



Dynamic Microsimulation Models: A Review and Some Lessons for SAGE

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Editorial note

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Dynamic Microsimulation Models: A Review and Some Lessons for SAGE

Abstract

This paper reviews an extensive range of dynamic microsimulation models from across Europe, North America and Australia. The paper draws from this review lessons that should be learnt by anyone about to embark on the process of building a dynamic microsimulation model. In focusing on key design and implementation issues, the review thus constitutes a preliminary stage in the development of the SAGE research group's own microsimulation model.

1. Introduction

1.1 Microsimulation modelling introduced

Microsimulation modelling as a tool of social scientific inquiry has been in existence since the 1950s, although for various reasons, including constraints of computing power, it only entered widespread usage much later. Microsimulation models involve the generation of data on social or economic units (e.g., persons, households or firms). Frequently, such units are drawn from survey based microdata. By taking the individual unit as the basis of the modelling work, microsimulation allows for the analysis of the distribution of resources across different groups (e.g., elderly vs. non-elderly people). This micro-level focus thus distinguishes microsimulation models from other modelling work that operates with groups or cells, or aims to simulate the economy as a whole (i.e. through the construction of General Equilibrium Models). Further, unlike modelling where a typical or median case is the standard of analysis, microsimulation models open up a much richer vein of research by enabling the exploration of heterogeneity and diversity within the simulated population.

Microsimulation has proven to be a particularly useful tool for policy analysis. According to Citro and Hanushek "The stock in trade of policy analysis is the production of answers to a series of 'what if' questions" (Citro and Hanushek 1991: 72). By operating beyond the bounds of available data, microsimulation models are uniquely placed to answer such 'What if..?' questions about social and economic policy scenarios and may also be used to 'play God' with individuals' lifecourses in order to analyse the impact of specific lifetime events (Falkingham and Lessof 1992; Rake 2000). In addition, where models operate prospectively (i.e. involve projections into the future), questions may be posed about the future profile of individuals. This is particularly important in capturing the full distributional impact of some policies, specifically pension policy, whose full effects take a considerable amount of time to filter through.

Microsimulation models fall on a continuum. At one end, static tax-benefit models examine the immediate impact of a policy change. Such models do not attempt to incorporate behavioural change, and are used principally to calculate the impact of institutional changes in the tax and benefit system. Without discounting the merits of static models,¹ our focus in this paper will be on the other end of the continuum, namely on dynamic microsimulation

¹ For an excellent survey of static microsimulation models in Europe, see Sutherland (1995).

models. Dynamic models are concerned to incorporate behavioural response as well as simulating the policy environment. While the dynamic models reviewed here vary in a great number of respects, they share a common concern with extending the time frame of analysis beyond the short or immediate term. They may, therefore, be able to offer us a unique perspective on the lifecourse by exploring the lifetime impact of social and economic policies as well as examining the impact of discrete events over the longer term. In addition, unlike static models, dynamic models are able to operate prospectively and, as a result, play an important role in informing social scientific thinking about the future.

1.2 Adding a dynamic element to the model

Adding a dynamic element into a microsimulation model requires that changes in characteristics or behaviour be applied either to an individual case, groups of cases or to the model as a whole. These changes are commonly referred to as the ‘ageing’ of a case. There are, in fact, two approaches to such ageing – static and dynamic.

‘Static ageing’ involves the re-weighting of the microdata base in such a way that the characteristics of the model individuals are brought into line with an external data source. For example, labour force participation rates in time $t+1$ are given by external data and microdata are re-weighted to align the model with the external source. By contrast, ‘dynamic ageing’ simulates the attributes of each person at time $t+1$ using the attributes at time t . Such dynamic ageing involves the application of a behavioural equation with, for example, the aid of the Monte Carlo process. Thus, to model labour force participation change from one year to the next for persons of certain attributes, we will first calculate the probability of labour force participation rate (using e.g., logit regressions or hazard rates). Next, we draw a random number for each unit that is uniformly distributed between 0 and 1. If this number is smaller than the estimated probability of labour force participation, we assign the labour force participation to that individual unit, otherwise the person will be assumed to be out of the labour force. The attributes of the unit in question will determine whether the labour force participation is on full-time or part-time basis. Once an entry to the labour force is projected, the wage will be generated using the estimated wage equation for persons of the same attributes.

This simple example points out a rather important distinction between the two kinds of models. ‘Static ageing’ brings a sample into line with external estimates at one point in time, ignoring the processes that generated individual observations in the sample. This requires that such external estimates exist (clearly an impossibility if the model is a prospective one) and where they do exist are accurate. ‘Dynamic ageing’, on the other hand, is concerned to generate underlying social processes. In light of this distinction, it is clear that ‘dynamic ageing’ is the process which opens up the greatest opportunities for basic social science research, in addition to addressing policy concerns (Caldwell, 1996). In reality, however, most models also use a form of ‘static ageing’ in their alignment procedures.

An additional distinction needs to be drawn between deterministic and stochastic processes within dynamic modelling. In a deterministic model, the relationships are fully determined by the parameters defined within the model. A stochastic model, on the other hand, incorporates random processes, either to reflect the random nature of the underlying relationship or to account for random influences due to incomplete model specification. Most dynamic microsimulation models in the social policy make use of a combination of stochastic and deterministic simulation processes.

1.3 The scope and purpose of this review

The purpose of this paper is to outline some salient features of microsimulation models that are, or have been, used internationally in order to draw lessons for future users and builders of such models. While every attempt has been made to make the review comprehensive, it is not an exhaustive itinerary of all dynamic microsimulation models. Rather models are covered where there is sufficient documentation, and if they have unique and interesting features that merit review. Table 1 details the models that are currently operational and presents their key features.

The review that follows is informed by our desire to answer, where information permits, a number of questions about each model. These are:

- What processes are parameterised in the model? What data is this parameterisation based on?
- How comprehensive is the model overall?
- How is the model structured? If modularised, how do modules inter-relate?
- Is there a model of the macro-economy? If so, how is it integrated?
- Are events modelled in discrete or continuous time?
- Over what time frame does the model operate?
- What base data was chosen and what informed that choice?
- What procedures are used to align the model?
- How is the model validated and what sensitivity tests are used?
- Has the model avoided producing a ‘black box’?
- What are the advantages and limitations of each model’s approach?

The remainder of this review is structured as follows. Section 2 comprises a review of selected dynamic microsimulation models currently operating internationally (a detailed itinerary of the models being provided in Appendix A). Section 3 summarises the lessons drawn from the modelling exercises of existing models for future model builders (such as the SAGE team). Section 4 concludes.

Table 1. An overview of existing dynamic microsimulation models

Name of the DMM	Country	Construction time	Nature of initial database	Event simulation or state simulation	Continuous or discrete time	Closed or open model	Alignment
DYNAMOD-2*	Australia	1999-2000	1/1000 sample from the 1986 census	Combination of the two (ie event simulation for fertility, mortality, marriage and disability; state simulation for other events)	Combination of the two (ie most demographic and labour force events are simulated using monthly time unit, whereas education and earnings using one-year as the time unit).	Closed	Yes (users can specify key macroeconomic indicators (such as fertility rates, disability and mortality rates) for the purpose of alignment)
HARDING model	Australia	1990	Hypothetical sample of 2000 males and 2000 females born in 1985 (a <i>cohort</i> model)	State simulation	Discrete	Closed	No
FAMSIM	Austria (prototype developed with an aim to extend it to other EU countries)	1996-1997	The prototype version used 3,700 women from the European Family and Fertility Survey	State simulation	Discrete	Closed	No
LIFEPATHS*	Canada	Late 1980s to the present	Synthetic database of numerous birth-cohorts (an <i>overlapping cohort</i> model)	Event simulation	Continuous	Open	Yes
DYNACAN	Canada	Completed in 1998	The Public Use Microdata Files of the 1971 Canadian census	State simulation	Discrete	Closed	Yes

DESTINIE*	France	Late 1990s	The 1991 Financial Asset Survey	State simulation	Discrete	Closed	No
NEDYMAS	Netherlands	Completed in 1994	Synthetic cross-section population created using the 1947 census for birth cohorts of 1930-1960	State simulation	Discrete	Closed	Yes
MOSART3*	Norway	1996-present (construction of MOSART1 started in 1988)	12% sample of Norwegian population in 1993, derived from official register data	State simulation	Discrete (simulations are carried out in one-year steps)	Closed	Yes
SESIM	Sweden	Currently under construction (initial version was presented with a name EDMOD)	Sample of 30,000 individuals of Swedish population in 1992 (extracted from the HINK survey)	State simulation?	Discrete?	Closed?	No?
MICROHUS	Sweden	1992	The 1984 HUS-income distribution database which is representative of Swedish population below the age of 75	State simulation	Continuous	Closed	No
PENSIM*	UK	1990	Combination of three sample surveys	Event simulation for labour market status	Near-continuous (to the nearest month)	Closed (no simulation for family structure or migration)	Yes
PENSIM2	UK	Currently under construction	LLMDB ? (LLMDB is 1% sample of NI records)	A combination of the two?	A combination of the two?	Closed?	Yes?
LIFEMOD	UK	1990	4000 individuals born in 1985	State simulation	Discrete	Closed	No

DYNASIM2*	USA	Late 1980s (the original DYNASIM was constructed during 1969-1975)	March 1973 Current Population Survey with direct matches of individuals to the Social Security Administration's earnings histories.	State simulation	Discrete	Closed	Yes
CORSIM*	USA	1.0 1987-1990 2.0 1990-1994 3.0 1994-1999 4.0 1999-present	1/1000 sample of 1960 census	State simulation	Discrete	Closed	Yes
PRISM	USA	1990	28,000 adults from March 1978, the March and May 1979 Current Population Surveys	State simulation	Discrete	Closed	Yes
MINT	USA	Completed in 1999	Census Bureau's Survey of Income and Participation (SIPP) for 1990, 1991, 1992 and 1993 panels (only birth cohorts 1946-60)	State simulation	Discrete	Closed	Yes?

* These models are reviewed in detail in Section 2.

Source:

King *et al.* (1999) for DYNAMOD-2; Lutz (1997) for FAMSIM; INSEE (1999) for DESTINIE; Nelissen (1994) for NEDYMAS; Gribble (1997) for LifePaths;

Morrison (1997) for DYNACAN; Klevmarken and Olovsson (1996) for MICROHUS; Strategic Forecasting (2001) for CORSIM;

Wertheimer *et al.* (1986) for DYNASIM; Harding (1993) for HARDING model; Curry (1996) for PENSIM; Ericson and Hussenius (1998) for SESIM.

2. A review of selected dynamic microsimulation models

2.1 DYNASIM: the pioneering dynamic microsimulation model for USA

The Dynamic Simulation of Income Model (DYNASIM) was amongst the first micro models to adopt the dynamic microanalytic simulation approach. It was developed by Guy Orcutt and other researchers in the early 1970s at the Urban Institute in Washington, D.C. (and maintained at the University of Michigan and the US Social Security Administration). The first version of the model (Orcutt et al., 1976) consisted of behavioural relationships for leaving home, divorce, birth, death, marriage and remarriage, disability, education, location, wage rate, labour force participation, hours in the labour force, unemployment, earnings, social security, other pensions, unemployment compensations and welfare programs. All these modules were included in a single model and were executed for each person every year. The base sample was processed three times for every year of simulation, and processing of individuals within the base sample made heavy use of random access files. Mainly due to such operating characteristics of the model, the DYNASIM model became impractical to use (Mot, 1992).

The second version, DYNASIM2, was subsequently developed and improved upon the operating characteristics and other features of the original model. In some cases the modules of the original model were transferred without change, but in most cases they were updated or totally re-specified and re-estimated. One significant improvement with respect to the operation of the model was that the simulation process was subdivided into two smaller models: the Family and Earnings History model (FEH) and the Job and Benefit History model (JBH). The FEH processes the full sample once for each year of simulation. The JBH model, on the other hand, processes the synthetic family and earnings history file generated by the FEH. Thus, the base sample is processed only once for the entire process of simulation. Moreover, the processing of individuals in the base sample is sequential which required minimal use of random access files. Notably, this subdivision of the model has improved the operation of the model but at the same time it has prevented interdependencies between the events/characteristics (Fredriksen, 1998). Both versions of the model used alignments to force the model's aggregate predictions to match up with external forecasts, worked as closed models, employed discrete time dynamic processes (with time unit being a single year) and operated on mainframe computers.

We focus on DYNASIM2 for our review in this paper, taking Wertheimer et al. (1986) as the main source of our information. The operation of DYNASIM2 was divided into four basic components:

- (1) The first component was the specification of the programmed functions which determines the annual micro-level outcomes of the events simulated by the model. The functions range from simple probability tables to highly complex functions based on regression analysis.
- (2) The second component was the formulation of the initial database in the required format.
- (3) The third component was an arrangement of the time series databank derived from external sources and used to steer the aggregate path of the micro-level outcomes.

(4) The final operating component was the user specified commands that include such elements as the base year of the simulations, the years for which histories are to be accumulated, which time series data are to be used as inputs to the model and which time series are to be generated by the model as outputs and which adjustment factors are to be employed in adjusting the number of events and their rate of change over time.

One of the crucial elements of the first component was the specification and programming of events that were to be modelled in DYNASIM2. Table A.1 of Appendix A outlines these events. As mentioned above, the simulation process was subdivided into the Family and Earnings History model and the Job and Benefit History model. The FEH model simulated demographic behaviour, annual labour force behaviour and federal income and payroll taxes. The output of the FEH model was a set of longitudinal demographic and labour force histories of each person present in the base sample and these histories were used as the input for all simulations carried out in the JBH model. The JBH model augmented the life histories generated by the FEH model and simulated additional variables. The JBH model simulated job change, industry, pension coverage, social security and private pension benefits and retirement age. The output generated by the JBH model can be processed like any longitudinal study of a real population.

The second component specified the initial database. DYNASIM2 takes as its initial database the March 1973 Current Population Survey with direct matches of individuals to the Social Security Administration's earnings histories. The requirement for the base survey has been a combination of family and individual attributes for each unit. Variables that were not present in the base survey were imputed. The most notable imputed variables were the number of hours worked annually and the fraction of labour force hours spent unemployed. The survey files are rearranged in nuclear families which became the basic unit of analysis of the FEH model.

Within the third component of the model, the aggregate outcomes of the DYNASIM2 model were aligned so that they can match selected aggregate trends based on macro-models and official government projections. A time-series databank was used for this purpose. The time series data was generally macroeconomic and demographic series in the form of 'adjustment terms' or 'scaling factors'. The final probability of the appropriate labour force or demographic event occurring were aligned by multiplying with these scaling factors. When these adjustments were made, the model determined the distribution among families and persons with different characteristics, and the exogenous control totals determined the aggregate number of events and their rate of change over time.

One crucial lesson that one can learn from the experience of DYNASIM modellers is that the subdivision of model into smaller modules is important. This aspect of dynamic microsimulation modelling may have become less critical given advances in the computer science, but it still 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.

2.2 CORSIM, the first PC-based dynamic microsimulation model (USA)

The CORSIM project began in 1987 and was originally based at Cornell University, USA. The CORSIM model has been much influenced by the content and design of DYNASIM and DYNASIM2. The model has gone through extensive updating since the completion of its first version in 1990 and is now running in its fourth generation. We review this latest version of CORSIM (i.e., Version 4.0, released in early 2000) which is based in the firm Strategic Forecasting, a New-York-based policy research firm. CORSIM has been instrumental in assisting the US Social Security Administration in their Social Security Reform Analysis.

The working of CORSIM can be divided into three components which are similar to the four basic components of DYNASIM2 (as mentioned above). They are:

- (1) The assembling of the initial database: This involves preparation of dataset into a single hierarchical database in the format required by the simulation component of the model. This component includes all imputations that one needs to carry out for the initial database.
- (2) Running the CORSIM simulations: This involves simulation of demographic and economic outcomes for the lifecourse of the base population, including those relevant for Social Security contributions and benefits. This component also includes the process of alignment and variance reduction. The outcome of the run of simulations is produced in the form of one file per simulated year.
- (3) Producing the CORSIM outputs: This component produces the user-specified information about families and individuals after the simulation run. This output is in addition to the annual cross-sectional files produced in the second component.

The base microdata for CORSIM is the 1960 Public Use Microdata Survey. This database is a one-per-thousand representative sample of families (and individuals) drawn from the 1960 US Census. This dataset consists of about 180,000 persons (70,000 families). All persons are identified in the aggregate unit of their family, whereas the unattached individuals are treated as single person families. The database also contains information on earnings corresponding to the 1959 calendar year. The most important imputation made in the data was the imputation of earnings histories back to the 1930s so as to obtain full history of social security contributions. Disability status in 1960 is also imputed. The educational attainment variable available in the Census was converted to the variable used in the education module.

Within the second component, CORSIM first ages the data for each individual unit (persons and families) in one-year steps up to the present, using Monte Carlo simulation. In this process, the simulated data has also been validated and aligned using the available external data. Next, it projects the sample into the future, going as far as 2090 for some projections. By starting from as early as 1960, CORSIM allows for the analysis of consequences of policy experiments over historical periods (from 1960 to the present) as well as in future time (from present to the future).

The ageing of data is achieved by a set of behavioural modules that seek to capture real life ageing processes of persons and families in the US. CORSIM, therefore, generates a synthetic longitudinal dataset of persons and families included in the base dataset. The modules included in CORSIM represent a diverse set of life course processes, and they are executed in the following order:

- 1) Internal migration (between states)
- 2) Net immigration to the US
- 3) Mortality
- 4) Fertility
- 5) Ageing (for those who survive, incrementing by one year)
- 6) Marriage (including remarriage) -- subdivided into two sub-modules
 - a) Entry of men and women into marriage pool
 - b) Marriage market (matching specific men and women as couples)
- 7) Divorce (including termination of common-law unions)
- 8) Leaving home (with no return once left)
- 9) Education (including education obtained in old age)
- 10) Disability (including rehabilitation)
- 11) Earnings -- subdivided into three sub-modules
 - a) Labour force participation
 - b) Total wages
 - c) Weeks worked
- 12) Housing
- 13) Wealth
- 14) Old Age, Survivors and Disability Insurance

Table A.2 in Appendix A outlines events that are included in these modules. The table also outlines subgroups for which events are separately modelled, determinants of the events and data used for estimation and alignment. Hundreds of stochastic equations and dozens of deterministic algorithms are used to represent these complex life events. Altogether, the model makes use of about 35 equation-based processes and about 25 rule-based processes, having over 5,000 parameters in both kinds of modules.

The CORSIM operating environment for Version 4.0 consists of a dual-processor 400 MHz Pentium II machine running parallelized code, 512 megabytes of RAM, and a fast hard disk. Most of the model's components are written in ANSI Standard C, and run under the Linux operating system. However, the model is portable to other operating systems, such as Windows or Windows NT. Depending upon the research interests the user may use only the demographic module or include other modules in the running of the model.

The fact that CORSIM starts with the 1960 population provides an opportunity to modellers to check how the estimated micro-equations representing life processes perform in predicting over the period between 1960 and the present. This empirical validation allows CORSIM modellers to estimate a set of alignment or benchmarking factors. This is a very desirable feature of a dynamic simulation model, since one of the ways the credibility of any model can be judged is how well it replicates the existing trends.

One unique feature of the operation of CORSIM is that it includes in its working an elaborate debugging mechanism. The debugger automatically calculates simulated means for all input and output variables for each equation in the model, so that the bugs can be discovered and traced at the source.

CORSIM has included a wide variety of modules in the model, and therefore has an enormous potential. New model builders will have to take careful account of available research resources before committing to building a CORSIM type model. This leads to one simple and rather useful conclusion that the model builders should have clarity in their

objectives and should aim to include modules that are relevant to the objective of modelling exercise. CORSIM also sets a laudable tradition of sharing the modelling knowledge across wider audience, and at least two models (DYNACAN in Canada and SVERIGE in Norway) use the CORSIM codes as their starting point. This possibility of sharing codes has allowed other model builders to ‘not reinvent the wheel’ while embarking on the task of building a dynamic microsimulation model.

2.3 DYNAMOD, the NATSEM dynamic microsimulation model (Australia)

DYNAMOD is the dynamic model of the National Centre for Social and Economic Modelling (NATSEM) at the University of Canberra, Australia. The model aims to provide empirical injections to a range of policy debates, in particular issues concerning education and earnings profile of students.

The working version of the model came under the name DYNAMOD-2, although most of what was planned in the construction of the original version is retained in DYNAMOD-2. We focus on the content and design of DYNAMOD-2 for our view in this paper, using King et al. (1999a) and Antcliff (1993) as the principal references. It should be noted here that the DYNAMOD-2 model is not deemed as an endpoint as yet, instead it is referred to as a stage in the construction of an Australian dynamic microsimulation model.

The base microdata for DYNAMOD-2 is one-per-hundred sample file from the 1986 census. This base dataset consists of approximately 150,000 persons. The preparation of the base dataset involved deletion and addition of cases, as well as isolation of cases which restricts their use in the model. Moreover, some characteristics of the chosen sample were imputed using other data sources. These characteristics are State of residence, disability status, level of current education, earnings and number of variables describing people’s family, education and labour force histories. Notably, the data from 1986 census is preferred over the recent censuses in 1991 and 1996 mainly for the fact that the use of the 1986 database provides the opportunity to build up historical data in the simulation prior to projection from the present to the future. Moreover, the data from the recent censuses can be used to check and align the output of DYNAMOD-2 (see King et al. (1999b) for further details).

Census data is preferred over alternative datasets, (e.g., the Income Distribution Survey) as it gives a more accurate representation of the population in the base year. However, this sample does not include detailed information on income or retrospective information on employment, family and earning history. Clearly, in this way, the accuracy of demographic information and the sample representativeness of the base survey is given more importance compared to e.g., availability of the income data in the survey. It is not clear, however, whether the model is portable enough to use a different base dataset, such as a more recent census or the Income Distribution Survey.

In order to obtain a high degree of computational efficiency and user friendliness, the DYNAMOD project followed the DYNASIM2 approach and split the simulation of the synthetic population from the simulation for policy analysis. This split has resulted in a self-contained population simulator, referred to as PopSim, and a potentially large number of independent and tailor made policy analysis modules using the output of PopSim as input. PopSim is designed to generate population projection over a period of up to 50 years and the analysis module would be tailored to the needs of users covering areas such as health services, superannuation, social security, taxation, student loans and household wealth.

DYNAMOD-2 is essentially the part conceived of as PopSim, although for some applications (e.g., projection of education and earnings profile of students) it also includes the analysis module. This coverage of the DYNAMOD-2 model reflects the initial objective of the model that was the analysis of student loans.

PopSim runs at the individual person-level and models the following modules:

- 1) Demographics
- 2) Education
- 3) Labour market
- 4) Earnings

Table A.3 in Appendix A outlines the life course events in each of these modules. Two distinguishing attributes of DYNAMOD-2 are the use of pseudo-continuous time, using month instead of a year as the time unit, and survival functions. Table A.3 also shows that not all events are simulated with a monthly time unit, and both survival functions and transition probabilities are employed to age individuals through their life. Most demographic events as well as the labour force activity are simulated with a monthly time unit, whereas education and earnings are based on one-year as the time unit. Survival functions are used to simulate fertility, mortality, couple formation and dissolution and disability.

Survival functions predict the hypothetical realisation times for the duration time before the occurrence of the event. In the first instance, this approach generates the times until occurrence for all modelled events that an individual could potentially experience. The times are stochastically generated, taking account of the individual's particular characteristics at time t_0 . An individual is then aged to the point in time when the first event is predicted to occur, say T . At T , this event is recorded as history and will censor all other events that vary with that change of status. The change in status will then trigger a recalculation of the predicted times for the events that depend upon the altered state of the individual in T . In effect, a new possible future is created for that person each time he or she experiences an event (Antcliff 1993). In theory, this system of censoring and triggering events takes a better account of full complexity present in our life than the use of annual transition probabilities as followed in most other microsimulation models. It should be noted here that DYNAMOD-2, by using the survival function approach, adopts the simulation approach in which the life-span of each individual is aged in one pass (referred to as longitudinal simulation), whereas the approaches adopted in DYNASIM2 and CORSIM are principally cross-sectional simulation (i.e., each individual is aged for one year at a time).

Initially the DYNAMOD project intended to include a stand-alone macroeconomic model that will supply parameters to, and receive feedback from, the microsimulation processes. However, this idea was abandoned in favour of a facility that allows users to specify key macroeconomic indicators (such as fertility rates, disability and mortality rates). This change in the design places more emphasis on the user flexibility and as a result DYNAMOD-2 is much more flexible than that envisaged in the original design.

2.4 PENSIM, the dynamic microsimulation model for the UK

The PENSIM model was built to project incomes of future pensioners, in order to inform policymakers for policies on income security in old age. PENSIM was first developed by Hancock et al. (1992). The model has gone through substantial amount of development work since 1992 in the Analytical Services Division of the Department of Social Security (DSS). The DSS is at present busy in a major overhaul of the model, updating PENSIM to PENSIM-2. Below we briefly review the current working version of PENSIM, using Curry (1996) as the main reference.

The initial database for PENSIM was derived from a combination of three different sample surveys. For individuals aged between 55 and 69, the 1988 Survey of Retirement and Retirement Plans (RS) was used. This survey provided detailed information on previous work and pension contributions, as well as general information on family structure. For individuals aged 70 or more, the 1988 Family Expenditure Survey (FES) was used. This source provided the required information on current pension income of retired people. The base data for individuals aged less than 55 was obtained from another sample survey: the Social Change and Economic Life Initiative (SCELI), which included information about previous work but no information was available on pension contributions. The combined dataset built a base of over 5,000 benefit units (over 2000 from RS, in excess of 1,000 from FES and over 1,500 from SCELI). Since this sample of initial population was rather small, additional cases were generated by replicating the RS and the SCELI cases. The replication meant generation of more than one life cycle for each case of the RS and the SCELI, keeping base characteristics as in 1988. This led to an effective sample size of approximately 20,000 for the initial database.

As outlined in Table A.4 of Appendix A, the modules included in PENSIM simulated mainly the work history and the pension and the National Insurance contributions of non-retired individuals in the base dataset. This included the duration of work episodes from 1988 to the perspective date of retirement, and level and growth of earnings in each employment state. The survival rate is employed for simulating duration in a labour market state and the time unit used is near-continuous (to the nearest month). The possible labour market states were full-time employment, part-time employment, self-employment, unemployment and non-participation.

Next, pension contribution records were simulated. For all FES cases (aged 70 or more) there was no need to simulate past contributions since data on the actual pension income was available. For all those who originated from the RS (aged 55 to 69), the base dataset already had recorded pension contributions till 1988. For later dates of RS cases (provided individuals had not retired) and for all SCELI cases pension contributions were simulated on the basis of likelihood of membership of different types of pension schemes. The National Insurance contributions to Basic State Pension, SERPS and the Graduated Pension Benefits were calculated using the historical, current and future NI rules as provided by a user worksheet.

The model also allowed for a receipt of NI credits, allowing for the Home Responsibilities Act. The recipients of NI credits were randomly determined, using Monte-Carlo methods, from amongst all those eligible. The entitlement to Basic State Pension, SERPS and Graduated Pension and Private Pensions were calculated by including amounts for Guaranteed Minimum Pensions (GMP) and Protected Rights (PR) from contracted out

schemes. Earnings from work after retirement are also simulated by randomly selecting cases and making sure that the selected number of cases match with the proportion in the 1992 FES working after retirement. Income from investments is also simulated for all RS and SCOLI cases. The calculation of tax and income related benefits (income support and housing benefits) were facilitated by a user-specified worksheet. The mortality rate was simulated based on age and sex.

The DSS intends to update PENSIM by also including demographic module as well as modules simulating disability status, retirement decisions and institutionalisation. The new version of PENSIM will also make use of a more solid initial database. One strong candidate is the Lifetime Labour Market Database (LLMDB) which is 1% sample of National Insurance records. The LLMDB may have to be matched to benefit records in DSS and possibly to the Family Resources Survey in order to obtain other necessary variables in the base dataset. This dataset is also a rich source from which to compute duration in different employment states and the probability of transition between states. The new model is likely to make use of the discrete time since the LLMDB is more appropriate for annual transition probabilities. Moreover, it is possible that the PENSIM2 model will use aggregate macroeconomic trends to align the forecasts generated by the model.

2.5 MOSART, the dynamic microsimulation model for Norway

The MOSART model was developed by Statistics Norway to investigate policy options in meeting the challenge to the financing of public expenditures in the future (Fredriksen 1998). MOSART has the potential for the analysis of the development of population size and composition, and the consequences for the educational level, labour supply and public pension benefits.

The first version of MOSART was developed from 1988 to 1990 and included only death, fertility, immigration, marriage, education and labour force participation in its simulations. The main aim of this model was to provide the demographically driven projections of labour force and educational attainment. This version of the model was of little use for analysing public policies mainly because of limited nature of its contents. The simulation of pension benefits was included in the second version of the model in 1992, and this led to an increasing use of the model to address the concerns about the sustainability of the social security system in Norway. MOSART is currently available in its third version which differs from the second version with respect to the inclusion of the module of household formation and addition of rehabilitation in the simulation of disability. In addition, there have been various technical changes, such as pension benefits are computed during the simulation rather than at the end.

The base dataset of the model consists of 12 per cent of the Norwegian population in 1993 (constituting more than 500 000 observations). This initial population is derived from a combination of numerous register data from Statistics Norway and the National Insurance Administration. It is in fact equivalent to a longitudinal database that contains rich retrospective information on many variables dating back to 1985 (labour income and pension entitlements data dates back to 1967). The transition probabilities for disability, rehabilitation and labour force participation have all been estimated on the panel data of the initial population. While most information in the initial population is derived from registers, it was still necessary to impute some characteristics. All events and consequences linked with

occurrence or non-occurrence of an event is simulated in the model in one year steps (the so-called cross-sectional simulation). The model is run forward from 1990 to 2050.

Table A.5 in Appendix A describes the life course events simulated in MOSART. These events are mainly represented by transition matrices or multi-nomial logit relationships which are assumed constant over time (the only exception to this steady state scenario is observed for the mortality rate that is assumed to decrease over time). The projections from the model are therefore conditional on behaviour remaining the same during the simulation period as observed during a short time period, often only between two years.

One strong feature of MOSART is that it is based on a very reliable initial database. The transition probabilities are also estimated using the same database. According to Fredriksen (1998), the theoretical foundation for the transition probabilities is rather weak, and includes fewer interdependencies. However, the model is under continuous revision and it is likely that very soon we will see a model with better attributes.

2.6 LifePaths, the dynamic microsimulation model of Statistics Canada

LifePaths is the model developed by the research team in Statistics Canada which has been busy for over a decade developing various static and dynamic microsimulation models for Canada. During this time, Statistics Canada has also developed a generic simulation language (ModGen) which can be used to generate models that can be seen as variants of LifePaths.

There are three important features in which LifePaths distinguished itself from other existing models:

- 1) The LifePaths model operates in continuous time,
- 2) The LifePaths model is an open model, and
- 3) The LifePaths model uses a synthetic initial database that is created using various overlapping birth cohorts.

The benefit of using continuous rather than discrete time is that an event can occur at any instant during the lifetime of an individual, and therefore allows modellers to more accurately represent causation and behaviour. Continuous time also helps in modelling certain outcomes, such as earnings, in a more reliable manner. In the LifePaths model, annual earnings are potentially the outcome of numerous sub-annual events, such as the loss of one job, waiting period of job search in which earnings were zero, followed by a take up of a new job at a different rate of pay. As opposed to this, the use of discrete time takes snapshots of situation at the end of each period.

The LifePaths model runs as an open model in which new individuals are generated in case one of the individuals in the initial population is selected to form marital or common-law union. As opposed to this, a closed model, such as CORSIM, generates new units only when a baby is born to individuals in the initial population. The open model has the advantage that the simulation of individuals in the initial database can be run independently of each other. The interaction of individuals in the closed model within the marriage market requires greater computer resources which can restrict the smooth running of the model.

The LifePaths model generates full life history of individuals of different birth cohorts. The model starts with a synthetic initial database as opposed to models that use as an initial

database a static cross-section of individuals and families from census data (as in CORSIM) or a longitudinal administrative record (as in MOSART). The advantage in using the synthetic initial database is that each life history produced by LifePaths is internally consistent throughout the lifetime (Gribble, 1997). The distribution of dates of birth for different time periods makes LifePaths an overlapping cohorts model that allows both cross-sectional (in a single time period) and longitudinal analysis of the Canadian population.

LifePaths contains modules that represent a number of demographic and economic events. The demographic module includes equations that simulate pregnancy, birth, common-law union formation, marriage, separation, divorce and mortality. The education module contains a highly detailed progress towards various levels of educational attainment. The employment module simulates entry into and exit from the state of employment. The earnings module projects earnings trajectories of lifetime hourly earnings. These earnings are combined with the simulated results of hours worked per day to produce daily earnings rate. Since the model makes use of a continuous time, it is easier to allow for interactions between various modules.

Researchers at Statistics Canada also developed a general-purpose microsimulation environment, called Model Generator (ModGen). This environment provides a common code-base for modellers which they can use to generate microsimulation models that are variants of LifePaths. Statistics Canada used this environment to generate several daughter models. One example is the Population Health Model (POHEM) which uses the demographic module of LifePaths but replaces the mortality equations with a highly detailed model of morbidity and mortality. POHEM is used to empirically evaluate competing health care scenarios. The other variants of LifePaths includes Student Loan model, Time-Use model and an Inter-Generational Accounting model.

LifePaths appears to offer a modelling strategy of a contrasting nature to the modelling strategy offered by DYNASIM and CORSIM. The choice of initial database as a synthetic overlapping birth cohort offers opportunities in cases where a strong initial database cannot be found (say no census data is available and sampling surveys may not be fully representative of different groups of population). The LifePaths's choice of the continuous time is definitely desirable from theoretical point of view, although the use of continuous time puts heavy demand on the underlying data and computer resources.

2.7 DESTINIE, a dynamic microsimulation model for France

DESTINIE was developed in the late 1990s as an analytical tool for pension policy which produces pension projections from 1992-2040. Because public and private sector pension schemes operate on such distinct rules, the current model assumes that all model individuals are engaged in the private sector. There are, however, aspirations to extend the modelling to incorporate the public sector in the near future. The model draws its base data from the 1991 Financial Asset Survey. In creating the based data, complex family forms were selected out of the survey in order to simplify the modelling processes. Following this, cases from the Financial Assets Survey were duplicated so that the survey matched the age and sex profile of the French population. Model individuals were then selected from this re-weighted sample, with the result that some 37,000 individuals (forming approximately 15,000 households) were used as base data for DESTINIE (INSEE 1999: 18-20). Given that the Financial Assets Survey contained only limited longitudinal data, a retrospective simulation of career paths was performed for all those active in the labour market between 1945 and 1991.

DESTINIE is modularised, operating with a demographic, labour market and earnings submodules, followed by a module simulating the tax and benefit system and then a final module which calculates net household income (Bonnet and Mahieu 2000: 178; INSEE 1999: 26). The model works on an annual basis, cycling through the submodules in sequence. A simple wage equation (which includes schooling and duration in the labour market as explanatory variables) is applied for each sex, with the residual randomised to create some earnings mobility. While age affect subsequent risks of demographic transitions and transitions into early retirement, it is not clear whether other characteristics in year t (such as income and job tenure) feed into the risks calculated in $t+1$.

The model is closed and along with all such closed models, creates a marriage market from within the model. An innovation of DESTINIE is to operate a matching process in cases where the Financial Asset Survey identifies family members who are not present in the household. This creates fictitious family links between members of the sample according to the recorded characteristics of the 'missing' family members. Macro economic parameters (such as economic growth and the rate of unemployment) are specified *prior* to each simulation run and operate to constrain certain probabilities. Thus a base case of 'reasonable' assumptions, may be compared with alternative assumptions about the macro economy. DESTINIE has overcome problems of a highly complex pension system and limited options for base data to produce an operational model, much utilised for policy analysis. There are, however, concerns that the choice of base data, and its manipulation to increase representativeness, might have introduced quite considerable bias into the model. In addition, the model tends to reduce the complexity of some socio-economic processes, such as wages, and runs the risk thereby of producing results that do not do full justice to the heterogeneity of actual experience.

3. Lessons learned from existing models

3.1 The parameterisation of underlying processes and the comprehensiveness of existing models

A principal source of variation within the models reviewed here is in the processes that have been parameterised in building the model. Models vary according to the task they were designed for, and the comprehensiveness of the model produced. Building dynamic microsimulation models has proved to be rather expensive and cumbersome. This has had the result that the pragmatic concerns of producing a functioning model may have limited the comprehensiveness of the final model. It remains a distant possibility that a single dynamic microsimulation model will be exhaustive in responding to all issues in public policymaking. It is, in addition, not clear that comprehensiveness is necessarily a desirable feature of any model. Greater complexity increases the risk that the model functions as a ‘black box’ in which it is very difficult to separate out the impact of individual processes. Most models are, therefore, built with a specific purpose in mind. The effectiveness and suitability of a dynamic microsimulation model should therefore be judged in relation to the purpose for which the model is built.

Lesson 1: A successful model requires clear objectives. From these objectives, model builders can identify the processes which are essential to the model and design a developmental strategy for the model, whereby other processes are incorporated over the longer term.

In addition to the time and modelling constraints that limit the range of parameters that may be included, there are considerable constraints on the data which is available for the estimation of parameters. It is therefore important that modellers engage in the broader social science community in order to exert influence on national strategies for data collection. Where national data is unavailable modellers are obliged either to omit a process or to make ‘reasonable’ estimates on the basis of international data and evidence on the process in question. Given that this is a ‘make-do’ solution, these parts of the model might be subject to particularly thorough sensitivity analysis. In addition, data in use is constantly changing as new waves of a survey are released and new surveys are initiated. Model builders should be in a position to capitalise on these developments.

Lesson 2: Model builders need to be sensitive to the shortcomings of data used in estimating model parameters, and need to feed their concerns into the national data strategy. Sensitivity analysis is essential in gauging the impact of particular parameters on the output of the model as a whole.

Lesson 3: The model should be flexible enough to incorporate the most recent and robust data. Key parameters should be held separately from the functioning of the model so that they can be changed with minimum cost.

Many of the models reviewed have produced their richest analysis in the distribution of earnings, income and pensions. One of SAGE’s concerns is that the broadest possible understanding of financial resources is incorporated in the model. This means that analysis will need to extend to wealth and housing assets, both of which have major implications for the experience of later life. Modelling work in this area is limited (although see Keister 2000) and data notoriously unreliable. A preliminary task of the SAGE team will be to review

evidence on asset accumulation, and to assess the viability of including this process as part of the core model. In addition, SAGE is concerned with modelling the interaction between financial resources, health, disability and long-term care. This holistic view of later life is essential to understand the complexity of social phenomena affecting the ageing process. Understanding this complexity provides an ambitious and innovative agenda for the SAGE project.

Lesson 4: Innovation in model building may be desirable, although it involves taking risks, with parts of the model building process having unknown rewards and pitfalls.

3.2 Links between microsimulation modelling and modelling the macro economy

The models presented here offer different options with regards to linking in the macro economy. Traditional approaches have been either to take macroeconomic indicators from external sources (including official projections that operate for prospective models) or to operate with a steady-state assumption (e.g. adopt the prevailing economic conditions and project them forward). Most models have also made provision for sensitivity analysis of alternative ‘optimistic’ and ‘pessimistic’ scenarios of the developments in the macro economy.

It would be useful also to construct a macroeconomic model that operated alongside, and interacted with, the microsimulation model. Thus, the macroeconomic model is designed to provide input to and receive feedback from the microsimulation model. However, as the experience of DYNAMOD shows, model builders may prefer to allow flexibility in specifying macroeconomic aggregates.

Lesson 5: Running a model of the macroeconomy that can interact with a microsimulation model raises serious questions about feasibility and costs (particularly in terms of transparency of the model). Simpler solutions, in the form of taking macroeconomic indicators from external sources and performing sensitivity analysis may be preferable in the short/medium term.

3.3 The treatment of time and the timeframe of the models

Any dynamic model has built into it a particular treatment of time. Models typically run through a ‘cycle’ on an annual basis, with individuals ‘aged’ once a year (e.g. a number changes in status are generated at one point in time). Calculating annual transition probabilities has shortcomings in that it divides time into discrete chunks rather than treating it as a continuous phenomenon (as mentioned in our review of the LifePaths model). Thus, intermediate transitions, such as an employment status that lasts for less than a year, are not allowed. More importantly, the complexity and interdependence of events cannot always be modelled using such an approach. The annual cycle of events through which individuals pass has to be ordered, with the ordering implying a certain line of causality between events. In LIFEMOD, for example, family formation was modelled before labour force participation, and as the model-builders comment, a consequence was that:

while a woman's labour force status can depend on the number of children she has and on her marital status, it cannot also influence the probability of the woman having a child in any year. The ordering of the modules necessarily involves making assumptions about the direction of causality in relationships between variables. (Falkingham and Lessof 1992: 9).

An alternative approach is to model life events using a survival function in which the risk of experiencing a range of events is assessed according to the characteristics of the individual (Antcliff, 1993: 18-26). This is the approach used in the DYNAMOD-2 model for some selected events, and clearly offers a *theoretically* preferable approach as compared to the traditional approach of annual transition probabilities. However, this approach has considerable practical limitations. The estimation of competing risks and survival functions place very high requirements on data which are rarely matched by the actual data available. Furthermore, given current data constraints, it is questionable whether modelling continuous time would bring with it significant rewards. In the British case, much data is collected using an annual timeframe such that the model would *de facto* operate on the basis of annual transition probabilities.

Lesson 6: Limits of data, and the difficulties of modelling 'continuous time' mean that a traditional structure may be preferable. However, it may bring dividends to introduce innovations into a traditional structure. For example, the feasibility of looking at certain events on a shorter timescale (e.g. monthly) should be explored. In addition, the possibilities of, and potential rewards from, estimating joint probabilities, hazard rates and survival functions should be examined.

The second time dimension refers to the period over which models operate. A historical start date, as pursued in CORSIM, may be chosen as a way of validating the model (see below) while end dates are frequently dictated by concerns about particular demographic transitions or by a desire to capture the full impact of a particular policy. As the literature widely acknowledges, the credibility of any model is stretched the longer the time period it operates over.

Lesson 7: Producing output that covers the short and the medium term as well as the longer term is an essential way of ensuring that the model remains credible. In setting the end date of the model attention needs to be paid to known demographic transitions and the life-span of policy reforms in order to show its full impact.

3.4 Base data

For model builders who have decided not to generate data synthetically, much care is taken over the choice of the base data. The representativeness of the initial database for different segments of population carries huge importance, since initial bias is likely to be magnified during the simulation period. Notably, DYNAMOD researchers have opted for an initial database that has very little information on duration of events of interest, on income and on other variables of interest but that is representative of the population. CORSIM researchers have also shown similar preferences in the choice of the initial database, though it seems the census data in the US offers more than the data from the Australian census. Synthetic matching may be used to compensate for the lack of information in the base survey, although attention needs to be paid to the limitations of such a technique and the possible bias it

introduces. As an alternative, model builders have not shied away from using more than one survey to form the initial database. The original PENSIM used three surveys to form the base survey. However, it appears that a single base data set will be preferred in the development of PENSIM2.

Lesson 8: The choice of base data is an early, important decision in the model building process. The representativeness of base data is a principal concern here, with the use matching techniques to be one way of compensating for the shortage of variables in such datasets.

3.5 Model validation: de-bugging, sensitivity tests and alignment

Model validation is a broad term incorporating the techniques available to modellers that ensure the internal validity of models as well as their credibility among the broader policy and social scientific community. Given this broad aspiration, it is not surprising that some disagreement exists about the techniques best suited for validating models.

A model will be internally invalid where it has eliminated programming bugs and coding errors that affect the output. The process of debugging can be a lengthy one, with bugs often revealing themselves only when the model has been asked to perform a particular function. An automatic process of debugging can be introduced into the model (as is done in CORSIM).

Error may also be introduced into the model where parameters are not or *cannot* be accurately specified (e.g. future macroeconomic conditions). Sensitivity analysis is one way of assessing the effects, although not the accuracy, of parameter estimates. Each simulation run is principally an experiment that generates a single numerical solution based on a particular set of model specifications. This specific solution is taken as a realisation of the more general solution of the model. The sensitivity analysis will show how change in specifications will generate different results and a different realisation of the general result. This may include showing sensitivity with respect to the choice of equations and their estimates and by including and excluding certain life path processes. For instance, there is no simple way to disentangle age, cohort and period effect from the model. However, it is possible to state explicitly the assumptions on which the model is based and explore the impact of varying assumptions on the model specifications and outcomes. Sensitivity analysis does not itself enable a more accurate specification of the underlying parameters but may enable the researchers to specify a ‘funnel of doubt’ (e.g. a range of estimates bounded by an upper and lower estimations).

Lesson 9: Internal validity requires first that the model is scrutinised for coding errors. Automatic processes of debugging should be followed as far as possible. Sensitivity analysis is a way of estimating the impact of specific parameters on model output and is a first step in validating a model.

Broader issues of validity can refer to the comprehensiveness of the model (What key processes have been omitted and with what effect on results?) and the lines of causality that the particular sequencing of modules imply. In short, does the model produce a credible picture of the social world? The obvious way to answer the broadest questions of validity is to compare model output with external estimates. An additional, although discrete, step is to

align the model's output with such estimates. While various in actual operationalisation, all alignment processes operate to constrain the outputs of the model in order to bring them into line with external data.

Where a model starts at a historical period, there are obvious ways of aligning the model. For example, CORSIM started their modelling using a 1960 dataset and in this way, the potential for all kinds of alignment was opened up. It could be argued that these alignment processes give the model credibility through historical accuracy, and that this credibility has some spill over into the prospective modelling work. The fact that accuracy in producing historical data and accuracy in projections are not equivalent means that CORSIM's alignment process does not stop here. While no external data exists on the future, government agencies and public bodies frequently produce forecasts, and a process of alignment to these forecasts also takes place. Models that work prospectively only, such as DYNAMOD or DESTINIE, may be disadvantaged in not gaining the credibility of this dual (historical and prospective) process of alignment, although clearly there are trade-offs between the costs and benefits of performing such retrospective modelling.

An additional level of complexity derives from the fact that where models are constructed from submodules, there are multiple sources of error and many levels at which validation can occur. Multiple-module validation appears to be a relatively less travelled route, and can offer additional insights into the working of a microsimulation model. Caldwell puts this issue as follows:

When the interaction among modules produces additional information on sources of error in the overall model, the benefit for the analyst is additional leverage with which to improve the model as a whole, as well as its individual components. (Caldwell 1996: 515).

Lesson 10: Policy makers and scientific researchers alike are likely to raise questions about the validity of any dynamic microsimulation model. Attention needs to be paid to how model outputs compare with external estimates, and to the various techniques of alignment. Operating a retrospective microsimulation model is one attractive, although not complete, way of establishing its validity.

3.6 Transparency

An important aspiration for any new microsimulation project is to avoid creating a model that operates as a black box e.g. where processes are hidden within the operation of the model, making it impossible to identify why the model is producing particular outcomes. Put positively, a microsimulation model should be transparent. A primary concern is that a model be transparent to its builders and core user group (often drawn from the research project itself). Clear and thorough documentation of the model is a necessary, although not sufficient, condition for transparency. The transparency of the model may be increased where provision is made for easily interpretable, intermediate output (i.e. produced for each submodule or for each year on which the model runs). A secondary concern, is that the model be transparent to a broader, possibly external audience. The 'user friendliness' of the model counts here. However, engaging in a process of explaining the model, and its limitations, may turn out to be a more complex process than a menu based front-end for the model.

Lesson 11: Thorough and clear documentation is key to a successful, and long lived model. If possible, provision should be made for producing automated documentation to reduce this burden on model builders. The model should produce intermediate output that allows for the identification of the processes driving model results. Transparency to a broader audience is a secondary concern, and is a more complex requirement than simply providing a user friendly front-end to the model.

3.7 Computational efficiency

With cheaper, faster and more powerful computers, the demands of computational efficiency become less pressing by the day. Nevertheless, attention needs to be paid to the appropriateness and flexibility of the programming language used, and how best to handle the slowest parts of the process, namely accessing the database and writing output to external databases.

Lesson 12: A computing strategy needs to be developed alongside the microsimulation strategy. Alternative strategies may be tested in the development of a simple prototype model.

4. Conclusions

Having conducted a review of existing models, the prospect of building a dynamic microsimulation model may seem even more daunting. However, what the review demonstrates is that there is now a critical mass of international expertise in this area. Many models are now in their second, third or even later generations. Each new model reflects a considerable amount of learning that followed from building the previous model. The challenge for SAGE in developing a new microsimulation model for Britain, is to capitalise on this expertise, and to learn from the successes (and failures) of model building across the international community.

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APPENDIX A
Tables for Section 2

TABLE A.1 Life course events (and their determinants) modelled in DYNASIM2

Life course events / characteristic modelled in DYNASIM2	Determinants/covariates
<i>FAMILY AND EARNINGS HISTORY MODEL:</i>	
Death: Married women 45-64	Age, race, sex, marital status, education, number of children
Death: others	Age, race, sex, marital status, education
Birth	Age, marital status, number of children, race, education
Multiple birth	Race
Sex of new-born	Race
Marriage: age 18-29	Age, race, sex, previous marital status, income, education, region, weeks worked, hourly wage, asset income, welfare, unemployment compensation
Marriage: others	Age, race, sex, previous marital status
Mate matching	Difference in age, difference in education
Leaving home	Age, race, sex
Divorce	Distribution over time of expected divorces for this marriage cohort, age at marriage, education, previous marital status, presence of young children, weeks worked, wages
Education	Race, sex, age, years at current school level, parents education
Onset of disability	Age, race, sex, marital status
Recovery from disability	Age, race, sex, marital status, education level
Labour force participation	Age, race, sex, education, South, disability, marital status, student, children, spouse earnings
Hours worked	Age, transfer income, expected wage, disability, marital status, children
Wage rate	Age, race, sex, education, South, disability, marital status, student
Unemployment and proportion of year unemployed	Age, race, sex, education, South, disability, marital status, children
Geographical mobility	
<i>JOB AND BENEFIT HISTORY MODEL:</i>	
Job change	Age, sex, tenure on current job, industry
Industry of new jobs	Sex, education, previous industry
Pension coverage	Sex, education, earnings level
Pension plan member	Age, tenure on job, FT or PT, sex
Type of pension coverage	Industry
Retirement eligibility	Age, industry, years of service, type of pension
Vesting	Industry
Benefit formula	Industry and type of pension coverage
Benefit plan constants	Benefit formula, industry, type of pension coverage
IRA plan participation	Sex, earnings
Retirement probability	Age, sex, disability, marital status, pension eligibility and amounts, social security eligibility and amounts, wage, earnings
Probability of re-entry in labour force after retirement	Age, disability, marital status, pension eligibility and amounts, social security eligibility and amounts, imputed wage

Source: Citro and Hanushek (1991); Wertheimer et al. (1986)

TABLE A.2 Life course events modelled in CORSIM, determinants of events, differential groups and data used for estimation, and meso-data used for alignment

Life course event / process modelled in CORSIM	Groups for which process is differentially specified (estimation technique)	Range of determinants (within group)	Data used for estimation	Meso-data for estimation, alignment (number of groups aligned annually)
<i>Individual Demographics</i>				
Fertility	30 groups (among women); on the basis of age, have child, marital status, race, work status (logistic model, with cohort-race specific parity cap on live births/woman)	age, $birth_{t-1}?$, $birth_{t-2}?$, duration of current marriage, earnings, family income, homeowner status, marital status, parity, schooling status, work status (F/T, P/T)	National Longitudinal Study (NLS): 1969-87	1.) Vital Statistics (28 groups; age-race-marital) 2.) SSA Total Fertility Rate
Sex of newborn	2 groups based on race			Vital Statistics
Mortality (Note: Mortality determines widowhood, orphanhood)	51 groups based on age, sex, race, marital status (logistic model)	age, birth place (US or other), education, employment status, family income, marital status	National Longitudinal Mortality Study: 1980-89	1.) Vital Statistics (88 groups; age-race-sex) 2.) SSA age-sex adjusted death rate
<i>Family Demographics</i>				
Enter marriage market for first time	20 groups based on race, schooling status, sex, weeks worked (logistic model)	age, age^2 , education, $\ln(\text{earnings})$, number of children, weeks worked	NLS: 1973-87	Census (16 groups; age-sex)
Matching within the marriage market	<i>all</i> non-related opposite-sex <i>pairs</i> in marriage market at t (logistic to estimate probability of match; highest joint ratings married, others return to market for possible marriage at t+1)	age difference, age difference*(1 if female older, 0 otherwise), $\text{abs}(\text{male's total income} - \text{female's total income})$, difference in education, interaction of labor force participation, male's education*(1 if older, 0 otherwise), racial interaction, state of residence, woman's number of children	Census: 1980 Public Use Micro Sample	none

Divorce	4 groups based on earning status of wife, presence of children under 18 (logistic model)	age difference, duration of union, husband's wages, race, wage advantage	Panel Study of Income Dynamics (PSID): 1968-87	National Center for Health Statistics data (14 groups; duration of marriage)
Child custody at death of parent(s)	2 groups based on age (rule-based algorithm)	no assignment if over age 18; adoption based upon state of residence if under age 18	none	none
Child custody at divorce of parents	2 groups based on age (rule-based, with random component for children of both parents)	each spouse's exclusive biological children accompany them; if equal ties to both parents, 90 percent probability to go to female parent	none	none
Leaving family of origin	8 groups based on age, race, school attendance, sex (logistic model for ages 14-29; mandatory at age 30)	age, have child, $\ln(\text{earnings}_{t-1})$, number of parents, parents' education, presence of younger sibling, sex, student status _{t-2} , work status	High School and Beyond (HSB): 1980-86	none
Net immigration	112 groups based on age, marital status, sex ("clone" existing family)	age, marital status, race, sex of head of household	Immigration statistics	SSA
Re-enter marriage market upon widowhood, divorce	7 groups based on age (under 60/61+), race, sex, widowed or divorced? (logistic model)	age, age ² , education, $\ln(\text{earnings})$, divorced (v. widowed), has child, $(1-\text{nowork}) * \log(\text{inc})$, weeks worked	PSID: 1968-87	NCHS data (26 groups; age-sex, divorced or widowed)
<i>Individual Social and Economic Attainments</i>				
Education: Grade attendance, completion	33 groups based on grade level (17 definitions, from pre-school to beyond third year graduate school), race, sex, schooling status (logistic model)	age, have child, living on own, marital status, parents' education, parents own home	HSB: 1980-86; NLS: 1979-87	1.) CPS (2 groups; sex) 2.) ACTS, Census, DOL

Work status (0/Part-Year/ Full-Year)	174 groups based age, have child, live with parents, marital status, race, sex, weeks worked _{t-1} =0, weeks worked _{t-1} >47 (probit model; after age 62, deterministically set to zero after two continuous years of non-participation)	age, education, have child, married _{t-1} ?, marital status, number of kids, percent unemployment, youngest child's age	PSID: 1972-87	1.) Census (35 groups; age-race-sex; children-marital for females) 2.) SSA coverage rate (2 groups; sex)
Number of weeks worked	58 groups based on age, have child, marital status, race, sex, weeks worked _t > 47, weeks worked _t ≤47 (OLS regression)	age, education, have child, married _{t-1} ?, number of kids, percent unemployment, youngest child's age	PSID: 1972-87	none
Weekly earnings rate	116 groups based on age, have child, marital status, race, sex, weeks worked _t , weeks worked _{t-1} (OLS regression, with lower threshold based on minimum wage legislation)	age, earnings _{t-1} , education, education*earnings, married _{t-1} , number of children, percent unemployment, youngest child's age	PSID: 1972-87	1.) Census, (70 groups; age-race-sex-FT/PT; for females, children-marital) 2.) NIPA
<i>Family Wealth (Generated every three years rather than annually)</i>				
Asset/Debt ownership (14 separate asset/debt types)	2 groups based on prior ownership status (logistic model)	age, education, family size, income, marital status, ownership status _{t-1} , race	Survey of Consumer Finances (SCF): 1983-86; to impute, Survey of Financial Characteristics of Consumers: 1962	1.) Estate Tax data (80 groups) 2.) SCF (70 groups) 3.) Flow of Funds data
Asset/Debt value	2 groups based on prior ownership status (OLS regressions)	age, asset value _{t-1} , education, family size, income, marital status, race		
Bequests and inheritances	2 groups based on death and divorce (rule-based algorithms)	more detailed algorithm under development for top wealth holders	Statistics of Income, IRS data	none
<i>Individual Taxes</i>				
OASI / DI contributions	2 groups based on Social Security coverage (rule-based algorithms)	coverage, earnings, year	law	none

<i>Individual Transfer Payments</i>				
DI Receipt (Social Security Disability Benefits)	Eligibility (function of age, coverage, earnings) (logistic for workers; deterministic for children, spouses)	age, age ² , change in total work hours _{t-1,t} , coverage, disability status, DI _{t-1} , earnings, education, homeowner, income, live alone, ln(asset income), marital disruption _{t-1,t} , marital status, race, sex, work hours _{t-1}	PSID: 1986-91	SSA Administrative data 1961-1995 (14 groups; age-sex)
DI benefit size	Person-specific (deterministic based on legal entitlement)	earnings, work/coverage history (t-1, t-2 . . . to maximum of t-46) of both worker, dependent (if relevant), year	law	none
Social Security Retirement Benefit Receipt timing	Eligibility (function of age, coverage, earnings), 2 groups among eligibles based on sex (logistic for workers; capped at age 70, when receipt is mandatory; deterministic for children, spouses)	age, change in work hours _{t-1,t} , coverage, earnings, education, homeowner, live alone, ln(asset income), ln(change in absolute value of income _{t-1,t}), marital disruption _{t-1,t} , marital status, race, sex, work hours	Survey of Income and Program Participation: 1990-93	SSA Administrative data (12 groups; age-sex)
Social Security Retirement Benefit size	Person-specific (deterministic based on legal entitlement)	earnings, retirement timing, work/ coverage history (t-1, t-2 . . . to maximum of t-50) of both worker, dependent (if relevant), year	law	none
Survivors' Benefit Receipt	Eligibility (function of age, coverage, earnings) of deceased parent/spouse (deterministic)	age, earnings, timing of parent/ spouse's death	none	none
Survivors' Benefit size	Person-specific (deterministic based on legal entitlement)	earnings, receipt timing, work/ coverage history (t-1, t-2 . . . to maximum of t-50) of both worker, dependent (if relevant), year	law	none
<i>Individual Health</i>				
Disability	1 group based on age (logistic model)	age, age ² , disability _{t-1} , education, homeowner status, live alone, ln(asset income), ln(change in absolute value of income _{t-1,t}), weeks worked, race, sex	PSID: 1986-1992	none
<i>Kinship Links</i>	3 groups based on parent-child, spouse, sibling	all determinants in fertility, family formation	1960 Census	none

Source: Fevreault and Caldwell (1999: 17-20).

Table A.3: Life course events modelled, method and time unit used, provision for flexibility and alignment used in DYNAMOD-2

Life course event modelled	Method	Frequency	Flexibility	Alignment
<i>Demographics:</i>				
Fertility	Survival functions	Monthly	users can specify future age-specific fertility rates	
Couple formation	Survival functions	Monthly		
Couple dissolution	Survival functions	Monthly		
Mortality	Survival functions	Monthly	user can specify mortality rates, and how mortality improvement will be shared by disabled and others	
Disability	Survival functions	Monthly		
Overseas immigration	adding new cases	Annual (distributed monthly)		Immigrant numbers and structure
Overseas emigration	deleting cases	Annual (distributed monthly)		emigrant numbers and structure
Young people leaving home	Transition probabilities	Annual		
<i>Education:</i>				
Education	Transition probabilities model for participation and progress	Annual		Key education progressions are aligned using targets
<i>Labour Force:</i>				
Labour force status	Transition probabilities between - employment - unemployment - inactive	Monthly		Labour force status outcomes are calibrated to align with exogenously-specified time series of unemployment and participation rates for males and females.

Hours of employment	Transition probabilities distinguishing between full-time and part-time employment	Monthly		
Employment for full-time students	Transition probabilities for any paid work during the year; given employment annual hours are estimated	Annual		
Earnings:				
Full-time students	Estimated hourly wage	Annual		- align earnings outcome to exogenously specified real earnings time profiles for 18 groups; - control the degree of variation in earnings over individuals' lives
Other than full-time students	Separate earnings estimations (24 in total) with a distinction between -full-time wage or salary -part-time wage or salary -self-employed	Annual		

Source: King *et al.* (1999).

TABLE A.4: Life course events modelled in PENSIM, dynamic microsimulation model for the UK

Life Course Event or Outcome Modelled	Groups for which process is differentially specified	Estimation Technique	Important explanatory variables	Micro + Macro data used for estimation
1. Length or Duration of individual work episodes (from the date of interview until the perspective date of retirement)	Duration is modelled for 8 distinct groups (i.e., FT males, FT females, PT, SE, unemployed Males, unemployed Females, inactive males and inactive females)	Censored Log Likelihood Function is estimated - censored for the fact that a work episode must finish before retirement.	Economic position, Age, Social class, Start date of work, Unemployment levels, Sex, Marital Status, Survey type, and Type of employer	SRRP/ SCELLI data on post-1970 work episodes.
2. Transition between employment states	5 employment states are identified (i.e., FT, PT, SE, unemployed and inactive). Transition equations are estimated separately for males and females	Multinomial Logit → no sensitivity analysis (a kind of validation)	Age, Previous employment state, Occupation type, Firm size, Marital Status, Switch to 1985 (?)	Post 1970 transitions in the SRRP /SCELLI data
3. Level (and growth) of earnings in each employment state	Earnings equation is calculated separately for 4 groups (i.e., FT males, FT females, PT and SE)	Ordinary Least Squares	Personal characteristics Industry and occupation Social class Earlier work history	
4. Pension contributions during the working life	<u>For SRRP cases</u> , recorded pension contributions till the interview date are used; for later dates of SRRP cases and <u>for SCELLI cases</u> pension contributions are generated on the basis of membership of different types of pension schemes.	User-defined input sheets are used, which gives the proportion of people in occupational and personal pension schemes, and the characteristics of a scheme for each work episode.	Pension scheme participation is distinguished between FT and PT workers, and by industry. Pension scheme characteristics are defined by whether a scheme is contracted in or out from SERPS, whether it is a DB or DC scheme, what level of contributions are made, how deferred pensions are revalued and how pension is indexed.	
5. NI contributions to Basic State Pension, SERPS and Graduated Pension Benefits	Historical, current and future NI rules, as provided by a user spreadsheet, are applied to generated earnings.	All pre-announced policy changes, (e.g., 1995 Pensions Act) have been incorporated in the current and future NI rules.		

6. Selection of recipients of NI credits (allowing for Home Responsibilities Act)	Recipients are randomly determined using Monte Carlo methods, from amongst the eligible population.			
7. Entitlement to Basic State Pension, SERPS, Graduated Pension and Private Pensions.	Final pension entitlements are calculated by including amounts for Guaranteed Minimum Pensions (GMP) and Protected Rights (PR) from contracted out schemes	Additions are made for those aged 80+		
8. Earnings from work after retirement	Randomly selecting cases to work after the retirement, and making sure that the selected number of cases matches with the proportion in the FES 1992 working after the retirement.	Level of earnings is determined from a normal distribution about the average of log annual earnings calculated from the FES 1992 (the level of earnings are therefore independent of earnings during work-life)		
9. Income from investments	<u>FES cases</u> : Recorded investment income is available <u>SRRP cases</u> : Capital accumulation factor is applied to the recorded amount of capital. Rate of return is used to determine investment income. <u>SCELI cases</u> : A capital sum is generated at the time of the interview, and a procedure same as for the SRRP cases is applied to determine final amount of capital and the investment income.	Capital accumulation factor takes account of re-investment and inheritance. Rate of return is based on social class.	<u>For SCELI cases</u> , the amount of capital sum is generated dependent upon the age. The amounts are generated so that the distribution of capital is identical to that in the 1992 FES. Each individual is first allocated to a capital band, according to probability, and then randomly generating an amount of capital within a band (derived from a normal distribution about the mid-point of the band).	
10. Tax and income related benefit calculations	Tax and benefit rates are provided by a user spreadsheet. First income tax liabilities are calculated, then income support and housing benefit entitlements.			
11. Year of death	Age and sex specific mortality rates are used.			

FT: Full-time; **PT**: Part-time; **SE**: self-employed; **DB**: defined benefit; **DC**: defined contribution
FES: Family Expenditure Survey; **SRRP**: Survey of Retirement and Retirement Plans; **SCELI**: Social Changes and Economic Life Initiative.

Table A.5: Life course events modelled in MOSART, dynamic microsimulation model for Norway

Event	Estimation methods and datasets used	Conditional upon
Net immigration	Exogenously imposed; 7000 per year; distribution by age, sex and marital status simulated using 1991-1995 data	Sex, age and marital status
Mortality	Derived from 1994-1995 data	Sex, age, marital status, educational attainment and disability pension
Transition between private and institutional households	Constant transition matrix	Age, sex, type of households
Leaving parental home	Constant transition matrix obtained using 1988 Family and Occupation Survey	Age and sex
Marriage and cohabitation	female dominant; constant transition matrix obtained using 1988 Family and Occupation Survey	women's age and women's household parity
Matching couples	Constant transition matrix obtained using 1988-89 data	Age of male partner depends on women's age
Couple dissolution	Constant transition matrix obtained using 1988 Family and Occupation Survey; Divorce: 1994 data	Women's age, divorce for separated couples depends upon women's age
Fertility	1995 data, implyign a Total Fertility Rate 1.86	Mother's age, number of children and age of youngest child
Educational activities	Observed 1987-rates	Sex, age and educational activities and attainment
Entry into disability pension or rehabilitation	Multi-nomial logit function (independent of time) estimated using the base data for the period 1985-1993	Sex, age, marital status, educational attainment, pension status and labour force participation
Transition to retirement	age 67 for all individuals	
Labour force participation and labour market earnings	Multi-nomial logit fuction (independent of time); levels of earnings given exogenously; labour force participation: 1993 level Labour market earnings: 1985-1988	Sex, age, children, marital status, age of youngest child, educational activities and attainment, pension status and previous year's labour force participation

Source: Fredriksen (1998), and Andreassen and Texman (1997).