state to another is considered (for example changing from the state of ‘employed’ to the state of ‘unemployed’). The chance that a person makes the transition varies with their circumstances at that time. The calculation of transition probabilities is done through the use of regression equations that apply weightings to each of the influences based on historical data. This method is used extensively by DYNAMOD to simulate changes in relation to the labour force.

The second method used to simulate an event in a person’s life is through survival functions. With this method, rather than do a calculation for every person every month, the calculation is only done when trigger events take place. When a trigger event occurs, a calculation is made of when a subsequent event will occur. For example, when a birth occurs (a trigger event), the date of death of the baby is decided (the subsequent event). The advantage of this method is that calculations only have to be made a few times rather than every month (as an example, date of death is only calculated once or twice in a person’s life - at birth, if a person becomes disabled, or if a person recovers from a disability - rather than 12 times per year). The disadvantage of the survival function method is that estimated durations of being in a given state are required and only limited amounts of data are available in this form. DYNAMOD uses survival functions to model most demographic occurrences. As the simulation steps through time, DYNAMOD uses a diary called the ‘crystal ball’ to keep track of the various events that are due to occur. The crystal ball contains details of dates, events and people.
The method used to record what happens during a simulation is to write the details of every person and any change in their circumstances to a series of ‘history files’. The files can then be analysed after the simulation. The items stored relate to each person, relatives, parents, residences, qualifications, education types, educational institutions, education levels, the labour force, industries, occupations, sectors, income, employment status (full-time, part-time, unemployed, not in the labour force), marital statuses, pregnancies, migration, disabilities, deaths and wealth. These history files enable comparisons at various points in time to be undertaken or allow the circumstances of an individual to be analysed over time.

The output obtained from the original DYNAMOD model design was not in harmony with expected answers and a number of papers questioned whether DYNAMOD could become a credible and useful model in its then form. The key element missing was identified to be alignment processes — a point supported by the experiences of the successful CORSIM and DYNACAN dynamic microsimulation models. Importance of alignment as an essential element for a useful model has subsequently been emphasised during development of the more recent versions of DYNAMOD. The various versions of alignment and its increasing sophistication are described in detail in Kelly and King (2001).

Ann Harding, who was NATSEM’s Director during the construction of DYNAMOD, offers the following observations of relevance to APPSIM and future model builders. ‘With the benefit now of 15 years of experience in the construction of extremely large and complex microsimulation models, the crucial importance of project management has become clearer to me. Academics naturally tend to want to do an outstanding job in their modelling work — and this often means that the earlier stages of a project absorb a greater than anticipated share of the total time and budget for the project. The end result is that important processes that were part of the original project scope often then do not get included within the model — or they get included in a much more rudimentary way, or they are less well documented or validated or, by the time the model is completed, there are no more funds left to produce the papers that illustrate the useful questions that the model can answer (and thus to keep stakeholders and future funders engaged).’

‘Today, I would place a much greater importance on developing the simplest possible (but functioning) version of a model, on getting that well documented and on producing papers containing illustrative results within the project budget and timeframe. It is then easier to persuade stakeholders to provide additional funds to support refinements to particular modules or the development of new modules to simulate additional processes. Such an approach militates against the taking of risk, which was a feature of the development of our original DYNAMOD model (such as the use of survival functions and the attempt to build an integrated macro model). But it seems to me to better reflect the reality of research funding today, given the
very high costs associated with the construction of dynamic microsimulation models. One possible solution to this ‘risk’ dilemma is for PhD students to undertake the high-risk development of new methods and innovations, which can subsequently be included within the core model.’

‘A second lesson now learnt though an additional 15 years of experience is a greater appreciation of the significance of the deficiencies of the microdata upon which microsimulation models are based and the transition probabilities are calculated. It can seem theoretically desirable to simulate the demographic and social processes typically included in a dynamic model in a very complex way, based on numerous explanatory variables. But most researchers exist in countries where the sample sizes of the available longitudinal surveys are relatively small and the statistical reliability of estimates that are drawn from the data can be relatively low. In other words, the impression of greater sophistication and precision in the modelling can be nullified in practice by the introduction of more ‘statistical noise’ into the estimates. This again emphasises the importance of building the simplest possible microsimulation model, with the goal of returning to improve key areas once the initial model is functioning.’

‘The third lesson I have drawn from both the Australian and international experience of the past 15 years is the importance of collaboration with and funding from government, if complex microsimulation models are to survive in the long-term. Construction and maintenance of such models outside government offers significant advantages, including that separation from the pressures of day-to-day policy development makes it easier to complete what can often be seen as less critical tasks within the policy hot-house (such as documentation). In addition, it creates the possibility of the model feeding into the policy deliberations of players outside government, with consequent benefits for the development of sound public policy within a country.’

‘But the costs of maintenance of complex microsimulation models are so high that it is difficult to keep them alive in the long-term without the injection of substantial public funds. In Australia, the contract for the maintenance and development of the STINMOD static microsimulation model by NATSEM for the Commonwealth government during the past seven years provides one example of successful long-term collaboration between government and academia. In my view, such an approach is likely to be required to keep APPSIM alive after the initial five year project expires. This underlines the importance of academics understanding the requirements of their government clients and meeting those needs – and, conversely, government understanding the needs of academics, such as the need to publish.’
3 Model Content

Based in part on the review of international and domestic experience presented in the preceding section, what lessons can be drawn for the development of APPSIM? Citro and Hanushek (1991) in their review of the uses of microsimulation models summarise some of the major reasons for models have not achieved their full potential in the past:

‘… some modelling efforts have foundered because (in addition to whatever data and other problems occurred) the design was too grandiose, the structure did not provide for sufficient modularisation, or the documentation was inadequate to permit easy updating or adaptation of model components. In addition, some models that were initially well designed lost significant flexibility and ease of use.’ (Citro and Hanushek 1991, p. 161)

Although written more than a decade ago, the reasons for failure presented above are still relevant to today’s model developers. The reasons that these models were not successful are important lessons learned. If the lessons are learnt it will result in future modellers developing more useful and reliable decision-making tools.

3.1 Clear Objectives

As with any project, regardless of scale, the need for clear objectives and outcomes are essential to the effectiveness, success and value of the project. The importance of a clear sense of purpose as a key feature of the successful development of a microsimulation model has been frequently noted in microsimulation literature (see for example, King and Bækgaard 1997; Citro and Hanushek 1991; Zaidi and Rake 2001). King and Bækgaard (1997, p. 7) have argued that ‘the most fundamental lesson for a dynamic microsimulation modelling exercise is the need for design and development to be clearly related to the purpose of the modelling exercise in terms of intended applications.’ Citro and Hanushek (1991, p. 155) reiterate the importance of applying resources and developmental priority to the main analytical goals of the model, stating, ‘no one model can or should try to be all things to all people.’

The potential to add more detail and sophistication to a model will always be a temptation to model developers — and historically this temptation has resulted in many over-ambitious failures. Consequently, it is of utmost importance that the objectives of the project are kept in mind and the model should be kept as simple as possible to achieve the objectives of the project. There is considerable potential to
move developmental priorities and project focus away from the original key objectives and outcomes during the development of the vast number of social and economic subsystems required in a dynamic microsimulation model. Zaidi and Rake (2001, p. 18) have noted that ‘the effectiveness and suitability of a dynamic microsimulation model should therefore be judged in relation to the purpose for which the model is built.’

It is clear that throughout the development of the Australian Population and Policy Simulation Model (APPSIM) the purpose of the project needs to remain a clear and central focus.

3.2 Data Sources

Base Data

A model cannot exist without data, and the quality of the initial dataset in a dynamic microsimulation model is critical to the overall strength and sophistication of the model. Dynamic microsimulation is extremely demanding in terms of data requirements, and it is not conceivable that any one data set will contain all the information required for the base population (Scott et al. 2003). Indeed more often than not, the choice of an initial base data set will require a trade-off between population representation, data reliability and richness of variables available in the data. Unfortunately, not all three of these essential elements of a base data set will be represented in equal proportions. For example, some data sets may capture 100 per cent of the population, but have low reliability and contain only 50 per cent of the variables needed for modelling. In other cases, the data may have good coverage and be reliable but the categories used in the variables are too broad — for example, age may be grouped into 10-year bands or incomes may be grouped into $10,000 ranges.

Due to financial constraints, increases in the coverage of a survey are usually accompanied by decreasing detail. Existing well-reputed dynamic models such as SAGE and CORSIM have assigned more value to representativeness (coverage) rather than content in the selection of the data source for the base population — the reasoning being that any initial bias in representativeness will be magnified during simulation (Scott et al. 2003, p. 4). O’Donoghue adds that a larger sample size will also mean the ability to ‘consider smaller groups’ or produce findings that have smaller sampling errors (2001, p. 7). As noted above, selection of a base population that is more statistically representative of the population often means that the level of detail/number of variables available is compromised. Overcoming the lack of detail
within variables or the imputation of new variables will add significantly to the
dynamic behaviour and usefulness of a model.

In choosing the base population source, there are inherent trade-offs between
population coverage, reliability and richness of variables available. Unfortunately,
almost no datasets have complete coverage, are reliable and are rich in variables and
detail. The selection of a base population will almost always result in compromises.
The choice of base data type can be divided into four groups – administrative,
longitudinal, cross-sectional and synthetic. Each of these groups possesses
advantages and disadvantages, and it will nearly always be the case that additional
data requirements will need to be imputed or matched in some way to any base data
population. Klevmarken notes the suitability of longitudinal data for use as base
data, estimation and validation — as longitudinal data contain the necessary
elements to estimate behavioural processes and histories (2005 p. 7). However, these
surveys rarely have the sample size necessary to reliably capture the range of
characteristics in an entire population. In Australia, choices of longitudinal data are
very limited, and those that do exist are only at embryonic stages and not yet long
enough to simulate life-cycle effects.

It has been argued that administrative data contains the most accurate data, as more
resources and effort are expended in data collection. However, administrative data
are usually confined to certain characteristics of a sub-population. For example,
administrative data are held on government welfare recipients in regards to
characteristics of the person that impact on the amount paid. In general,
administrative data are usually limited in the range of detail collected — and, even
when collected, there may be concerns about the reliability of some variables and
thus their usefulness for modelling purposes Administrative data can however, be
imputed onto another broader data set to enhance the detail in a particular area.
Some models such as DYNASIM have matched administrative data to survey data to
achieve a broad but detailed base population.

Cross-sectional data are the most common type of data used to establish a base data
set in existing dynamic microsimulation models – with the notable exception of those
lucky Nordic countries who have a very different national approach towards privacy
issues than does Australia and who have access to extensive longitudinal
administrative data! Cross-sectional data usually come in the form of census or unit
record survey data.

As with other data choices, cross-sectional census and survey data have both
strengths and weaknesses. Census data, whilst very broad in scope, lacks
behavioural detail and data richness. However, census data are usually far more
reaching in population coverage than any other survey data can endeavour to be.
Cross-sectional survey data typically contain more detailed information than
censuses although their usefulness is limited by smaller sample size. Further, cross-sectional surveys are usually targeted at gaining information on a particular topic — for example, income, expenditure or child care. This in itself is limiting for dynamic models that wish to capture a broader range of issues.

Synthetic data have been used by a number of dynamic microsimulation models as the base data, where no appropriate data exists. Such models include LIFEMOD, DEMOGEN, HARDING and LifePaths (Harding 1993a; Wolfson 1988; Falkingham and Hills 1995; Falkingham and Harding 1996; Gribble et al. 2003). However, the use of synthetic data has limited application. The first limitation is that outcomes based on synthetic data do not have the same level of acceptance with policy makers and the general public as outcomes based on survey or Census data (Scott et al. 2003, p. 4). It may be that those without a full appreciation of microsimulation methodology associate synthetic data with synthetic outcomes. In addition to the lack of appeal, Scott et al (2003) also argue that a synthetic population is difficult to implement.

The choice of base data is a critical decision and requires close attention by anyone embarking on building a dynamic microsimulation model. Existing models have generally taken the path of starting with the largest cross-sectional representative population of acceptable quality and supplementing this base with additional data either through imputation or data matching. Many researchers have found the imputation or data matching task to be a major undertaking, requiring very careful planning, design and implementation. Therefore, when selecting a base population, the additional data requirements should also be considered carefully.

**Additional Data Requirements**

As mentioned above, the selected source for the base data will normally not contain all the information needed for the dynamic simulation process and additional data will need to be sourced to fill in these missing gaps. The review of base data sources and each of their weaknesses and strengths in the previous section also applies to additional data needed to complete the model. Sample sizes, detail of data, imputation and merging techniques, for each data source need to be considered when selecting additional data sources.

**3.3 Population**

Another important choice that needs to be made is deciding what population is to be modelled. Typically populations in dynamic microsimulation have taken the form of either a single cohort or full population. A single cohort models a specific group of
people within the population over their lifetime (for example, O’Donoghue (2002) uses a single cohort model to study redistribution under the Irish tax-benefit system). Cohort models are typically used in response to a specific issue (for example the pension costs associated with the baby boomers) and have historically been used due to computing power and data constraints (O’Donoghue 2001, p. 17). A clear limitation of cohort models is that it is very difficult to calibrate these models as they often do not represent the total picture contained in aggregate external benchmarks.

Full population models are representative of the entire population (although they often refer to only the adult population). They have several advantages over cohort models, in that they enable modellers to take into account inherent differences that exist between various groups of people at specific points in time. ‘Age’ effects are those where we see a distinctive pattern relating to age – such as home ownership levels increasing as age increases, health decreasing as age increases, levels of education increasing then plateauing, etc. ‘Period’ effects are those that reflect the conditions prevailing at different times. For example, the returns on investments, fertility rates, and life expectancy vary over time. Finally, ‘cohort’ effects refer to the way in which cohorts of the population behave differently. Thus, people aged in their fifties in the 1990s behave quite differently to people aged in their fifties in the 1950s. And we know that there are many such differences in family formation, labour force activity and so forth. A model that only looks at one birth cohort is limited in its usefulness to undertake analysis of other cohorts.

As noted earlier, SAGE – the dynamic microsimulation model that has been developed in order to project the circumstances of older people in Britain — has opted to use a full population, with the reasoning that different generations will have different life experiences (such as higher rates of employment discontinuity and single parenthood (Scott et al. 2003, p. 2)). Scott et al have stated ‘in order to understand the characteristics of future older people, it is necessary to understand the forces that have moulded their lives to date’ (2003, p. 2) — in other words, the model needs to capture the impact of age, cohort and period effects. Full population models are also advantageous as ‘simulating the future life course trajectories of people who are currently young and in middle age allows us to obtain a realistic picture of the health and economic circumstances in later life amongst future cohorts of elders’ (Scott et al. 2003, p. 2).

Whilst the choice of a full population model provides a number of advantages, it is important to note the choice of a full population model will also increase the complexity, cost and development time of the model.
4 Structural Design

4.1 Suitability

King and Bækgaard note the importance of involving users in the design of the model and not just in the design of the outputs from the model (1997, p. 8). They highlight that a lack of user involvement in the design was one of the weaknesses of the original DYNAMOD model and that ‘the best way to ensure that model design and development is tailored to particular applications is to involve potential users in the process from the outset’. The importance of encouraging user input has also been well noted by the EUROMOD project, which concluded that ‘[user] consultation can only result in a better model, more widely used’ (Sutherland 1997, p. 17). EUROMOD has gone to great lengths to seek user input and consultation. For example, trial versions of the model at different stages of development were provided to potential users to ensure that users’ views were known and could be incorporated during the development of the model.

The importance of getting users involved in the model design is well understood by the APPSIM team and processes such as the establishment of technical advisory committees composed of users are being established to ensure that users will have opportunities to voice their opinions on the design of the model.

The benefit of having users of the model being involved in the design from the outset are many, including making sure that the model is user friendly. Citro and Hanushek note that: ‘good model design incorporates features that provide a high degree of accessibility of a model to analysts and other users who are not computer system experts’ (1991, p. 158). A model that requires an IT specialist to input scenarios, run the simulation or assess the output, will be of very limited value to government policy analysts (the key users of most dynamic microsimulation models). In making models more user friendly, Zaidi and Rake note the importance of a transparent model that doesn’t operate as a ‘black box’ but rather provides users with (a) a clear view of the underlying processes; (b) the limitations of the model; and (c) is user friendly (2001, p. 22). Put simply, it is not only important that users can operate the model and achieve results, but to also be able to see how the results were obtained. In addition, Zaidi and Rake note the use of thorough documentation as a tool for providing users with greater understanding of how the model works and its limitations. Therefore the documentation helps the model transparency, and consequently, its user-friendliness (2001, p. 22).
Model transparency can also assist with model acceptance. It has been noted that models that are more easily understood by the lay person will gain more acceptability and use in the public policy world. Peer review may aid in gaining model acceptance, but it is important that policy makers can see and understand the mechanisms used within the model (King and Bækgaard 1997, p. 9).

Providing adequate documentation, training and support has also been noted by Citro and Hanushek as an important requirement in making the model more user friendly (1991, p. 158) — and was also flagged in Section 2 as a key issue by the developers of the DYNACAN, SAGE and DYNAMOD models.

Clear and concise documentation is not only important for current users, but it is essential for future users and maintenance of the model. However, excessive documentation should be avoided and a balance struck (King and Bækgaard 1997, p. 12). Often documentation is not given enough priority when developing a model, and Scott et al amongst others, have reiterated the importance of allocating enough time and budget to this task (2003, p. 20).

Citro and Hanushek highlight the added value that making a model user-friendly and accessible to more people adds to the cost-effectiveness of the model (1991, p. 158). User input will aid in developing a user friendly model and improve acceptance of the model. In order to do this, throughout the model development there needs to be clear documentation and transfer channels to enable knowledge to flow smoothly between model developers and users. As well as this, a marketing mechanism needs to be put into place from the early stages – spreading news about the model and its value to policy makers and researchers in Australia.

### 4.2 Flexibility

A flexible model design means the ability to make changes to the model with minimal disruption. Scott et al. have remarked that ‘… the model should possess built-in flexibility that facilitates the extension of the model in subsequent versions with additional details/sophistication’ (2003, p. 19). One of the major reasons for dynamic models having failed or not realising their full potential in the past has been their inflexibility (Caldwell 1996).

Modularisation of dynamic models is one of the key factors in ensuring that the model maintains its flexibility and longevity. A modular design increases flexibility and ease of operation of the model in several ways. It enables easy additions or deletions to the model through only having to access or change one set of code, not having to rebuild the entire model. A modular structure also reduces run-times of the model, as most analysis will only require certain modules to be operating.
It has also been frequently noted that it is wise to parameterise modules and hold key parameters separate from the modules operation where possible, to allow changes to be made more easily (see for example Citro and Hanushek 1991, p. 156; Zaidi and Rake 2001, p. 18). Citro and Hanushek have noted that modular structures, if designed well, enable a model to respond to new policies quickly and flexibly (1991, p. 156).

A well structured modular dynamic model is therefore an extremely important aspect for the creation of APPSIM, and can mean the difference between a fast, easily edited model and a slow, rigid one. Considerable time and planning should be taken into designing the structure and interactions between the modules within APPSIM and considerable thought given to the ways in which the model will be used, not only in the present, but for future purposes.

### 4.3 Alignment

The ability to align the micro output to benchmark macro estimates has emerged as a crucial component of many models in the past few years. Alignment is one area where there has been substantial methodological work undertaken in the past decade, resulting in the development of an international consensus about the need for alignment. Today, ‘almost all existing dynamic microsimulation models are adjusted to align to external projections of aggregate or group variables when used for policy analysis’ (Anderson 2001, p. 2-6).

Aligning the micro values produced by dynamic models with known or projected macro aggregates usually involves some modification of model estimates. Whilst this modification does change aggregate outputs of the model, it generally doesn’t change the distributions, preserving the microeconomic content (Anderson 2001, p. 2-6).

The earlier attempt within DYNAMOD to build a linked economic macro-micro model failed and dynamic population models have subsequently usually adopted simpler strategies, such as forcing summed unemployment rates from the microdata to align with an exogenously specified aggregate unemployment rate. While there is increasing interest internationally in building much more sophisticated macro-micro linkages (Frederiksen et al. 2007; Bourguignon and Spadaro 2006), such work is unlikely to be achievable within the limited time and budget available for APPSIM.

While it may be important to align the model results with macro aggregates, it also has to be appreciated that these benchmarks are usually themselves also only estimates. For example, some demographers in Australia posit significantly different fertility rates in the future to those calculated by the ABS (for example, see Booth
2004). It is clear that the APPSIM model has to have the facility to align its estimates with those produced by an official organisation such as the Australian Bureau of Statistics, as this will give the model more credibility and broader acceptance within the policy environment. However, the flexibility of choosing alternative benchmarks is also required.

### 4.4 Relationships

There are two choices between the type of model to be used to establish the relationships between individual units in the dynamic microsimulation process – either an open or a closed population. ‘Closed’ populations are those where the model does not allow any other individuals to enter apart from overseas migration and new babies. Consequently, relationships such as marriage can only happen between two individuals that exist within the model — and a matchmaking procedure needs to be executed within the model to pair individuals up. That is, in completely closed models, the extra individuals needed to form crucial relationships cannot be sought from outside the model. The alternative, ‘Open’ population models, such as LifePaths in Canada, create extra individuals from outside of the model base (and, interestingly, as noted earlier, the SAGE model has opted for a mix of ‘closed’ marriage but ‘open’ other relationships).

Each model choice comes with inherent advantages and disadvantages. Closed models are easier to align, but require more computational power — while Open models provide greater flexibility but are less easily understood by users. It has been noted by a number of researchers that closed populations usually require more computational power. The researchers suggest that the focus on reducing the computing requirements of the matchmaking process may be taking resources away from other areas of the model. However, Closed models have the benefit of an easier alignment with macro aggregates (O’Donoghue 2002, p. 15). O’Donoghue has noted the advantage of Open models being that ‘simulations for individuals (and their immediate families) can be run independently of other individuals’, reducing model run times (2002, p. 15). The bulk of dynamic models that exist today (see for example, DYNAMOD, MOSART, and SESIM) use Closed models, mostly because of the ease of aligning the micro populations with macro aggregates.

### 4.5 Time Frame

There are two time frames to consider when developing a dynamic microsimulation model. The first is that of model duration — that is, from what point in time does the
model begin and end? The second time frame to consider is that of when to make changes to the population: should it be done discretely (with no real connection between time and the event), or should changes be made continuously (by linking events through time).

**Model duration**

When the model starts and finishes can be an important factor for validation of the model and output. Having a start date in the past rather than starting from today enables the model to be validated against historical data. This approach has been used by a number of models for exactly this purpose (see for example, CORSIM, DYNAMOD and DYNACAN). For example, an Australian model could use the 1986 census data and project forward to 2006 and be able to compare accurately the model’s projections with actual historical benchmarks over the 20 years to 2006. Zaidi and Rake have noted that models that have a longer overlap time period are generally given more credibility (2001, p. 20).

**Discrete or Continuous time**

Another very important time issue is when to make changes to the characteristics of the population. The vast majority of dynamic microsimulation models use discrete time frames, where changes in the model are normally made annually.

Discrete time models use transition probabilities in order to calculate changes of state and the modeller implements an ordered process for the different changes that need to occur based on presumed dependency structures. Discrete time is heavily reliant on knowledge about causality relationships and, once a particular sequence of events has been chosen, they cannot be changed. Some events, such as having to be born before being able to experience death, are very simple. However, most are complex, and dependency structures often differ amongst generations.

In continuous-time models, the time to each event is computed using survival functions. Dependency between processes may be implemented by means of a hierarchy in which one type of event, e.g. the birth of a child, censors the time to another type of event, e.g. labour market status change. The occurrence of the first type of event triggers the re-computation of the time to the next event of the second type. Output from continuous-time models is usually in the form of event histories for individuals or larger units of analysis. Continuous-time simulation has certain
theoretical advantages, but implementation is more difficult, and model operation less transparent to the user, than for discrete-time (Scott et al, 2003, p. 5).

The majority of dynamic microsimulation models use a discrete time process to age the population, due to the complexities involved in continuous time applications. There are some exceptions to this rule, such as the Canadian LifePaths model, which has distinguished itself from other models by adopting a continuous time frame, and is widely used by Statistics Canada. As Gribble explains, the use of continuous time ‘means that sub-annual events (e.g. persons whose employment follows a six-month cycle) can be accurately represented’ and ‘allows a more accurate representation of longer period quantities of interest (such as life expectancy or lifetime duration in various states), which are not restricted to integer values the way they typically are in discrete time models. Perhaps more importantly, the use of continuous time allows a more accurate representation of cause and behaviour … in continuous time, the equations that drive transitions correspond to actual behaviour of individuals whereas in discrete time the equations describe the changes that occur between two snapshots taken a year apart’ (2000, p. 385).

A major decision for the APPSIM team is to determine what type of time strategy will be used to move the population through time. Whilst continuous time processes appear to be the optimum theoretical choice, they are accompanied by inherent complexities which add to run-times and take away from transparency and user friendliness. As Zaidi and Rake also observe, ‘the estimation of competing risks and survival functions place very high requirements on data which are rarely matched by the actual data available’ (2001, p. 20). Choosing a discrete time process currently appears to have emerged as the norm amongst dynamic population modellers.

## 5 Model Performance

### 5.1 Computational Requirements

Dynamic microsimulation models are complex and computationally intensive. In the past, the computer requirements to handle these features have been major obstacles to the widespread acceptance and use of microsimulation. However, advances in technology and reductions in component costs over the last decade have had a significant impact on these obstacles (Caldwell 2006). Most modern desktop computers now have the memory and computing ‘grunt’ to produce timely
outcomes from a typical dynamic microsimulation model. This means the focus no longer relates mainly to the power and ability of the hardware but, rather, the ease of design, maintenance and user interface.

Despite the advances, the type of computing platform chosen will still determine many factors of the model, including run-time, user friendliness, and the form of output. King and Bækgaard have commented that, as favourable as computer efficiency may be, ‘there is a balance to be obtained between computer efficiency and a range of other model priorities such as transparency, flexibility, and the capacity for user input’ (1997, p. 10).

With computation efficiency no longer being the driving force, the use of object-oriented programming (OOP) in the design can be considered. OOP offers a range of advantages over a traditional design but is inefficient as it has a large computing overhead. While previously the overhead would have resulted in options such as OOP not being considered, the pace of technical advance now allows its advantages to be exploited.

**User Interface**

The user interface is critical in terms of user acceptance and marketability. However, Zaidi and Rake stress that there is no need to spend valuable resources on a customised interface as long as the input and output is easily imported and exported to existing well-known computing packages (2001, p. 20). There may be no need to spend time and resources on developing a complex user interface, when there already exist well-recognised and widely used computer packages that can produce the same results.

### 5.2 Validation and error detection

Measuring how the model results fare against real world outcomes is an important part of the dynamic modelling process. Incorporating validation techniques into the modelling process enables this measurement of the strength and accuracy of the model to take place and for errors to be found and attended to. Validating the model is not a simple task — and O’Donoghue has noted that ‘one of the major perceived problems of dynamic models is the fact that insufficient effort has been placed on validation matters’ (2001, p. 17).

Checking the extent to which the model aligns with macro aggregates, and choosing a past date to start the model, as discussed above in Section 4, are both ways to help achieve validation.
De-bugging computer code and conducting sensitivity tests are other ways in which a model can be validated. Debugging codes and fixing errors takes a considerable amount of time and resources, and it has been recommended that automatic de-bugging processes such as those used for CORSIM be implemented in order to shorten this process (Zaidi and Rake 2001, p. 21). Sensitivity testing involves viewing the impact of the results produced by the model when changes are made to underlying assumptions or parameters. It creates more confidence in the validity of the model by reducing errors (or, rather, accounting for them), when parameters cannot be accurately measured.

Validation of the model is an important part of the development of APPSIM. Choosing methodologies and designing procedures for validation should be an important focus of the project.

6 Conclusions

This literature review has made it clear that the construction of a reliable dynamic population microsimulation model for use in social policy formulation is a very demanding multi-year project. Indeed, the degree of effort involved seems more akin to the large scale multi-million dollar projects that occur in the natural sciences. In the social sciences, such large projects are relatively unusual — and many social scientists would not have extensive experience in managing projects of this scale and time span. In summary, construction of a dynamic population microsimulation model remains a demanding task!

Previous research into dynamic microsimulation modelling has suggested that the reason some earlier modelling efforts have foundered is because the designs were too grandiose; the structures did not provide for sufficient modularisation; and/or the documentation was inadequate to permit easy updating or adaptation of model components. This is in addition to the daunting data and other technical problems associated with dynamic population microsimulation models. While in the past the capacities of computing hardware used to create major problems for dynamic models, today that obstacle at least has been largely resolved.

From the many dynamic microsimulation models developed, we now know that models must have clear objectives, be user friendly, produce timely output, and be transparent and well-documented. We know that the choice of the base data is critical and that process of merging and imputation of data for the base data requires careful consideration. We also know that a number of models have failed over the longer term because they could not be maintained. To address this, in addition to the
documentation mentioned above, the design must be flexible, using a modular approach and ‘quarantining’ key parameters into separate sections. Finally, for acceptance by policy makers and the public, the outcomes need to align with external benchmark data.

In addition, international and earlier Australian experience has pointed to the risks of models being ‘too complex, too soon’, suggesting that the goal of the first version of a dynamic population model should be to construct a functioning model that is as simple as possible, with the aim of creating valuable deliverables for clients that can be developed progressively and enhanced over time.

The international experience has also indicated that the institutional framework within which dynamic models are developed is important for determining their long-term survival. Sustained funding from government appears to be required to maintain dynamic models, given the sheer size and complexity of the task — while academic input helps to generate innovation and provide ideas about new directions and applications. Overall, this suggests that a long-term partnership between academia and government will be required for a dynamic population model to first become and then remain part of the established modelling infrastructure in Australia. Considerable effort will have to be expended by both parties on understanding the needs of the other for APPSIM to become a well-used part of the policy analyst’s toolkit in Australia in the future.
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