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A METHODOLOGICAL SURVEY OF DYNAMIC MICROSIMULATION MODELS

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Abstract

More than 10 years ago O'Donoghue (2001) surveyed the dynamic microsimulation models that had been developed up to that point. However the 2000's have seen many of the barriers that existed for model development up until that point overcome. This paper surveys the development and practices in dynamic microsimulation over the past decade, and discusses the methodological challenges today. The paper provides an overview of the methodological choices made in more than 60 known dynamic microsimulation models and examines the advantages and disadvantages of different practices. In addition, this paper reviews the main progress made in the field and explores how future microsimulation models could evolve.

JEL Classification: C1 C5

Key Words: Dynamic Microsimulation, Survey

A METHODOLOGICAL SURVEY OF DYNAMIC MICROSIMULATION MODELS

I. Introduction

A dynamic microsimulation model is a model that simulates the behaviour of micro-units over time. Orcutt et al. (1961) described the first dynamic microsimulation model following the inspiration of Orcutt's (1957) article. Most dynamic microsimulation models that have developed in following decades trace a direct or indirect link back to this model. In this paper we shall review how the field has developed over the intervening decades.

Micro level data, such as data obtained from a household survey, is often chosen as the basis for social economic research. In order to evaluate certain impacts of public policies, e.g. the redistributive impact over the course of a lifetime, it is necessary to utilise a long panel dataset. In general, such datasets are not available, either because the analysis relates to the future, as in the case of pension forecasts, or because collected datasets do not cover sufficiently long time periods; therefore, analysts use dynamic microsimulation models to assist in their analysis, a concept which was initially suggested by Orcutt in 1957. Essentially, microsimulation is a tool to generate synthetic micro-unit based data, which can then be used to answer many "what-if" questions that, otherwise, cannot be answered.

Microsimulation models, as in the field of policy modelling, are usually categorised as "static" or "dynamic." Static models, e.g. EUROMOD (Mantovani *et al.*, 2007), are often arithmetic models that evaluate the immediate distributional impact upon individuals/households of possible policy changes. Dynamic models, e.g. DESTINIE, PENSIM, and SESIM (Bardaji *et al.*, 2003; Curry, 1996; Flood, 2007), extend the static model by allowing individuals to change their characteristics due to endogenous factors within the model (O'Donoghue, 2001). Although some static models, e.g. IZAΨMOD (Peichl *et al.*, 2010), also incorporate certain behaviour responses, this is usually limited to certain overnight effects. Dynamic microsimulation models in theory, could offer further insights as they can integrate long-term projections and time dependent behaviour simulations.

10 years ago O'Donoghue (2001a) surveyed the dynamic microsimulation models that had been developed up to that point. However the 2000's have seen many of the barriers that existed for model development up until that point overcome. Data collection projects such as the European Community Household Panel and the increased availability of longitudinal administrative data such as the Lifetime Labour Market Database in the UK have eliminated to some degree data constraints. A number of new model were developed in the past decade, for instance Pensim2 (Emmerson, 2004), IFS Model (Brewer *et al.*, 2007) and SAGE (Zaidi and Rake, 2001) models in UK, APPSIM in Australia (Harding, 2007b) and DESTINIE2 (Blanchet, 2009) in France etc. Meanwhile, a few generic software programmes have emerged, such as ModGen (Wolfson and Rowe, 1998), UMDBS (Sauerbier, 2002), GENESIS (Edwards, 2004) and LIAM (O'Donoghue, 2009), eliminating the need to create a model from scratch. It has allowed an internationalisation of the models with developments in Belgium (Dekkers and Belloni, 2009), Italy (Dekkers *et al.*, 2010), Canada (Spielauer, 2009), UK (Emmerson, 2004). Nevertheless, the decade has seen the demise of a number of models such as DYNACAN and CORSIM. The micro-econometric and micro-economic understandings of the processes that make up a dynamic microsimulation model have also greatly improved over this period. It is worth therefore in considering the progress made by the discipline over the past decade.

In this paper we shall describe the models developed, their uses and discusses some of the methodological choices faced. We then review the progress made by the discipline since the earliest models and suggest some directions for future development.

II. Overview of Models and their Uses

Dynamic microsimulation models can have many uses and this section provides an overview of the principle uses. Table 1 summarises many of the existing dynamic microsimulation models in terms of their main purpose, which covers projection, evaluating/designing public policies, inter-temporal behaviour studies, etc.

Following the introduction of the time dimension into dynamic microsimulation, these models are able to provide useful projections for the trend of socio-economic development under current policies. DYNASIM2/3 (Wertheimer *et al*., 1986; Favreault and Smith, 2004), APPSIM (Harding 2007b), the SfB3 population model (Galler and Wagner, 1986), DYNAMITE (Ando *et al*., 2000), SADNAP (Van Sonsbeek, 2009) and DESTINIE1/2 (Bonnet and Mahieu, 2000; Blanchet *et al*., 2009), have all been used for these purposes. In some cases, dynamic microsimulation models have been used as an input for macro models such as in the case of the MOSART (Andreassen and Solli , 2000), DYNASIM2 and DARMSTADT models.

Dynamic microsimulation models can also be used to evaluate the future performance of various long-term programmes such as pensions, educational financing, and health and long-term care, by analysing future cross-sectional data. The governmental models such as DYNCAN (Morrison, 2000), POLISIM (McKay, 2003), PENSIM2 (Emmerson, 2004), the Sfb3 models (Galler and Wagner, 1986), MOSART (Andreassen *et al*., 1996), PENMOD (Shiraishi, 2008) and SESIM (Ericson, and Hussenius, 1999; Klevmarken *et al*., 2007) have been extensively used for this purpose. The existence of baseline projections allows the design of a new public policy by simulating the effect of potential reforms. Models such as LIAM (O'Donoghue, 2009), PRISM (Kennell and Sheils, 1990), the Belgian dynamic model (Joyeaux *et al*., 1996), the SfB3 population model (Galler and Wagner, 1986), LIFEMOD (Falkingham and Johnson, 1995) and Begium MIDAS (Dekkers *et al*., 2010; Dekkers and Belloni, 2009), have all been used to look at pension reform. A number of models such as DYNAMOD, the SfB3 cohort model (Hain and Hellberger, 1986), LIFEMD (Harding, 1993), and SAGE (Zaidi and Scott, 2001) have been used to examine changes to education finance, whereby education costs are to be paid for over an individual's lifetime. Fölster (1997) used a microsimulation model to examine reforms to social insurance utilising personal savings accounts.

By using longitudinal information created from dynamic microsimulation models, researchers can study the inter-temporal processes and behaviours at both the aggregate and individual levels. For example, CORSIM (Keister, 2000), DYNAMOD (Baekgaard, 1998), and MIDAS (Stroombergen *et al*., 1995) have all been used to look at wealth accumulation. Models such as DESTINIE1/2, LIAM, LifePaths, and IFSIM have been used to examine intergenerational transfers (Rowe and Wolfson, 2000; Bonnet and Mahieu, 2000; Blanchet *et al*., 2009; Baroni *et al*., 2009; O'Donoghue, 2009), whilst FAMSIM (Lutz, 1997) has been used to study the demographic behaviour of women, and MICROHUS (Klevmarken and Olovsson, 1996) examined the impact of a tax-benefit system on labour market mobility. Models that simulate these processes can be used to design policies to combat these problems, for example DYNASIM, was used to study the effect of teenage childbearing, while CORSIM has been used to look at dental health within the US population (Brown *et al*., 1992). The models FEM and POHEM were designed to evaluate the evolution of the population's health status and its budget implications for the US and Canada (Eugenio, 2010; Will *et al*., 2001), whist the LifePaths modelling framework has been used in Canada to examine time use issues (Wolfson and Rowe, 1998).

By combining spatial information with dynamic microsimulation models, the model can then be used to predict the geographical trend of certain social economic activities. This type of model is usually referred to as a dynamic spatial microsimulation model and although spatial models can focus only on small areas, e.g. MOSES (Wu *et al*., 2008), there are a number of models that attempt to analyse policy changes at the national level. For instance, the SVERIGE model simulates a number of demographic processes for policy analysis in Sweden (Vencatasawmy *et al*., 1999; Holm *et al*., 2006), whilst the SMILE model (Ballas *et a*l., 2005a; O'Donoghue *et al*., 2011) analyses the impact of policy change and economic development on rural areas in Ireland. In addition to modelling economic policy, SimBritain (Ballas *et al.*, 2005b) looks at the evolution of health at the national level while models such as HouseMod (Phillips and Kelly, 2006) and SustainCity (Morand *et al.*, 2010) focus on the housing market within a dynamic setting.

Dynamic microsimulation models typically project samples of the population over time. If a full cross-section of the population is projected, then one can for example, examine future income distributions under different economic and demographic scenarios. DYNASIM2/3 (Wertheimer et al, 1986; Favreault and Smith, 2004), APPSIM (Harding 2007b), the SfB3 population model (Galler and Wagner, 1986), DYNAMITE (Ando *et al.*, 2000), SADNAP (Van Sonsbeek, 2009) and DESTINIE1/2 (Bonnet and Mahieu, 2000; Blanchet et.al, 2009) have been used for these purposes. These models typically utilise macro-models or forecasts to align their own projections. However, occasionally the opposite has occurred, where dynamic microsimulation models have been used as input into macro models as in the case of MOSART (Andreassen and Solli, 2000), DYNASIM2 and the DARMSTADT models.

Table 1 Uses of Dynamic Microsimulation Models

Model	*Country*	*Uses*
ANAC	Italy	Examines the effect of demographic changes on the Italian saving rate and the reform of the pension system
APPSIM	Australia	Designed to provide answers regarding the future distributional impact of policy change and other issues associated with policy responses to population ageing
BRALAMMO	Brazil	Models the Brazilian labour market for pension welfare analysis
CAPP_DYN	Italy	Analyses the long term redistributive effects of social policies
CBOLT	USA	Analyses potential reforms to federal entitlement programmes and quantifies the US nation's long-term fiscal challenges
CORSIM	USA	Models changes occurring within kinship networks, wealth accumulation, patterns of intergenerational mobility, the progressivity and the life course of the current social security system, as well as potential reforms, household wealth accumulation, health status, interstate migration, time and income allocation, and international collaborations
DEMOGEN	Canada	Models distributional and financial impact of proposals to include homemakers in the Canadian pension plan
DESTINIE I/II	France	Models public pensions and intergenerational transfers
DYNACAN	Canada	Models the Canada Pension Plan and its impact on the Canadian population
Dynamic Model	Ireland	Models inter-temporal issues relating to the degree of redistribution within the tax-benefit system
DYNAMIC TUSCAN	Italy	Simulates the demographic, social and economic characteristics of the Tuscan population
DYNAMITE	Italy	Models microeconomic issues and the impact of macroeconomic/institutional changes on the distribution of income
DYNAMOD I & II	Australia	Models life course policies such as superannuation, age, pensions and education, long-term issues within the labour market, health, aged care and housing policy, future characteristics of the population and the projected impact of policy changes
DYNASIM I & II	USA	Forecasts the population up to 2030 by employing different assumptions regarding demographic and economic scenarios, and analyses the cost of teenage childbearing to the public sector under alternative policy scenarios, also includes a link to a macro model

Model	*Country*	*Uses*
DYNASIM III	USA	Designed to analyse the long-term distributional consequences of retirement and ageing issues
FAMSIM	Austria	Models the demographic behaviour of young women
FEM	USA	A demographic and economic simulation model designed to predict the future costs and health status of the elderly and to explore what current trends or future shifts might imply for policy, developed by RAND
GAMEO	France	Analyses and assesses the consequences of various higher education policies
HARDING	Australia	Analysis of lifetime tax-transfer analysis, for analysis of policy concerning the Higher Education Contribution Scheme and redistributive impact of government health outlays over the lifetime of an individual
HouseMod	Australia	Simulates the impacts of different policy options at the small area level in Australia
IFSIM	Sweden	Studies intergenerational transfers and the interdependence between demography and the economy
IFS Model	UK	Studies pensioner poverty under a variety of alternative tax and benefit policies
INAHSIM	Japan	Simulates demographic and social evolution, able to simulate kinship relationships in detail
INFORM	UK	Developed for forecasting of benefit caseloads and combinations of receipt, designed to incorporate significant benefit reforms planned over the coming years, based entirely on administrative data
Italian Cohort	Italy	Analyses lifetime income distribution issues
Japanese Cohort	Japan	Looks at the impact on household savings of changes in demographic structure
LABORsim	Italy	Simulates the evolution of the labour force over future decades in Italy
LIAM	Ireland	Evaluates potential reforms to the Irish pensions system in terms of changes to life-cycle incomes
LIFEMOD	UK	Models the lifetime impact of a welfare state
LifePaths	Canada	Models health care treatments, student loans, time-use, public pensions and generational accounts
Long Term Care Model	UK	Models long term care reform options
Melbourne Cohort	Australia	Analyses income inequality in a lifetime context
MICROHUS	Sweden	Models dynamic effects of changes to the tax-benefit system on the income distribution and economic-demographic effects of immigration
MICSIM	Germany	Analyses German pension and tax reform
MiMESIS	Sweden	Evaluates Swedish Pension Reform
MIDAS	Multi	Analyses pension system and social security adequacy
MIDAS	New Zealand	Models wealth accumulation and distribution
MIND	Italy	Simulates the economic impact resulting from alternative values of the income growth rate and real interest rate
MINT	USA	Forecasts the distribution of income for the 1931-1960 birth cohorts in retirement, MINT5 extends to the 1926-2018 birth cohorts
MOSART 1/2/3	Norway	Models the future cost of pensions, undertakes micro level projections of population, education, labour supply and public pensions, incorporates overlapping-generations, models within a dynamic microsimulation framework

Model	*Country*	*Uses*
NEDYMAS	Netherlands	Models intergenerational equity and pension reform, the redistributive impact of social security schemes in a lifetime framework
PENMOD	Japan	Public pension system analysis
PENSIM	UK	Models the treatment of pensioners by the social security system across the income distribution
PENSIM2	UK	Estimates the future distribution of pensioner incomes to analyse the distributional effects of proposed changes to pension policy
PENSIM	USA	Analyses lifetime coverage and adequacy issues related to employer-sponsored pension plans in the USA.
Pensions Model	Belgium	Analyses and forecasts the medium term impact of a change to pension regulations
POHEM	Canada	A longitudinal microsimulation model of health and disease, it is used to compare competing health intervention alternatives within a framework that captures the effects of disease interactions
POLISIM	USA	Demographic-economic and social security projection for US social security administration
PRISM	USA	Evaluates public and private pensions
PSG	USA	Analyses the lifetime implications of social security policies for a large sample of people born in the same year
SADNAP	Netherlands	Evaluates the financial and economic implications of the problem of ageing
SAGE	UK	Dynamic demographic/tax model for the UK
SESIM	Sweden	Models budget and distributional impact of inter-temporal policy issues such as student grants, labour supply, savings decisions and pensions
SimBritain	UK	Simulates urban and regional populations within the UK
SMILE	Ireland	Population projections with spatial details for Ireland
Sfb3	Germany	Analyses pension reforms, the effect of shortening worker hours, distributional effects of education transfers
SIPEMM	Slovenia	A Slovenia Dynamic Microsimulation Model with the focus on pension system simulation
SustainCity	Multi	A dynamic model with a focus on land use simulations
SVERIGE	Sweden	Models human eco-dynamics (the impact of human cultural and economic systems on the environment)
Swedish Cohort	Sweden	Models the replacement of social insurance by personal savings accounts and the distribution of lifetime marginal effective tax rates
Tdymm	Italy	Analyses the Italian labour market and pension system, with a focus on pension adequacy and related distributional effects
XEcon	Canada	A model intended for theoretical exploration rather than practical empirical application (developed for the eXperimental Economy)

Model	*Country*	*Uses*

Sources: Andersson *et al*. (1992); Ando (1996); Ando and Nicoletti Altimari (1999); Ando *et al*. (2000); Antcliff *et al*. (1993, 1996); Baldini (1997); Ballas *et al*. (2005a, 2005b); Baroni *et al*. (2009); Blanchet *et al*. (2009); Bonnet and Mahieu (2000); Brewer *et al*. (2007); Caldwell *et al*. (2000); Citro and Hanushek (1991a, 1991b); Courtioux *et al*. (2008); Curry (1996); Dekkers and Belloni (2009); Emmerson *et al*. (2004), Ericson and Hussenius (1998, 1999); Falkingham and Lessof (1991); Favreault and Smith (2004); Fölster (1997); Fredriksen (1998); Galler and Wagner (1986); Gault (2009); Hain and Hellberger (1986); Hancock (2000); Hancock *et al*. (1992); Harding (1993); Harding (2007b); Holmer (2009); Holmer *et al*. (2001); Inagaki (2010); INSEE (1999); Joyeaux *et al*. (1996); Kelly and Percival (2009); King *et al*. (1999a,1999b); Klevmarken and Olovsson (1996); Leombruni (2006); Lutz (1997); Maitino (2009); Majcen (2011); Mazzaferro and Morciano (2008); McKay (2003); Morand *et al*. (2010); Morrison (2000); Nelissen (1996); O'Donoghue (2001b); O'Donoghue *et al.*(2009); Oharra *et al*. (2004); Osberg and Lethbridge (1996); Panis and Lillard (1999); Phillips and Kelly (2006); Pudney (1992); Pylkkänen (2000); Rowe and Wolfson (2000); Shiraishi (2008); Smith *et al*. (2007); Stroombergen *et al*. (1995); Tedeschi (2011); Toder *et al.* (1999); Troitzsch *et al.* (1996); Van de Ven (1998); Van Sonsbeek (2009); Vencatasawmy *et al*. (1999); Will (2001); Winder and Zhou (1999); Wolfson (1988); Zaidi and Rake (2001); Zaidi and Scott (2001); Zucchelli (2010); Zylberstajn *et al.* (2011)

Although Table 1 tries to cover as many known models as possible, it is nearly impossible to list all models as new ones are being developed every year. In addition, the list focuses more on the dynamic microsimulation models that are mainly used for social economic analyses at national level. Certain regional dynamic spatial models and transportation models are not included.

One can also tracks the development of models through a number of lineages. The original Orcutt Socio-economic System (Orcutt et al., 1961) led to DYNASIM described above, which in turn led to CORSIM which in turn led to POLISIM, DYNACAN and SVERIGE models. In parallel, large modelling developments in the 1970's took place in Sweden and Germany with current antecedents, while the LSE Welfare State programme of the 1980's and 1980's spawned the LIFEMOD, PENSIM, PENSIM2 and SAGEMOD models in the UK as well as the HARDING model in Australia and LIAM model in Ireland. Subsequently the HARDIING model led within the creation of NATSEM to a range of models in Australia, while the LIAM model has influenced a number of European models including the LIAM2 modelling framework. Separately to these largely related developments which have largely been closed, aligned models, Statistics Canada has developed a series of Lifepath/MODGEN based models based upon the original DEMOGEN that have traditionally been open and non-aligned.

All these powerful dynamic microsimulation models come with the cost of high complexity. Compared with static microsimulation, dynamic microsimulation is much more costly to develop and also has more issues with the methodologies used. This paper intends to discuss some of the methodological issues related to the construction of a dynamic microsimulation model, surveying current practice in the field around the world.

III. Methodological Issues – Part I

In this section, a number of methodological issues relating to the development of dynamic microsimulation models are discussed. There are many choices when constructing a dynamic microsimulation model and this paper discusses these choices and the pros and cons of different practices. Given the number of issues covered in the paper, the content is split into two parts; the first focuses more on general issues such as dataset and development, whilst the second pays more attention to the technical choices addressed in the models.

Base Dataset Selection

Base dataset selection is important in a microsimulation model as the quality of the input data determines the quality of the output. However, selection of a base dataset is not an easy task as hardly any micro dataset contains all the information required by a dynamic population microsimulation model and the difficulties of picking a base dataset have been discussed by Cassells *et al.* (2006) and Zaidi and Scott (2001). There are a number of different types of base data that a dynamic model can utilise and Table 2 describes the types used by different dynamic microsimulation models, including detailing of the data source and sample size. Typically, a dynamic microsimulation model starts with one or several of the following types of dataset according to their sources:

- Administrative Data
- Census Data
- Household Survey Data
- Synthetic Dataset

Administrative data often contains the most accurate information, as there is increased effort placed on data collection and as data is often collected for the whole population, sample sizes are usually much larger than survey samples. However, the data typically collected is only the information necessary for administrative purposes and, for this reason, countries who use administrative data often supplement information with extra survey data as in the SESIM and MICROHUS models.

Legal and privacy reasons may also prevent administrative data from being accessible. Models such as CORSIM, DYNACAN and DYNAMOD use census data and while census data typically has better coverage than household surveys, they often contain less information and have to be supplemented with imputed information from other sources.

Household survey data, e.g. the LII survey utilised in the LIAM model, is also frequently used as the base dataset because it is rich in the number of variables of interest and offers information on the dynamics of behaviour. However, household survey datasets may have the issues of smaller sample size and weights adjustment. The use of weights in a dynamic model adds complexity to many areas and can result in individuals being given different weightings at different points in their lives. One solution implemented in the DYNAMITE and ANAC models is to replicate households according to their non-response weights, so that consequently each household has the same weight.

Another type of base dataset is synthetic datasets. These are selected when either a longitudinal model is used, as in the case of DEMOGEN, HARDING, LIFEMOD and BALDINI, or where no data exists, as in the case of the NEDYMAS model, where a synthetic initial sample representative of the Dutch population in 1947 was generated. As synthetic datasets are artificially created, they often contain all the variables required and models based on synthetic datasets usually provide great tools in understanding a single policy in depth. However, adjustments are required before reporting the policy effects in real life.

For microsimulation models analysing the dynamics of elderly earnings or pensions, the dataset requirement is usually higher as it requires historical variables that affect the evolution of the elderly social economic status. This necessity implies that a long panel dataset containing rich demographic, employment, and pension data is required, something which is not readily available to most researchers. Hybrid sources of datasets are often used in such a scenario, whereby a combination of datasets from various sources, statistical matching and simulation techniques are utilised; for instance DYNASIM3 (Favreault and Smith, 2004) matches two survey datasets, namely, Survey of Income and Program Participation (SIPP) and Panel Study of Income Dynamics (PSID). CBOLT (Oharra *et al.*, 2004) uses a similar approach to complement its main dataset with SIPP, PSID and data from the Current Population Survey (CPS). A new model Tdymm (Tedeschi, 2011), intends to match administrative records with the European Union Statistics on Income and Living Conditions (EU-SILC) dataset. For researchers without access to certain required data, simulation is used to impute the longitudinal history. The CORSIM model simulates part of the historical profile based on a historical cross-sectional dataset and matches the model output to historical aggregate information such as fertility and mortality rates (Caldwell, 1996), whilst LIAM simulates a historical profile by exploiting retrospective variables, previous censuses and other data sources (Li and O'Donoghue, 2012).

Another issue in the base dataset selection is sample size; the larger the sample size, the more smaller consider groups can be considered. Sample sizes are more important for inter-temporal analysis because here the number of dimensions is increased as similar individuals in a cross-sectional sample may in fact be very different due to the different paths taken to reach the same state. Regardless the source of the dataset, panel data is usually preferred as it records changes over time. Sample size also has an impact on run time of the model; the larger the samples size, the longer the run speed, resulting in a trade-off. Faster computer power does however reduce the impact of this trade-off.

Table 2 Base Dataset Selection of Dynamic Microsimulation Models

Model	*Country*	*Base Dataset*	*Observation*
ANAC	Italy	Household Income and Wealth, 1993	67000 households
APPSIM	Australia	1% census sample drawn from the 2001 Census	188,013 individuals
CAPP_DYN	Italy	Survey of Households' Income and Wealth (SHIW), 2002	21,148 individuals and 8,011 households
CBOLT	USA	Continuous Work History Sample (CWHS), complemented with SIPP, PSID and CPS datasets	300,000 individuals
CORSIM	USA	0.1% sample drawn from the1960 census	180,000 individuals
DEMOGEN	Canada	Synthetic cohort aged 0	1,000-5,000 individuals
DESTINIE I & II	France	Financial Assets Survey,1991	37,000 individuals
DYNACAN	Canada	1% sample drawn from 1971 census, public use file	212,000 individuals
Dynamic Model	Ireland	LII survey, 1994 (Pop.), synthetic cohort aged 0 (Cohort)	Around 4,500 households
DYNAMIC TUSCAN	Italy	EU-SILC 2003 wave	
DYNAMITE	Italy	Household Income and Wealth, 1993	67,000 households
DYNAMOD I and II	Australia	1% sample drawn from the 1986 census	150,000 individuals
DYNASIM I	USA	1960 Census1-10000 Public Use Sample 1970 Census1-10000 Public Use Sample	4000 individuals 10000 individuals
DYNASIM II	USA	CPS 1973 matched to Social Security Administration (SSA) data	
DYNASIM III	USA	SIPP panels 1990 to 1993	100,000 individuals and 44,000 households
FAMSIM	Austria	Family and Fertility Survey (Austria), 1995-96	4,500 women
FEM	USA	Individual records drawn from the Medicare Current Beneficiary Survey (MCBS), 1992-1998	10,000 individuals
GAMEO	France	French Labour Force Survey (FLFS), 2003-2005	
HARDING	Australia	Synthetic cohort aged 0	4,000 individuals
IFSIM	Sweden	Swedish micro dataset on the Household Market and Non-market Activities HUS, 1996	3,000 individuals
IFS Model	UK	English Longitudinal Study of Ageing (ELSA), 2002-2003	12,100 individuals

Model	*Country*	*Base Dataset*	*Observation*
INAHSIM rev1/2/3	Japan	Rev1: 1974 Comprehensive Survey of the Living Conditions of People on Health and Welfare (CSLC) with private household only Rev2: 2001 CSLC (private household only) Rev3: 2004 CSLC, aligned with population census	Rev1:32,000 individuals and 10,000 households Rev2: 126,000 individuals and 46,000 households Rev3: 128,000 individuals and 49,000 households
INFORM	UK	1% sample drawn from Department for Work and Pensions (DWP) administrative data	110,000 individuals
Italian Cohort Model	Italy	Synthetic cohort aged 0	4,000 individuals
Japanese Cohort Model	Japan	Synthetic multiple cohorts (single representative of each cohort type)	4,000 individuals
LABORsim	Italy	2003 Rilevazione Trimestrale delle Forze Lavoro (RTFL)	50,000 individuals
LIAM	Ireland	LII survey, 1994-2001	15,000 individuals
LIFEMOD	UK	Synthetic cohort aged 0	4,000 individuals
LifePaths	Canada	Synthetic cross-section	Varies
Long Term Care Model	UK	Family Expenditure Surveys, 1993-1996	1,770 individuals
Melbourne Cohort Model	Australia	Synthetic sample of 20 year olds in 1970	50,000 males and families
MICROHUS	Sweden	HUS income distribution database, 1984	
MIDAS	Multi	PSBH dataset for Belgium, 2002, GSOEP dataset for Germany,2002, ECHP dataset for Italy, 2001	
MIDAS	New Zealand	Synthetic cross-section based on 1991 Census	10,000 individuals
MIND	Italy	ISTATA, IRP and SHIW Data, 1995	
MINT	USA	SIPP, 1990-93, matched to SSA data, SIPP, 1990-96, matched to SSA data for MINT5	85,000 individuals, expanded in later versions
MOSART 1/2/3	Norway	1% sample drawn from administrative data, 1989, version 3 used a 12% sample drawn from administrative data, 1993	40,000 individuals, 500,000 observations in version 3
NEDYMAS	Netherlands	Synthetic cross-section based on 1947 census	10,000 individuals
PENMOD	Japan	Synthetic dataset based on the official aggregate statistics	
PENSIM	UK	Retirement Survey, 1988, Social Change and Economic Life Initiative Survey, 1986 and Family Expenditure Survey, 1988	5,000 benefit units
PENSIM2	UK	Family Resource Survey, British Household Panel Survey and Lifelong Labour Market Database, 1999-2001	
PENSIM	USA	Synthetic cohort aged 0	
Pensions Model	Belgium	Synthetic cross-section based on survey data	
POHEM	Canada	Administrative data	

Model	*Country*	*Base Dataset*	*Observation*
POLISIM	USA	A subset (1-10%) of the 1960 US Census Bureau Public use Microdata Sample (PUMS)	
PRISM	USA	CPS, March 1978, March and May 1979, matched to SSA data	28,000 adults
PSG	USA	Mixed	100,000 individuals
SADNAP	Netherlands	Administrative data from Statistics Netherlands (CBS)	
SAGE	UK	10% sample drawn from the Individual/Household, 1991 anonymised records combined with several survey datasets	54,000 individuals
SESIM	Sweden	Household Survey on Income (HINK), 1992	30,000 individuals
Sfb3 Population	Germany	Integrated Micro Data File, 1969 (Pop.), synthetic cohort aged 0 (Cohort)	69,000 households / 7,300 individuals
Sfb3 Cohort	Germany	Integrated Micro Data File, 1969 (Pop.), synthetic cohort aged 0 (Cohort)	69,000 households / 7,300 individuals
SimBritain	UK	UK Census and BHPS, 1991	
SIPEMM	Slovenia	Administrative dataset by Slovenia Statistical Office (SORS), 2007/2010	115,000 individuals / 40,000 households
SMILE	Ireland	Census of Population of Ireland	
SustainCity	Multi	Multiple data sources, including survey datasets and administrative datasets	Depends on the end user, 120,000 individuals for the Paris demography module,

Source: See Table 1

Development Environment of Dynamic Microsimulation Models

Microsimulation models are usually built for specific purposes and are thus custom developed, although there are a few packages that are often used in the development of dynamic microsimulation model. These packages can be grouped in to three main categories according to their development environments, each with their own advantages and disadvantages:

- General purpose programming language tool (C/C++/C#/Java etc.)
- General purpose statistical package (Stata/SAS/R/MatLab/Mathematica etc.)
- Simulation modelling package (Modgen, LIAM2, GENESIS etc.)

Development using a general purpose programming language clearly enjoys the highest degree of flexibility and possibly also a speed advantage. FORTRAN was popular among some earlier models, e.g. PRISM, DYNASIM2 in U.S while C language family seems to be a popular choice for later models. SAGE, DYNAMOD, LIAM, DYNACAN and a few others models were all developed using C++, whilst POLISIM used a mixture of C and C++, and APPSIM and MOSART were programmed in C#. Models have also been developed in Java (e.g. IFSIM). Evaluation based on the prototype microsimulation models by Percival (2007) suggested that there is a substantial speed gain by switching the prototype model from SAS to C++; however, the cost of development is much higher when compared with other approaches, as all the potential numeric calculations and related data management need to be programmed. In practice, it is likely that policy modellers are not adequately proficient in programming, while professional programmers may not be able to fully understand the economic principles that are to be implemented.

The second approach is to develop microsimulation models based on existing statistical or mathematics packages, such as GAMEO, DYNASIM, and PENSIM2 which were built on SAS. Modern statistical packages are capable of executing computation commands in batch and the code of a model is commonly referred to as a "script", "do-file" or "syntax file" etc. The main advantage of this approach is a fast development time and easy access to the statistical power of the package. However, the speed of the model might be lower as script commands are usually interpreted at the time of analysis; the increased performance time is most obvious when large loops are being implemented.

Another tool with which to develop microsimulation models is the use of specific modelling packages. Software in this category ranges from generic purpose modelling software, e.g. AnyLogic etc. to microsimulation specific packages. Whilst agent based simulation modellers use more generic purpose packages, microsimulation modellers tend to use more specific software. The most notable dynamic microsimulation modelling tools include

- Modgen, developed by Statistics Canada
- UMDBS, developed by Sauerbier (2002)
- GENESIS, developed by UK Department for Work and Pensions (Edwards, 2004)
- LIAM, developed by O'Donoghue (2011)
- LIAM2, developed by the Belgium Federal Planning Bureau (Bryon et al, 2011)

Modgen provides a C++ library in order for developers to incorporate required common actions and modules. It is often used to develop continuous microsimulation models, such as LifePath. In contrast, LIAM2 is a microsimulation scripting engine which is capable of reading its own syntax. Microsimulation packages such as this one offer the great benefit of rapid development. There are also a few dynamic microsimulation models that were built with generic deployment in mind. For example, LIAM avoids hardcoded parameters and variable names during the development, which greatly reduce the repetitive work load of a new modeller. GENESIS offers a platform to dynamically generate SAS based microsimulation code by reading the model specification from an Excel Sheet. However, these models still require end users to understand the internal mechanism and make changes at source code level when building larger models.

Most models today are based on a statistical package or a generic purpose programming language. However, it is not uncommon to see mixed combinations of environments in order to utilise the advantages of different software, especially for pre- or post-simulation analysis, e.g. DYNACAN, LIAM.

Cohort Model or Population Model

One issue that is closely related to the base dataset selection is the type of data structure that a model uses. Harding (1993) and others have categorised inter-temporal dynamic models into two types: cohort/longitudinal models that model a single cohort over their lifetime, and population/cross-section models that model a population cross-section over a defined period of time. In addition, some models focus only on adults (i.e. ignore children) and thus, although these models may contain a cross-section of the population, they do not represent the entire age spectrum. This flaw is also seen among models dedicated to pension analysis, e.g. IFS Model (2007).

From a model design perspective, the distinction between cohort and population model is less significant than the use that the model is put to. The distinction made in the literature from a historical viewpoint has more to do with computing power and data constraints rather than any major methodological differences. Cohort models were typically used because the computing costs required to simulate whole lifetimes for cross-sections with sufficient sample sizes to be able to examine specific cohorts were too high. Both types of models can be simulated in the same modelling environment: a cohort model is simply a model that ages a sample of unrelated individuals aged zero, while a population model ages a sample of individuals of different ages some of whom are related. Both samples are then passed through ageing procedures, to produce life event histories over the modelled period.

It is also possible to model both types using the same computing platform. The potentially larger size of the cohort modelled in dynamic cohort models allows life time income patterns for smaller population groups such as recipients of disability benefits or lone parents to be studied. Some cross-section models such as MOSART combine the advantages of both types of models due to access to a very large dataset. Access to administrative datasets that contain detailed labour market and life event histories for 1% of the population allows a model to be run over the lifetime of a particular cohort while comparing their position to other cohorts.

Model Complexity

The complexity of a model is often guided by the potential policy questions that the model is required to answer. Models focusing on pension issues usually simulate detailed labour market behaviour for decades ahead, as a change in the pension system can only mature when the youngest cohort in the labour market retires. In contrast, short term tax policy models usually forward simulate 3 to 5 years and are typically limited to tax related variables only. If a model is being utilised to answer different research questions, then it usually needs to simulate more variables for a longer period of time, which involves higher levels of complexity.

An ideal microsimulation model should have the capacity to simulate details of all possibly related variables; however, the costs of building large models, both in terms of model validity and management needs to be taken into consideration. Dynamic microsimulation models have the reputation of being complex and the potential to run “out-of-spin” with regard to some aspects. Complex models, while having more power, are much more difficult to validate and may often contain bugs in their implementation. In addition, the complexity of the processes often means development takes longer than expected.

Large general purpose microsimulation models are usually built by large teams with access to large and complex datasets. These models usually simulate a wide variety of economic and demographic processes and can therefore be used for many different applications. These forecasting models usually incorporate alignment systems in order to keep the model in line with external forecasts or are in fact linked to macro-models. Models of this type include DYNASIM from the USA, the Canadian Pensions Program DYNACAN, the MOSART model in Norway and the APPSIM model in Australia etc.

Given the high cost of model development, Harding (2007a) suggested that developers “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”. Some newer models, e.g. SustainCity (Morand *et al.*, 2010), advocate this approach, especially during the initial development phase.

Model Validation

Given the increasing complexity of models, it is becoming increasingly important to validate the model in order to maintain its credibility. Unfortunately, only limited effort has been placed on validation matters and there is no international consensus on validation procedures. DYNACAN (Morrison, 2008) has published the most comprehensive validation process documentation which included:

- Context of Validation
- Data/Coefficient/Parameter Validation
- Programmers/Algorithmic Validation
- Module-Specific Validation
- Multi-module Validation
- Policy Impact Validation

Ex post analyses of previous periods can also be used to assess the reliability of a model and it is for this reason that a number of the major microsimulation projects have taken historic datasets as their starting population base for simulations. For example, the CORSIM and POLISIM models takes as their base a sub-sample of the 1971 and 1960 US Censuses respectively, and the DYNACAN model takes a sample of the 1970 Canadian Census as its base. By running the model forward to the present day, the model forecasts can be compared to what has actually happened (see for examples Morrison, 2000; Caldwell and Morrison, 2000). However, these models invariably incorporate historical information such as macro-aggregates into the model and as this information would not have been known to forecasters, this may produce better forecasts than would have otherwise been the case. One method to overcome this is to compare directly generated forecasts with what happened in reality, for example comparing forecasted labour participation rates with actual rates. Another method described by Caldwell (1996) is to use an indirect approach, known as a multiple module approach. An example cited by Caldwell is the case of validating the numbers of married persons with health insurance, when the directly simulated processes are marriage and medical insurance membership. Sources of error may result from errors in either or both direct processes, or because of mis-specified interactions. However, some types of dynamic model may have no comparable source of validation. For example, models which solely look at a single cohort living in a steady state have nothing with which they can be validated as the model does not attempt to mimic real life, but merely a stylised version of it. Additionally, countries that have only recently developed their micro-data resources may not have alternative sources of data with which to validate, although this problem will become progressively less with time.

Recent developments in microsimulation methodology suggest an alternative validation method using a simplified model. Since no future data is available to validate a forecasting dynamic microsimulation model, Morrison (2007) suggests comparing a model’s result to a trustworthy model’s result. Dekkers (2010) argues that the general trend of certain indicators estimated by a simple model could be seen as a benchmark for more complicated microsimulation model as there is no black box in a simple model. The Belgium MIDAS model used this approach to validate against a “simple stylised” model, which is essentially a representative household model with only demographic and pension indexation components.

IV. Methodological Issues – Part II

This section continues the discussion of methodological issues faced in constructing dynamic microsimulation models but focuses on the technical implementation and choices made in a model. Table 3 provides an overview of the technical choices discussed in this section.

Table 3 An overview of the technical choices made by dynamic microsimulation models

Model	*Country*	*Base Pop*	*Type of Time Modelling*	*Open or Closed Model*	*Use of Alignment Algorithms*	*Use of Behavioural Equations*
ANAC	Italy	Cross	D	C	Y	N
APPSIM	Australia	Cross	D	C	Y	N
CAPP_DYN	Italy	Cross	D	C	Y	N
CORSIM	USA	Cross	D	C	Y	N
DEMOGEN	Canada	Cohort	D	O	N	N
DESTINIE I & II	France	Cross	D	C	Y	N
DYNACAN	Canada	Cross	D	C	Y	N
Dynamic Model	Ireland	Both	D	C	Y	Y
DYNAMIC TUSCAN	Italy	Cross	D			N
DYNAMITE	Italy	Cross	D	C	Y	N
DYNAMOD I & II	Australia	Cross	C/D	C	Y	N
DYNASIM I & II	USA	Cross	C/D	C	Y	N

Model	*Country*	*Base Pop*	*Type of Time Modelling*	*Open or Closed Model*	*Use of Alignment Algorithms*	*Use of Behavioural Equations*
DYNASIM III	USA	Cross	D	C	Y	Y
FAMSIM	Austria	Cross	D	C	N	N
FEM	USA	Cross	D		N	N
GAMEO	France	Cross	D		Y	
HARDING	Australia	Cohort	D	C	N	N
IFSIM	Sweden	Cross	D	C	Partial CGE	
IFS Model	UK	Partial Cross	D	C	Y	Y
INAHSIM	Japan	Cross	D	C	Y	N
INFORM	UK	Cross	D		Y	
Italian Cohort Model	Italy	Cohort	D	C	N	N
Japanese Cohort Model	Japan	Cohort	D	C	Y	Y
LABORsim	Italy	Cohort	C	C	Y	N
LIAM	Ireland	Cross	D	C	Y	Y
LIFEMOD	UK	Cohort	D	C	N	N
LifePaths	Canada	Cross	C	O		N
Long Term Care Model	UK	Cross	D	C	Y	N
Melbourne Cohort Model	Australia	Cohort	D	O		N
MICROHUS	Sweden	Cross	C	C	N	Y
MIDAS	Multi	Cross	D	C	Y	Y
MIDAS	New Zealand	Cross	D	C		N
MIND	Italy	Cross		O	Y	
MINT	USA	Cross	C/D	O	Y	N
MOSART 1/2/3	Norway	Cross	D	C	Y	N
NEDYMAS	Netherlands	Cross	D	C	Limited CGE	Y
PENSIM	UK	Cross	C	C	Y	N
PENSIM2	UK	Cross	D	C	Y	Y
PENSIM	USA	Cohort	C/D	O	N	N
Pensions Model	Belgium	Cross	D	C		N
POHEM	Canada	Cohort	C		N	N
POLISIM	USA	Cross	D	C	Y	Y
PRISM	USA	Cross	D	C	Y	Y
PSG	USA	Cohort	C	O	N	N
SADNAP	Netherlands	Cross	D	C	Y	Y
SAGE	UK	Cross	D	C	Y	Y
SESIM	Sweden	Cross	D	C	N	Y
SIPEMM	Slovenia	Cross	D	C	Y	Y
SustainCity	Switzerland	Cross	D	C	Y	N
Sfb3 Population	Germany	Cross	D	C	Y	N
Sfb3 Cohort	Germany	Cohort	D	O	N	N
SVERIGE	Sweden	Cross	D	C	Y	N
Swedish Cohort Model	Sweden	Cohort	D	C	N	N

Model	*Country*	*Base Pop*	*Type of Time Modelling*	*Open or Closed Model*	*Use of Alignment Algorithms*	*Use of Behavioural Equations*
Tdymm	Italy	Cross	D	C	Y	Y

Source: See Table 1

Key: Cross, cross-sectional, C, continuous, D, discrete, Y, yes, N, No

Static and Dynamic Ageing

"Ageing" within dynamic microsimulation refers to the process of changing characteristics of micro units over time. There are two types of ageing processes; static ageing and dynamic ageing. Static ageing involves adjusting the weights of the observations so that the simulated population distribution matches the macro aggregates. For example, in order to simulate an ageing society, the weighting of young people gradually decreases over time while the weighting of elderly people would increase; however, there is no change to the attributes of these individuals. Dynamic ageing by contrast, changes the attributes of the individuals instead of altering their weights. In the same example of simulating an ageing society, models with dynamic ageing will update the age and other related attributes of individuals over time instead of changing their weights.

While static ageing can ideally produce the same population representative cross-sectionals as models with dynamic ageing, it has the benefit of having a simpler simulation engine as the only variable that needs to be changed over time is the weight of the observations. Dekkers and Van Camp (2011) noted that this might be attractive for modellers who already have a static microsimulation model, however, static ageing also has a number of disadvantages. Klevmarken (1997) highlighted that whereas static ageing may avoid some problems of drift in the projected cross-section associated with dynamic ageing because of misspecification in dynamic equations, it cannot account for mobility between states. In addition, he pointed out that from a statistical point of view, it is inefficient not to use all available historical information to project into the future. A consequence of not modelling the mobility of individuals between points in time is that it reduces the type of analyses that can be undertaken by a microsimulation model, for example, it is not possible to conduct analyses that require life event histories such as the simulation of pensions. Furthermore, future weights need to be forecast in order to age a dataset. Although macro models or other forecasting devices can be used they may not forecast weights at the level of detail required. Besides, the weight calculation may be further complicated when the target distribution involves more than one variable[1]. Generally speaking, static ageing cannot be used where there are no individuals in the sample in a particular state. If there are a small number of cases in a particular household category, then a very high weight may have to be applied, resulting in unstable predictions. As a result, static ageing procedures are mostly used in short to medium term forecasts of approximately 3-5 years, where it can be expected that large changes have not occurred in the underlying population. However, it may be more difficult to use static ageing over longer periods of time due to changing characteristics of the population.

Dynamic ageing can consistently estimate characteristics of future income distributions under ideal circumstances in which all transition probabilities and state specific expectations can themselves be estimated consistently. This may be possible in a simple model with a small number of processes; however, in a fully dynamic model of work and life histories, many more processes need to be jointly estimated, a formidable requirement given the available data. Therefore, it is necessary to assume that the marginal distributions of different processes are independent. In addition, projections over time at the micro-level are particularly susceptible to misspecification error as modelling at this level involves

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[1] For some examples of the multi-dimensional reweight algorithm, see Deville *et al.* (2003), Tanton *et al.* (2011) etc.

more detail than in macro models, also current knowledge regarding micro-behaviour is not good enough to specify a fully dynamic model. As a result, dynamic ageing combined with an alignment (calibration) mechanism to keep aggregate outputs in line with predictions from macro models is more commonly used. This procedure combines the best of both static and dynamic ageing as it allows individual transitions to be simulated as well as ensuring that aggregate outputs track macro forecasts (see, for examples, Chénard 2000a, 2000b).

Discrete or Continuous Time Modelling

Another choice in the development of dynamic microsimulation models is the treatment of time. Discrete time models simulate which individuals experience particular events in given time intervals while continuous time models treat time as a continuous variable and determine the exact time that an event occurs (Willekens, 2006).

Discrete time microsimulation models usually incorporate a probability model or a transition matrix, for example the demographic module. Demographic modules in dynamic models are often constructed using annual transition probability matrices. Individuals are passed through a collection of transition matrices in each time period of the simulation (usually a year) to determine their simulated life paths, e.g. death. This method assumes that life events are independent of each other, however in reality they may be interdependent as in the example given above and consequently the order in which the transition matrices are applied is very important. In the example given above, if marriage is determined first, then the potential fertility rate changes and similarly, a pre-marital pregnancy will increase the probability of getting married. Galler (1997) discussed a number of options in this situation including the procedure of random ordering as used by the DARMSTADT (Heike *et al.*, 1987) and Hungarian models (Csicsman *et al.*, 1987).

There are a number of other problems with this type of approach. Firstly transitions are assumed to take place at a single point in each time period and the duration of the event must last at least one time period (typically a year, but may be of shorter duration). For example if the time period is a year, then this approach rules out transitions in and out of unemployment over the course of a year, which is unrealistic, as many people will have unemployment transitions for periods of less than one year as in the case of seasonal workers. Therefore, the discrete time transitions simulate net transitions (see Galler, 1997) at discrete points in time, ignoring the transition path taken to reach the end state.

Continuous time microsimulation models usually use survival models to simulate the time of events. Rather than simulating annual transition probabilities, survival functions model the length of time an individual will face in his/her current state, e.g. DYNAMOD and SOCSIM (Hammel, 1990) and this method was extensively discussed by Willekens (2006). Once a referencing event has occurred such as marriage, an individual is passed through each survival function that, given their current states, they are eligible for. For example, once an individual is married, then they become eligible for divorce, the event given their current state with the nearest event time is selected and then repeated until death.

Although the continuous time model does have some theoretical advantages, it also has considerable practical limitations. The estimation of competing risks and survival functions place very high requirements on the data that are rarely matched by the actual data available (Zaidi and Rake, 2001). Given that most base datasets were collected on an annual timeframe, it is therefore easier to incorporate a discrete time model. In addition, the potential interdependence of transitions for members (e.g. family) further raises the complexity of implementation. Alignment for continuous models is more difficult as cross-sectional adjustments would erode the advantages of duration models, and the potential computation cost of alignment is much higher in continuous time models.

Behavioural Equations or Probabilistic Based Modelling

Microsimulation models could use probabilistic based modelling, behavioural equations or a mix of two to simulate changes. Behavioural models are grounded in economic theory, in the sense that changes to institutional or market characteristics result in a change in the behaviour of agents within the model. In contrast, probabilistic models aim to reproduce observed distributional characteristics in sample surveys without necessarily having a theoretical underpinning. Depending on how they are constructed, probabilistic models may or may not be able to respond to external market and institutional characteristics dynamically.

Probabilistic based modelling is often used to simulate mortality, fertility, family formation, labour market transitions etc. Although not necessarily grounded in microeconomic theory, they are based instead on a probability-based matrix and do not depend on policy parameters within the model. In practice, many transitions are based on only a small number of factors such as age and sex. This method is commonly used in static tax benefit microsimulation models as well as some dynamic models such as POLISIM.

In a behavioural model, individual behaviour changes are as a result of changing policies, therefore the policy parameters must have a direct or indirect impact on the model. An example is a labour supply model that responds to changes in the tax-benefit system, not normally the case in a probabilistic method. A requirement of behavioural models is the stability of the parameters. Klevmarken (1997) outlined three criteria for choosing what types of behavioural equations should be included in a microsimulation model in general:

- They should be relevant for the objectives of the model
- There should be major behavioural adjustments to the policy changes the model is built to analyse
- Behaviour that influences the fiscal balance should be included

Examples of behavioural responses that fit these requirements include labour supply, retirement decisions, the effect of income and price changes on consumption, fertility and marital decisions, the take-up of social benefits etc. In the case of labour supply models, behaviour simulation models typically consist of three subcomponents: an arithmetic tax benefit model to estimate budget constraints, a quantifiable behaviour model using variables that can be simulated, and a mechanism to predict the labour supply under a new policy environment (Creedy and Duncan, 2002).

Compared with earlier microsimulation models, more models today have incorporated behavioural responses into their design although these responses are often limited to labour market simulations. Models such as MICROHUS, PRISM, SESIM, NEDYMAS, SAGE and LIAM all incorporate labour supply behavioural responses to the tax-benefit system, while DYNAMITE, ANAC and SADNAP model retirement decisions depending on the social security system. However, there is still only limited implementation in life-cycle models and Pudney and Sutherland (1994, 1996) have found that predictions based on behavioural models have very wide confidence intervals. In addition, certain behaviour models, e.g. a labour supply model based on policy independent personal characteristics (usually logit/probit), contain the implicit assumptions that the policy remains the same. This type of model is not suitable for reform analysis, and is often restricted to simulating status quo only.

Open vs. Closed Model

A decision dynamic microsimulation model builder has to consider is whether the model should be open, closed or a mixture of the two. A model is defined as closed if, except in the case of new born and new migrants, the model only uses a fixed set of individuals. Thus, if an individual is selected to be married, then their spouse is selected from within the existing population of the model. In contrast, an open model starts with a base population and if spouses are required, then new individuals are generated. This has the advantage that simulations for individuals (and their immediate families) can be run independently of other individuals, and thus allows the model to be run in parallel on different computer processors, allowing overall run times to be reduced.

Open models, for instance, PENSIM and LifePaths, have the advantage of having simpler interaction models, e.g. a newly married partner can be created artificially to fit the social economic characteristics of an individual. However, an open model is more difficult for alignment as the sample may not stay representative of the population as new individuals are created. Although possible, it is a non-trivial task to align a varying population with macro-aggregates, as the weights would require constant dynamic reweighting and in the case of heavy alignments, the benefits of running the model in parallel might be lost. As a result, most dynamic models in use utilise a closed model method.

Despite this, most models have to incorporate a degree of openness because of migration. While immigration requires the generation of new individuals, it has little effect on alignment as macro-aggregates are typically based on a partially open population.

Alignment with Projections

As statistical models are typically estimated using historical datasets with specific characteristics and period effects, projections of the future may therefore contain errors or may not correspond to exogenous expectations of future events. In addition, the complexity of micro behaviour modelling may mean that simulation models may over or under predict the occurrence of a certain event, even in a well-specified model (Duncan and Weeks, 1998). Because of these issues, methods of calibration known as alignment have been developed within the microsimulation literature to correct for issues related to the adequacy of micro projections.

Scott (2001) defines alignment as "a process of constraining model output to conform more closely to externally derived macro-data ('targets')". Clearly, in an ideal world, a system of equations would be estimated that could replicate reality and give effective future projections without the need for alignment. However, as Winder (2000) stated, "microsimulation models usually fail to simulate known time-series data. By aligning the model, goodness of fit to an observed time series can be guaranteed." Some modellers suggest that alignment is an effective pragmatic solution for highly complex models (O'Donoghue, 2010), as it offers a limited connection between micro and macro data.

Over the past decade, despite this controversy, aligning the output of a microsimulation model to exogenous assumptions has become standard. As Anderson (2001) noted, almost all existing dynamic microsimulation models are adjusted to align to external projections of aggregate or group variables when used for policy analysis. Continuous variables such as earnings are typically aligned with a fix ratio in order to meet the projected average or distribution, whilst binary variables, such as working status, are aligned with various methods, including multiplicative scaling, sidewalk, sorting based algorithms etc. (See Morrison, 2006). Microsimulation models using historical datasets, e.g. CORSIM, align their output to historical data to create a more credible profile (SOA, 1997), while Models that work prospectively, e.g. APPSIM, also utilise the technique to align their simulations with external projections (Kelly and Percival, 2009).

Alignment also has its downsides, as highlighted by Baekgaard (2002). Concerns raised regarding alignment include the issue of consistency within the estimates and the level of disaggregation at which this should occur. It has been suggested that equations should be reformulated rather than constrained *ex post*. The existence of an alignment mechanism may constrain model outputs to always hit aggregate targets even if there has been an underlying behavioural or structural change. An example would be if education levels rose, as this would be expected to reduce mortality rates and increase female labour force participation. If the alignment mechanism for each process did not incorporate the impact of educational achievement, then an increase in the education level would have no effect on these aggregates. In most cases, alignment methods are only documented briefly as a minor technical part of the main model. Currently, there is a lack of studies analysing how projections and distributions change as a result of the use of different alignment methods.

Link between Micro and Macro Models

Microsimulation models increasingly meet the need to interact with macro economy through either an alignment process or computational general equilibrium (CGE) feedback. Alignment, as discussed in earlier, offers a simple but limited way to enforce the aggregate statistics within a simulation; however, it is usually limited to very specific variables and does not change based on the feedback from simulated micro data. Besides alignment, there is also a growing interest in using CGE models to link macro, meso and micro models (see Ahmed and O'Donoghue, 2007; Davies 2004). CGE models offer a potential opportunity to allow macro models interact with micro models via prices in different markets, which is particular useful for analysing large scale macroeconomic shock. For instance, IFSIM links a microsimulation model with a simple CGE model assuming a single sector economy.

There are a few papers discussing the potential methods of linking a microsimulation model and a CGE model. Cockburn (2001) used an integrated approach to link a survey dataset within a CGE framework, where the main concept was to replace the traditional unit of analysis in CGE, representative household, with a real household. Another approach is to separate macro and micro components while allowing the result of the micro or macro models is fed into the other models. Depending on the direction of the output feeding and the number of iterations, this approach was further subcategorised into "Top-Down", "Bottom-Up", "Top-Down Bottom-Up" and "Iterated Top-Down Bottom-Up" approaches (Galler, 1990; Baekgaard, 1995; Savard, 2003). Colombo (2010) compared several CGE microsimulation linkage methods and suggested the "Iterated Top-Down Bottom-Up" as the currently most complete approach. However, with only few exceptions like NEDYMAS (Dekkers *et al.*, 1993) which used the iterated approach, most macro-micro linking attempts in dynamic microsimulation models are limited to one-way only.

At the current stage, the integration of CGE or partial equilibrium with microsimulation is still limited at the current stage (Ahmed and O'Donoghue, 2007), and is mostly found in static models, e.g. IZAΨMOD. This might be the result of several factors, including modelling complexity, data issues, model stability and computational costs. Robilliard and Robinson (2003) indicated that current approaches in linking micro-macro may still need to be refined before addressing distributional issues. In addition, linking with CGE requires decent quality of household income and expenditure data, which is not widely available. Furthermore, the integration between CGE and dynamic microsimulation could potentially exaggerate the uncertainty introduced in the results due to the complexities in interactions of different social economic variables and consequently result in a greatly increased computation time.

Links and Integrations with Agent Based Models

Although this study mostly focuses on the development of dynamic microsimulation models, it is also worth to note that microsimulation is closely related to two other individual level modelling approaches, cellular automata and agent based models (Williamson, 2007). In particular, agent based models are also used in social science to analyse macro level phenomena gathered from micro units. An agent based model (ABM) typically consists of a set of autonomous decision-making entities (agents), a set of agent relationships and methods of interaction, and the agents' environment (Macal and North, 2010). It is often used to show how macro level properties such as spatial patterns and levels of cooperation emerge from adaptive behaviours of individuals.

Traditionally, agent based models are highly abstract and theoretical without many direct empirical applications (Boero and Squazzoni, 2005; Janssen and Ostrom, 2006). In recent years, however, there is a growing interest in ABM literature of injecting empirical data in an attempt to simulate some real-world phenomenon (Parker *et al.*, 2003; Hassan *et al.*, 2008). From a practical point of view, when agent based models add more social economic attributes to the agents and when microsimulation models add more behaviour rules and interactions, they are moving toward to a common ground (Williamson, 2007).

Agent based models covers an important aspect of social economic modelling, network effects, which has long been discussed by sociologists and economists but hardly exists in microsimulation beyond the spouse matching. Microsimulation modellers often implicitly assume that the effects of social pressures and peer effects are already embedded in the existing distribution and they are likely to keep constant, i.e. there is no need to update the model as time passes. While this assumption might be acceptable for some research, such as tax reform analysis, it might be too strong for some other types of research, e.g. evaluating alternative health intervention policy. Agent based models, on the other hand, often explicitly model these interactions and allow certain social factors to change as the population evolves.

With the growing number of social networking data, it is theoretically possible to integrate the adaptive behaviours from ABM into microsimulation models to produce a more realistic model. The potential introduction of network effects could benefit a set of microsimulation models, e.g. health simulation models, in which the social factors may play a role. In addition, peer effects may also help to model the evolution of marriage/fertility patterns, the formations and dissolutions of neighbourhoods in a spatial microsimulation model etc.

It should also be noted that the benefit of this potential integration may also bring some disadvantages. The implementations of micro interactions would greatly increase the computational cost and complexity, thus makes the model more difficult to understand and validate. Besides, the current base datasets of the microsimulation models are often standard surveys or census data that do not cover extensive network attributes. At the current stage, the implementation of extensive interactions like ABM in microsimulation models is still at its infancy, the existing attempts are limited to the introduction of simple behaviour rules, e.g. copying consumption habits as in Lawson (2011).

V. Progress in Dynamic Microsimulation

Progress of Dynamic Microsimulation Modelling since 1970s

In reviewing progress made by the field, it is useful to consider an early model development, the DYNASIM model developed by Orcutt et al. (1976) in the Urban Institute in the early 1960s to mid 1970's. In terms of our classification above, DYNASIM was a longitudinal closed model running a 10000 person dataset. It contained

- A demographic module, modelling leaving home, births, deaths partnership formation and dissolution, disability, education and broad location.
- A labour market module containing participation, hours, unemployment and labour income
- A Tax-Transfer and Wealth module containing capital income and the main tax and transfer instruments
- A marriage matching module
- As well as a simple macroeconomic model and feedback loops linked with the microsimulation model via alignment.

Thus in terms of generic structure, this 1970s model incorporates much of what has been included in later dynamic microsimulation models, although each component has been largely improved by the newer models. Despite the progresses in 1970s and 1980s, early microsimulation modellers faced a number of challenges which were summarised by Hoschka (1986):

a) Many of the behavioural hypotheses in micro-simulation models are of insufficient theoretical and/or empirical basis
b) Dynamic changes in the behaviour of the population are mostly not regarded by micro modellers
c) The problems of including more than the primary effects of a policy programme is still unresolved
d) Quality and accessibility of the data required by micro models often are restricted severely.
e) The development of micro-models frequently needs too much time and its costs are accordingly high
f) Running micro models usually requires a lot of computer time
g) The prediction quality of micro-models has not yet been systematically evaluated and validated
h) Large microsimulation models are so complex that they are difficult to comprehend and control.

These challenges can be broadly categorised into five different areas: behaviour response modelling (a-c), microdata quality (d), development cost (e), limited computation capacity (f) and model validation (g-h). Comparing with some recent discussions in issues of microsimulation (Harding, 2007a), it is clear that most issues mentioned are still relevant and high on the list several decades later.

By comparing the DYNASIM model structure with today's dynamic microsimulation models and the challenges faced by the modellers in 1980s and today, what we are seeing are gradual advancements in the methodologies rather than breakthrough in model designs and applications. Improved computer hardware has allowed both improved speed and increased databases as have model software developments such as Scott (2001), O'Donoghue et al. (2009) etc. Improvements in micro-econometric techniques and data have improved the sophistication possible in individual models (See O'Donoghue, 2001). There has been some improvement also in the incorporation of behavioural response. This allows us to analyse the social economic impact on individuals when the policies are not kept constant. In addition, today's microsimulation modellers have proposed several methods to systematically validate the simulation output (Morrison, 2008), and consider the use of stylised model to assist the validation of a more complex model (Dekkers, 2010). Another major advancement in the past decades is the emerge of generic models, including Modgen (Wolfson and Rowe, 1998), UMDBS (Sauerbier, 2002), GENESIS (Edwards, 2004), LIAM (O'Donoghue, 2009) and LIAM2 (Bryon et al, 2011). These generic models can greatly reduce the workload of new modellers by providing commonly used microsimulation routines.

Obstacles in the Advancement of Microsimulation

Nonetheless, the rate of progress in dynamic microsimulation is arguably slow given that we still share the same model design and face similar problems as early DYNASIM modellers did nearly 40 years ago. There are a number of reasons could be ascribed to this lack of progress, including:

- Knowledge transfer
- Model ownership
- Unrealistic expectations

One criticism of the knowledge transfer mechanisms within the field is that most of the transfer has been via tacit knowledge rather than codified knowledge. Much important knowledge and methodologies have mainly been codified as "documentation", with the main aim to facilitate other team members utilising the models. In addition, microsimulation models are mostly developed in governmental or policy institutions, where developing a literature on which a wider group of scientists has built has been a lesser objective. Furthermore, the documents are mainly spread with limited books and conference presentations, which may not be easily available for researchers outside of the network. Additionally, academic publication relies on preparing papers of 5 to 10 thousand words, which may not be enough for complex dynamic microsimulation models. Thus a significant proportion of the extensive methods used in the field are not formally codified, meaning that to a large extent new models have had to reinvent the wheel and re-develop existing methods over and over again. This has made it very difficult to work in the field.

The non-transparent knowledge transfer has also manifested itself in a proprietary versus open source view in relation to the software, where either code or coding consultancy has been sold to potential clients. While this model of intellectual property makes sense when an economic return can be gained and motives private R&D, given the relatively small demand for these tools by clients with the capacity to pay for them, it seems to be a business model that will stymie intellectual development. With low funded demand, the returns will be low, limiting private investment, while the private good nature of the intellectual property will limit transmission. In addition, the protection of the source code makes replicating others' findings very difficult, which could harm the credibility of the research. The availability of open source model frameworks such as ModGen, UMDBS, GENESIS, LIAM and LIAM2 can facilitate the development of new models, however it will require the publication of full models to fully realise the benefits of scientific interaction.

Another reason for the lack of progress was the perceived “failure” of the earlier models. However this failure to some extent can be attributed to failing to meet unachievably high expectations. Orcutt et al. (1961) focused on the capacity to undertake prediction at a micro level to facilitate planning. In addition the alignment debate has centred around the argument that if one needs alignment, the model is not good enough. However human behaviour is of such complexity and is endogenous to economic analysis that dynamic microsimulation models cannot hope to make accurate predictions. Even well specified econometric model may over or under predict the outcomes (Duncan and Weeks, 1998). As George Box (1987) said “All models are wrong, some are useful”. In being useful we can hope at best that a dynamic microsimulation model can provide a consistent mechanism with which to undertake scenario analyses incorporating inter-temporal events and the distribution of the population.

VI. Future Directions

Model Uses

The applications of microsimulation are widespread as suggested by Table 1. With the availability of better modelling tools and greater number of researchers from different field engaging in microsimulation, the method is now applied in many fields other than the traditional welfare policy research. For instance, using microsimulation model as part of the tools to estimate impact of climate change (Hynes *et al.*, 2009; Buddelmeyer *et al.*, 2009), modelling disease spread (Will *et al.*, 2001), time use simulation (Anderson *et al.*, 2009), and even personal finance planning tool (Avery and Morrison, 2011). The use of dynamic microsimulation models can be even further expanded as more micro-level data becomes available. With the better availability of the longitudinal data and administrative data, it is possible to better understand the consequence of ageing. In addition, the raise of the network data could help use to model the disease spread and knowledge diffusion in a more realistic way.

While large dynamic models have their advantages for providing more comprehensive simulation outputs, the complexity also increases the difficulties in validation, model usages and also funding issues. It might be beneficial to also develop some specialised simple dynamic models. Smaller models could be better validated and make it easier to publish the model details within the length limit of a journal article. Furthermore, a large microsimulation models could absorb different validated smaller models to reduce the development and validation cost.

Additionally, instead of expecting an accurate long run simulation, researchers could focus more on scenario analyses, where the assumptions are explicit and less pressure to be a fortune teller. The changes in economic and politics climate also mean that all the simulations results may become obsolete in relative short time. Focusing on the scenario analyses could be more cost effective and relevant to the debate of contemporary issues.

Furthermore, academics can also use dynamic microsimulation to improve the understanding and modelling of inter temporal behaviours. Traditionally, labour economists do not have access to the longitudinal data that covers the whole life-span of individuals. With the help of microsimulation, it is possible to generate budget constraints for use as input into life-cycle behaviour choice modelling, e.g. retirement choice as in Li and O’Donoghue (2011). The method would assist us to better understand the many inter temporal processes, e.g. fertility decision, education choices etc.. The raising interesting from the academic side would benefit the field development and ensures the sustainability of the knowledge.

General Methodological Development

In terms of methodological development, a primary need is to codify the various methodologies that are currently being used in dynamic microsimulation models. There are many methods being used; most without any published description or evaluation. As university academics are typically measured in relation to the volume and quality, as measured by citations, of their peer reviewed work. Formally documenting the methods used and publishing in peer-reviewed journal could improve the knowledge diffusion and increase the public good returns by academics, providing incentive to innovate. Additionally, publications could preserve the knowledge that could have been lost due to the end of project funding. It is hoped that in time that the journal, the new *International Microsimulation Journal* can provide an opportunity for citable peer reviewed publications. However as a new journal, its impact factor will be low which will discourage researchers from publishing.

The widely used alignment technique is still under documented. While some models have published their alignment implementation details, it is still unclear how alignment should be used when combined with more complex econometric models, e.g. categorical behaviour models. Generally, there is limited understanding on the simulation properties of many algorithms used, including alignment, error term manipulation, complex reweighting, random numbers etc. Additional, papers using microsimulation model typically provide the result of only one-run due to the complex and time constraint. Given the raising computing capacity available for researchers these days, modellers could potentially provide more information about the simulation, e.g. the confidence intervals of the result using Monte Carlo techniques.

Despite the discussions and the general consensus to improve validation process in microsimulation, there is still little guideline how dynamic microsimulation models should be validated (Harding, 2010). While DYNASIM documented many issues involved n the model validation, there are still many areas that need to be explored, such as behaviour responses validation, longitudinal consistency validation, module interactions etc. Besides the validation from the technical side, it is also worth considering to validate the simulation with historical data, from which we can learn what has been done right, how the simulation performances under different assumptions etc.

Assumptions and Technical Choices

There are also a few technical aspects that could be improved to make microsimulation model more useful. For instance, the unit of analysis is traditionally individual or household. However, the sharing within household assumption may not hold if there’s complex family structure. By modelling the kinships within the family, like INAHSIM, it allows us to better understand the welfare network and poverty alleviations in the society.

While the models that focus on the individual social economic patterns and behaviours have improved greatly in the past decade, there is limited modelling effort in the institutions except tax benefit system within microsimulation. Future models could potentially benefit from incorporating some of these important social fabrics, e.g. companies, unions in a labour market simulation exercise, or hospitals, clinics, emergency response in a health model. The also relates to the discussions of better behaviour modelling and CGE models linkage referred in earlier section. These improvements could potentially provide us a more accurate picture of the consequences of large scale policy change.

In addition, most microsimulation models these days ignore the budget and political constraint from the government side, either by assuming fiscally neutral or unlimited resources. The macroeconomic constraint and the political feasibilities are not discussed in most papers. Future microsimulation modellers may want to incorporate these factors to assess the feasibilities of a proposed reform.

VII. Conclusion

This paper has discussed some of main issues involved in constructing a dynamic microsimulation model and described some of the choices made by different models in use worldwide. The main issues discussed have covered some of the general model development issues, such as base dataset selection, cohort or population based model structure, programming environment, and model validation. The paper has also discussed some of the technical choices made in model implementation, such as whether the model should be open or closed, whether alignment algorithms should be used, whether the model should incorporate behavioural response to policy changes, and links to the agent based models etc.

Over the past decades, microsimulation models have been applied to many different policy areas and a comparison of models as given in Table 1 illustrates the scope of application of dynamic microsimulation models. Most dynamic microsimulation models listed can be categorised as discrete cross-sectional models using dynamic ageing. For newer models, alignment has become a standard component allowing interactions with macro aggregates and more recently, simulation packages that are dedicated solely to microsimulation have become a viable option in model development. These packages, together with increased co-operation through meetings and code sharing (e.g. LIAM, Modgen model series), could significantly increase the development process.

The increasing use of microsimulation models has raised many technical challenges to meet the needs of more complex and accurate policy analyses. From instance, there is a growing interest in integrating CGE into microsimulation models, although the actual implementations of CGE-microsimulation are at this stage restricted due to data and technical limitations. Behavioural responses in microsimulation could also be further improved and there is only limited implementation in life-cycle models when simulating inter-temporal choices. Microsimulation could potentially implement some elements from ABM to allow dynamic behaviour changes. In addition, some other technical improvements, e.g. unit of analysis, budget and political constraints, could benefit the usefulness of the models. Furthermore, certain practices within the simulations, such as alignment for complex models and error term simulation, should be more thoroughly studied.

Besides the technical challenges, there are also some general issues in the field. The lack of documentations often forces new modellers need to reinvent the wheel; closed sourced models which slow down the knowledge transmission. The unrealistically high expectation in long run simulation may challenge the creditability of the model and the funding sources in long run. Future modellers may help to address these issues by publishing model details in academic journals and be more open on the algorithm implementations. Newer modelling platform like LIAM2 tries to be more open and transparent in the software source code, which would benefit the field development and knowledge transmission. In addition, the field can also apply the techniques in evaluating some other important issues, e.g. climate change, broader analysis on the consequence of ageing etc.

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