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The DYSEM Microsimulation Modelling Platform

by Kevin Moore, Chantal Hicks, Jennifer Jones and Martin Spielauer

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...	not applicable
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0^s	value rounded to 0 (zero) where there is a meaningful distinction between true zero and the value that was rounded
^{p}	preliminary
^{r}	revised
x	suppressed to meet the confidentiality requirements of the *Statistics Act*
^{E}	use with caution
F	too unreliable to be published
*	significantly different from reference category ($p < 0.05$)

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Analytical Studies: Methods and References

Papers in this series provide background discussions of the methods used to develop data for economic, health, and social analytical studies at Statistics Canada. They are intended to provide readers with information on the statistical methods, standards and definitions used to develop databases for research purposes. All papers in this series have undergone peer and institutional review to ensure that they conform to Statistics Canada's mandate and adhere to generally accepted standards of good professional practice.

The papers can be downloaded for free at www.statcan.gc.ca.

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Abstract

The DYSEM microsimulation modelling platform provides a demographic and socioeconomic core that can be readily built upon to develop custom dynamic microsimulation models or applications. This paper describes DYSEM and provides an overview of its intended uses, as well as the methods and data used in its development.

Keywords: microsimulation, dynamic, socioeconomic, distributional, projections

1 Introduction

This paper provides an introduction to version 1.0 of the DYSEM microsimulation modelling platform. It includes a discussion of the context for its development, the platform's intended uses, and an overview of the methods and data used in its development.

DYSEM is a platform upon which dynamic socioeconomic microsimulation models can be built. Microsimulation models are computer models that simulate individual actors, which can be aggregated to represent a population. These models are particularly useful for exploring policy-oriented "what-if" questions and producing distributional results. They have been used in many domains—for example, the 2015 winter edition of the *International Journal of Microsimulation* contained articles describing microsimulation models used to explore issues related to subway carriage design (Cao et al. 2015), health care financing (Hennessy, Sanmartin et al. 2015), pension reform (Tikanmäki, Sihvonen and Salonen 2015), and tax evasion (Albarea et al. 2015). To create such models, a number of data sources are often integrated, thereby yielding more comprehensive portraits of the phenomena being modelled than those available from traditional data sources.

Statistics Canada has developed a number of microsimulation models. The oldest, the Social Policy Simulation Database and Model (SPSD/M) (Bordt et al. 1990), released in 1988, is a static model used to estimate the distributional impact of changes to taxes or transfers. Demosim (Caron-Malenfant and Coulombe 2015), a detailed population projection model, projects the Canadian population according to various ethnocultural characteristics, the Aboriginal population, and the labour force. Statistics Canada has also created a variety of health models: POHEM (Hennessy, Flanagan et al. 2015) models health, risk factors and disease; POHEM-Neurological (Finès et al. 2016) models seven neurological conditions; and ONCOSIM[1] (Evans et al. 2013), developed with the Canadian Partnership Against Cancer, models the health and economic impacts of cancer treatment and control programs.

Dynamic microsimulation models, which, unlike static models, simulate individual life histories from birth to death, have also been used to model socioeconomic outcomes in Canada, including education, earnings, pensions, and taxes and transfers. The two oldest- LifePaths and DYNACAN—are no longer being developed. LifePaths (Rowe and Gribble 2007), developed at Statistics Canada, was used to analyze topics such as student loans, pensions, disability, and savings. DYNACAN (Morrison 2007) was used by Human Resource Development Canada to model the Canada Pension Plan. SIMUL (Clavet et al. 2014) is a newer model for Quebec, which was developed at Laval University.

DYSEM is intended to be used as a platform to develop dynamic microsimulation models with similar goals-answering forward-looking questions that hinge on income or education in domains such as retirement income and long-term care of the elderly. It allows the simulation of millions of detailed, realistic individual life courses that, together, represent the Canadian population at the national and provincial/territorial levels.

1. ONCOSIM was originally called the Cancer Risk Management Model.

2 Overview: The DYSEM microsimulation platform

The aim of Statistics Canada's DYSEM project is to create a flexible, relatively simple, user-friendly "model core" that can serve as a foundation for model development. Users can build on this backbone to produce custom microsimulation models to address specific research questions by developing modules for additional demographic or socio-economic aspects of actors' life histories, such as marital dynamics, pensions, savings, and caregiving. Because DYSEM will be released to the public, these models can be built by clients themselves; alternatively, Statistics Canada can provide services on a cost-recovery basis.

DYSEM simulates and projects the Canadian population starting on July 1, 2011.[2] It is a dynamic continuous-time[3] event-based modelling platform. Figure 1-1 and Figure 1-2 display the current contents of the DYSEM platform.[4] The synthetic actors simulated by DYSEM are created either as part of the July 1, 2011 'starting' population, or by births or immigration to Canada after that date. In order to project the evolution of the population after July 1, 2011, mortality, emigration, and interprovincial migration are modelled. In all cases, actors are created at birth and followed until death or emigration from Canada. The demographic components in DYSEM use Statistics Canada's population projections as inputs. The default scenario replicates the M1 scenario of the most recent population projections for the provinces and territories (Statistics Canada 2015*a*), but users may substitute other scenarios. Details about the methods, data, and assumptions underlying the M1 scenario and the official population projections are available in a technical report (Statistics Canada 2015*b*).

The current version of the DYSEM core also simulates four levels of educational attainment: less than high school graduation, high school graduation, graduation from postsecondary education below a bachelor's degree, and graduation with a bachelor's degree or above. It is anticipated that the next release of the DYSEM core will also include the simulation of earnings.

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2. DYSEM does not model non-permanent residents, such as international students and temporary foreign workers. Such individuals have been excluded from the parameters governing the creation of DYSEM's population.
3. Continuous time is time that is infinitely or highly divisible. Traditionally, most microsimulation models have operated in "discrete time," where events happen and individual states are assessed according to fixed time periods, such as annually or quarterly. In contrast, in microsimulation models that support continuous time, events can happen any day, hour or minute in a simulated individual's life. As well as being more realistic, this helps avoid multiple events occurring at the same time, which can create uncertainty about the order of events.
4. Technically, birth is not an "event" in the model—the birth of a new actor is initialized in the model's Start function.

Figure 1-1
DYSEM components — Actors in DYSEM

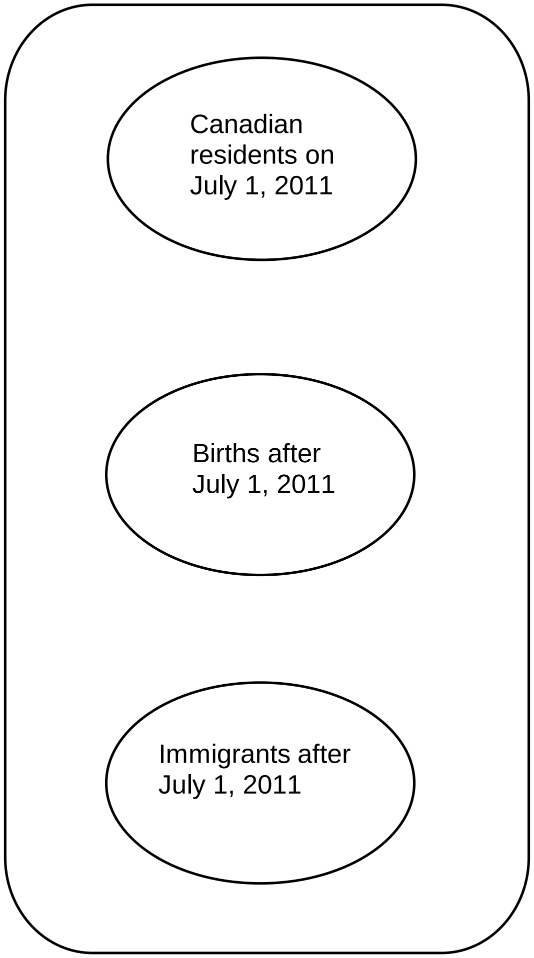
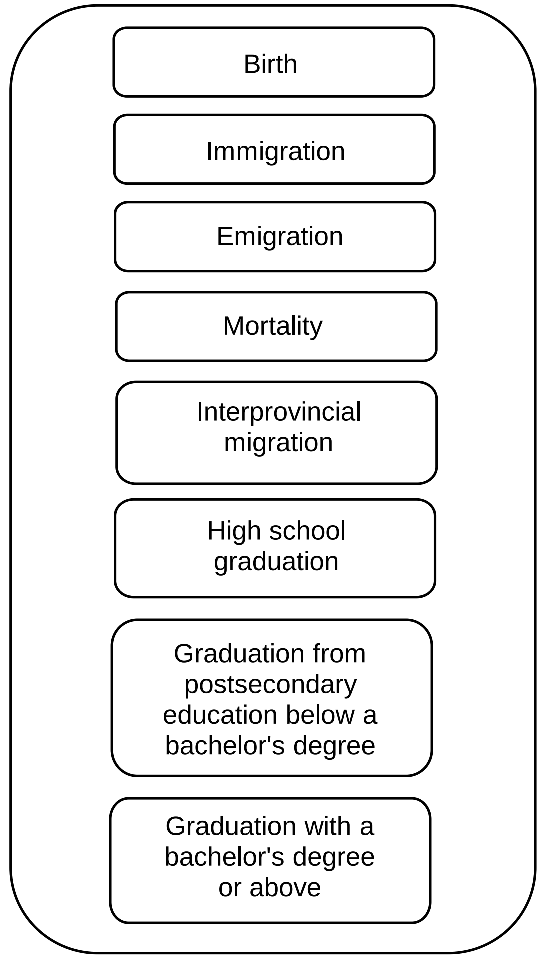


Figure 1-2
DYSEM components — Demographic and socio-economic events in DYSEM



Particular care has been taken to ensure that the platform not only produces appropriate national-level results, but also reproduces observed provincial-level differences. DYSEM is implemented in the Modgen microsimulation language developed and maintained at Statistics Canada.[5]

The remainder of this report documents the methods and data used to develop the existing components of DYSEM in more detail, and provides some validation of the model's results.

3 DYSEM demography: Technical details and validation

3.1 Creating actors

Unlike models that start with a pre-existing database and project that population forward, DYSEM creates all actors at birth by sampling from a distribution. The distribution consists of three separate subpopulations: the population at July 1, 2011, the number of people born after that date, and the number who immigrated after that date. DYSEM users specify the total number of actors that they wish to be modelled in a simulation, and can vary the distributions of the subpopulations, which are stored as parameters. With this information, DYSEM creates the desired number of actors by randomly sampling from the overall distribution. The final results are weighted to represent the total population. With this methodology, users can run small simulations (fewer actors) for testing purposes, medium simulations for most purposes, and extremely large simulations to oversample and create more precise results for rare populations (for example, residents of Nunavut or individuals living past age 95).

After their creation, actors are assigned additional characteristics in accordance with these subpopulations, as discussed below.

3.2 Starting population – July 1, 2011

DYSEM creates a starting population that is consistent with Statistics Canada's population estimates for July 1, 2011. Individual actors are assigned a year of birth (from 1901 to 2011), sex, and province of residence (10 provinces and 3 territories) as of July 1, 2011, according to a random draw from the distribution of the population in the population estimates.

These characteristics are used to impute each actor's province/territory of birth, according to a custom tabulation from the 2011 Census. Immigrants in the starting population are assigned "Born Abroad" as their province of birth.

Individuals are randomly assigned a birthday within their year of birth. Immigrants in the starting population are also assigned an age at immigration to Canada, according to the distribution observed by year of birth and sex in custom tabulations from the 2011 National Household Survey (NHS).

Although individuals in the starting population are modelled from their birth, demographic processes such as mortality, emigration, and interprovincial migration are suspended until July 1, 2011, in order to reproduce the population estimates as of that date. Modelling these individuals from their birth rather than imputing them solely at July 1, 2011, provides additional flexibility.

5. For more information on Modgen see Statistics Canada (n.d.).

3.3 Additions to the population - Births and immigrants

DYSEM creates new actors (births and immigrants) in each year of the simulation from July 1, 2011, onward. The number of new actors is determined by modifiable parameter tables. These new actors are not related to existing actors in the simulation—that is, fertility is not modelled, and no parent/child links are created between actors. A random draw is used to assign sex and province of residence to new actors upon their birth or immigration to Canada according to the distribution of the relevant subpopulation in the parameters. Immigrants are assigned an age at immigration in the same manner.

As a default, the number of births and immigrants each year, by sex and province of residence, is drawn from Statistics Canada's 2015 population projections, M1 scenario (Statistics Canada 2015*a*). In this scenario, it is assumed that fertility rates increase modestly in all provinces and territories from 2011 to 2021, after which they are held constant. It is also assumed that the rate of future immigration remains comparable to the recently observed medium-term average, while reflecting observed provincial/territorial differences (Bohnert and Dion 2015). The characteristics of new immigrants are assumed to remain stable in the future.

Estimates for the number of projected births and immigrants in 2013 were assumed to apply to 2011 and 2012 as well (reduced by half for 2011 because only additions after July 1 need to be modelled).[6]

3.4 Emigration after July 1, 2011

DYSEM simulates emigration to other countries. Starting in the second half of 2011, each individual faces a hazard[7] of emigrating. These hazard rates are used to determine a waiting time until emigration by drawing randomly from an exponential distribution. Emigration hazards vary by age, sex, and province of residence. The random waiting times are re-estimated whenever one of these attributes changes. Simulation of individuals ends at their emigration.

Return migration—individuals who return to Canada after emigrating—is not modelled explicitly in DYSEM; instead, migration is implemented using "net emigration rates," which are calculated by summing the number of regular and net temporary emigrants and subtracting returning emigrants. A limitation of this approach, although minor in impact, is that the population modelled will be somewhat more stable, in terms of consistency of residence in Canada, than the actual population.

The default net emigration rates are those underlying Statistics Canada's 2015 population projections, M1 scenario. Net emigration rates in this scenario are assumed to remain constant over time. Discussion of these emigration concepts and details about this scenario are available elsewhere (Bohnert, Dion and Chagnon 2015).

3.5 Mortality after July 1, 2011

After July 1, 2011, each individual simulated in DYSEM faces a mortality hazard, which is used to determine a waiting time until death by drawing randomly from an exponential distribution. Users can choose one of two mortality hazards—national or province-specific. These vary by age,

6. Technical differences between the starting populations for DYSEM and the population projections, as well as DYSEM's emphasis on longer-term outcomes, made investing the resources to faithfully reproduce the 2011 and 2012 population estimates unattractive.
7. A hazard rate is the proportion of the population affected by a risk in a given time period. In DYSEM, the hazard rates associated with different events are typically transformed into competing waiting times to determine not only which events happen to an individual, but also, the timing of these events.

sex, and calendar year. The random waiting times until death are re-estimated whenever one of these parameters changes. Simulation of individuals ends at their death.

The default mortality hazards used are those underlying Statistics Canada's 2015 population projections, M1 scenario. Projected average life expectancy for males rises from 79.3 in 2010 to 87.6 in 2062/2063; for females, it increases from 83.6 to 89.2 (Dion et al. 2015).

Because projected mortality hazard rates were not available for 2011, those for 2012 were applied for the second half of 2011.

3.6 Interprovincial migration after July 1, 2011

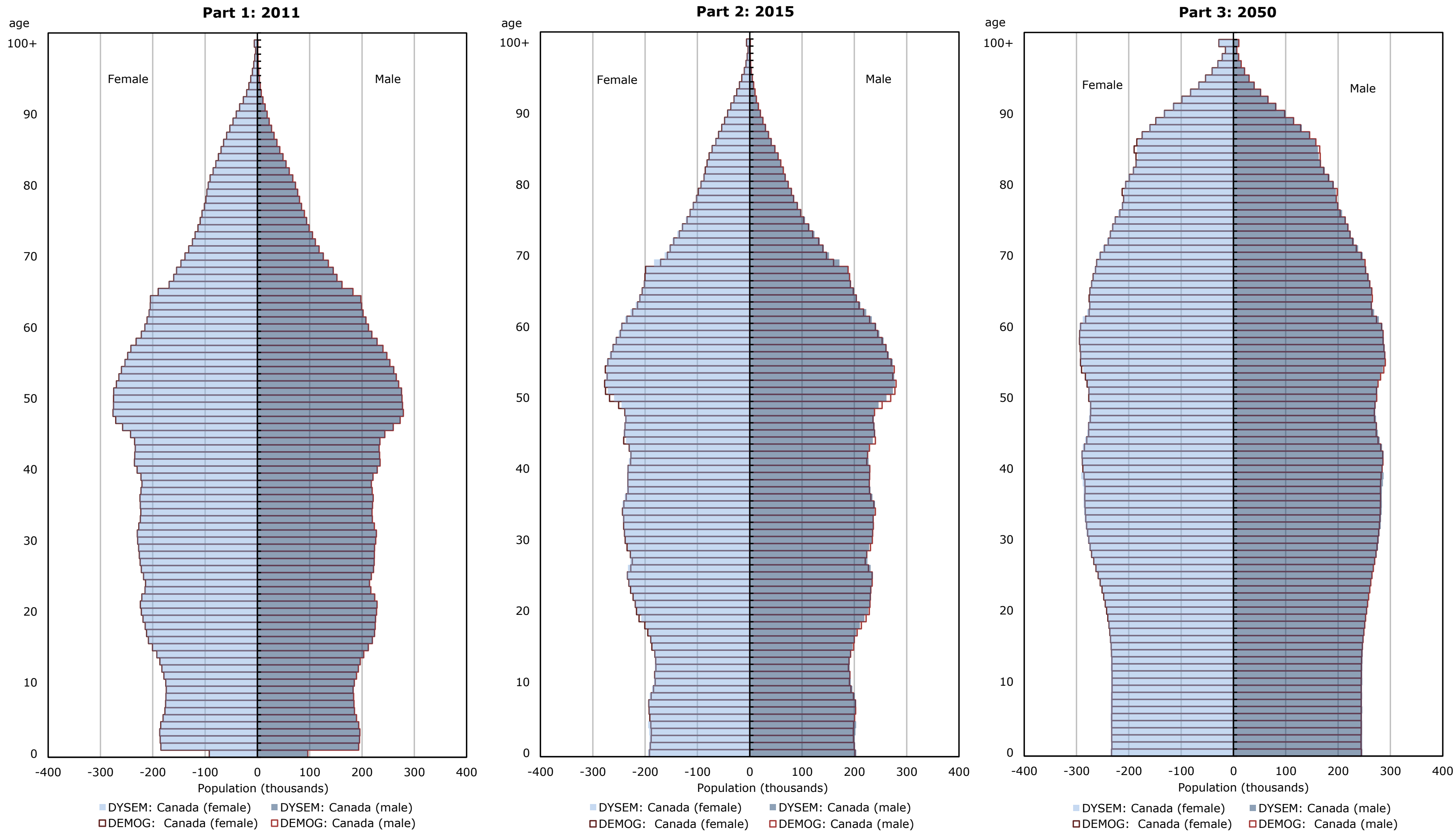
Interprovincial migration (changes in province or territory of residence) is modelled by applying annual transition probabilities to each actor, starting in the second half of 2011. After 2011, they are applied at the beginning of each year. These probabilities are disaggregated by sex, age and current province or territory of residence. Probabilities are set for individuals moving from their current province or territory of residence to each of the remaining twelve. The probability of not moving is calculated as the residual (1 minus the sum of all the probabilities of moving to the other provinces and territories).

The parameters for projecting interprovincial migration were adapted from a series of age-, sex-, origin- and destination-specific transition rates computed for the M1 scenario of Statistics Canada's population projections for the provinces and territories. In this scenario, it is assumed that the transition rates in the first projection year correspond to the average annual rates observed between 1991 and 2011, and that they evolve over time (to take into account the changes in the shares of the regions of the total Canadian population). This adjustment over the course of the projection aims to stabilize the projected net migration of the regions, and is applied every projection year (Dion 2015). In DYSEM, a set of baseline transition probabilities is used the first year, and these probabilities are modified according to a series of adjustment factors reflecting variations observed in the M1 scenario. Generally, the M1 scenario suggests that British Columbia and Alberta experience positive net interprovincial migration, whereas Ontario and Prince Edward Island experience near-zero net migration, and the other provinces, negative net migration.

3.7 Validation of demographic results

Population pyramids effectively demonstrate the net impact of all demographic processes combined—births, deaths, immigration, emigration and interprovincial migration. Chart 1 compares the population pyramid for Canada generated by DYSEM with the population pyramid provided by population estimates and population projections for three points in time—the end of 2011, 2015, and 2050—the DYSEM results (shown in blue) and demographic estimates/projections (shown in red) are overlaid. Counts for females are shown to the left of center, and for males, to the right. Results are displayed by single year of age, from age zero at the bottom of the pyramids to 100+ at the peak.

Chart 1
Population pyramid, 2011, 2015 and 2050, DYSEM demographic estimates and demographic projections, Canada



Sources: Statistics Canada, 2015, *Population Projections for Canada (2013 to 2063), Provinces and Territories (2013 to 2038)*, scenario M1, and Statistics Canada, DYSEM version 1.0, custom tabulation.

The DYSEM results for 2011 have been validated against the population estimates used in the imputation of its starting population, and confirm the accuracy of the process—the DYSEM and population estimates are indistinguishable (Chart 1).

The DYSEM results for 2015 and 2050 have been validated against Statistics Canada's 2015 official population projections, M1 scenario. Because the assumptions and methods used to project future outcomes in DYSEM were chosen to replicate these official projections as closely as possible, a strong match is expected. For this validation, provincial-level rather than national mortality rates were used.

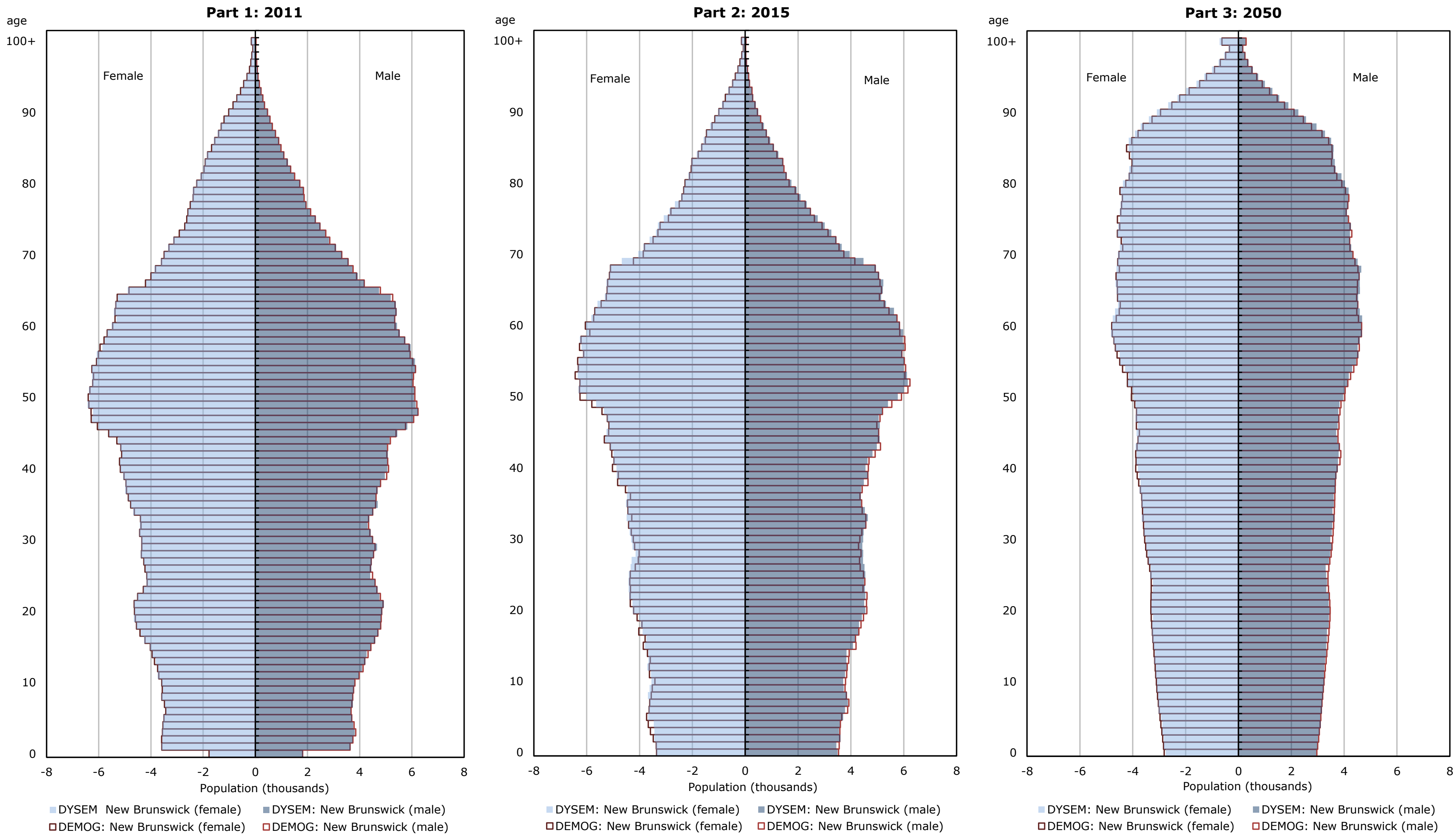
Overall, DYSEM results match the official population projections for 2015 and 2050 very closely. The main reason why they would not be identical after 2011 is that they use different starting populations. DYSEM uses the official population estimates at July 1, 2011, as its starting population and moves it forward, whereas the 2015 population projections use the population estimates at July 1, 2013, as its starting population. Any divergences between DYSEM's assumptions for births, deaths, emigration, immigration, and interprovincial migration in that 24-month period and actual observed outcomes will create ongoing differences between DYSEM results and the official population projections. Indeed, between 2015 and 2050, the differences between the two sets of results are pushed up the population pyramid, leaving virtually no differences in the younger half of the population.

Charts 2, 3, and 4 present the same information for New Brunswick, Saskatchewan and Nunavut, respectively. The population pyramids of these jurisdictions reflect differing demographic histories and projected trends. They also represent relatively small populations—in 2011, 2.2% of the Canadian population resided in New Brunswick; 3.1%, in Saskatchewan; and 0.1%, in Nunavut.

DYSEM reflects the differences in the population pyramids between these three areas. The differences in 2015 are more pronounced, especially in Saskatchewan. But DYSEM reproduces the population projections well by 2050. The precision and fine-level of detail in these validation results are attributable to an unusually large simulation performed to minimize Monte Carlo variability.[8]

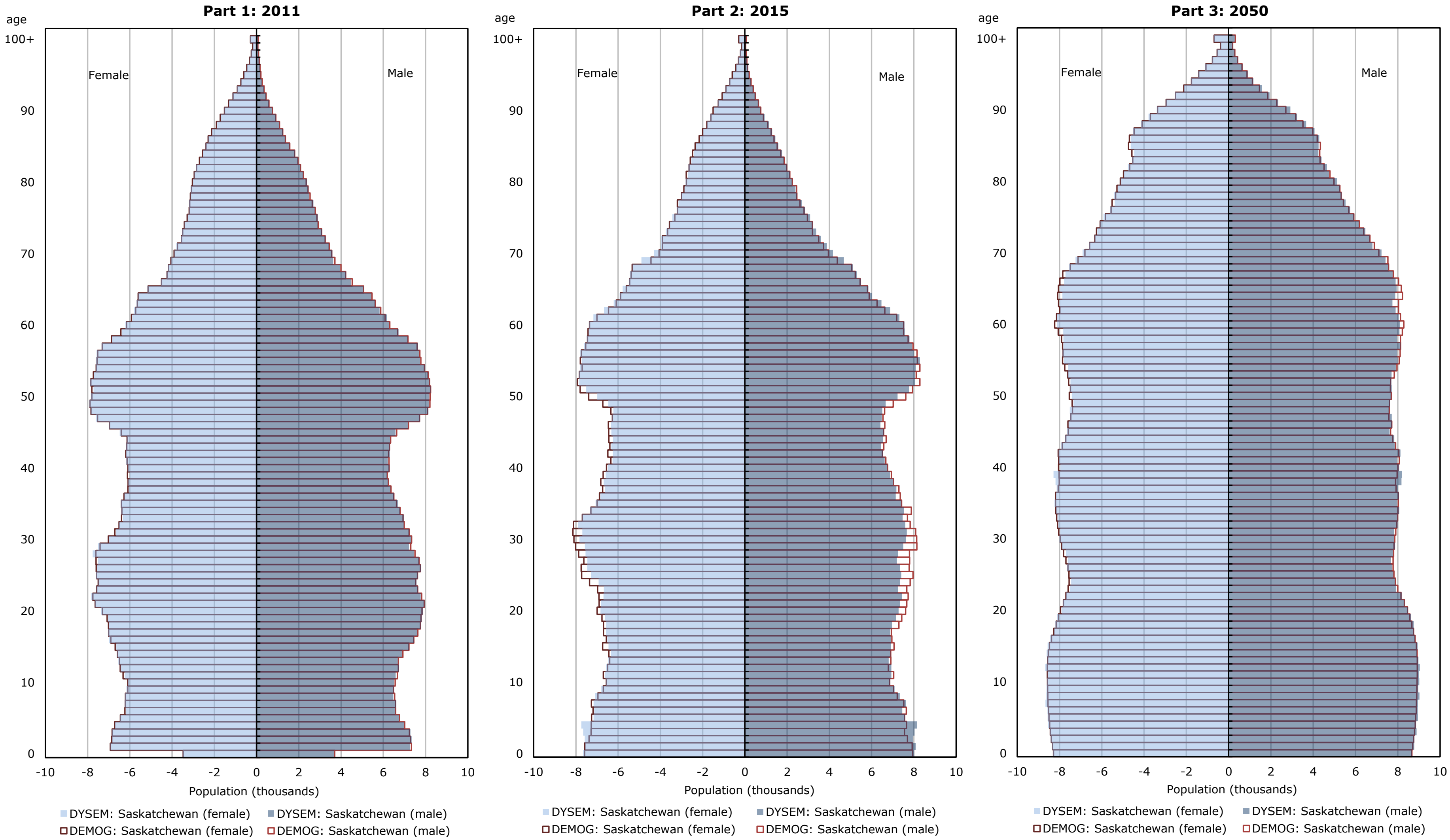
8. Microsimulation models tend to make heavy use of random number generators to determine which actors are affected by which risks or events, and with what timing. This is necessary to create diverse realistic outcomes for the population of actors being simulated. Monte Carlo variability is the variability of the model outputs associated with the specific stream of random numbers underlying a particular simulation. It can be rendered insignificant by simulating a large enough number of actors.

Chart 2
Population pyramid, 2011, 2015 and 2050, DYSEM demographic estimates and demographic projections, New Brunswick



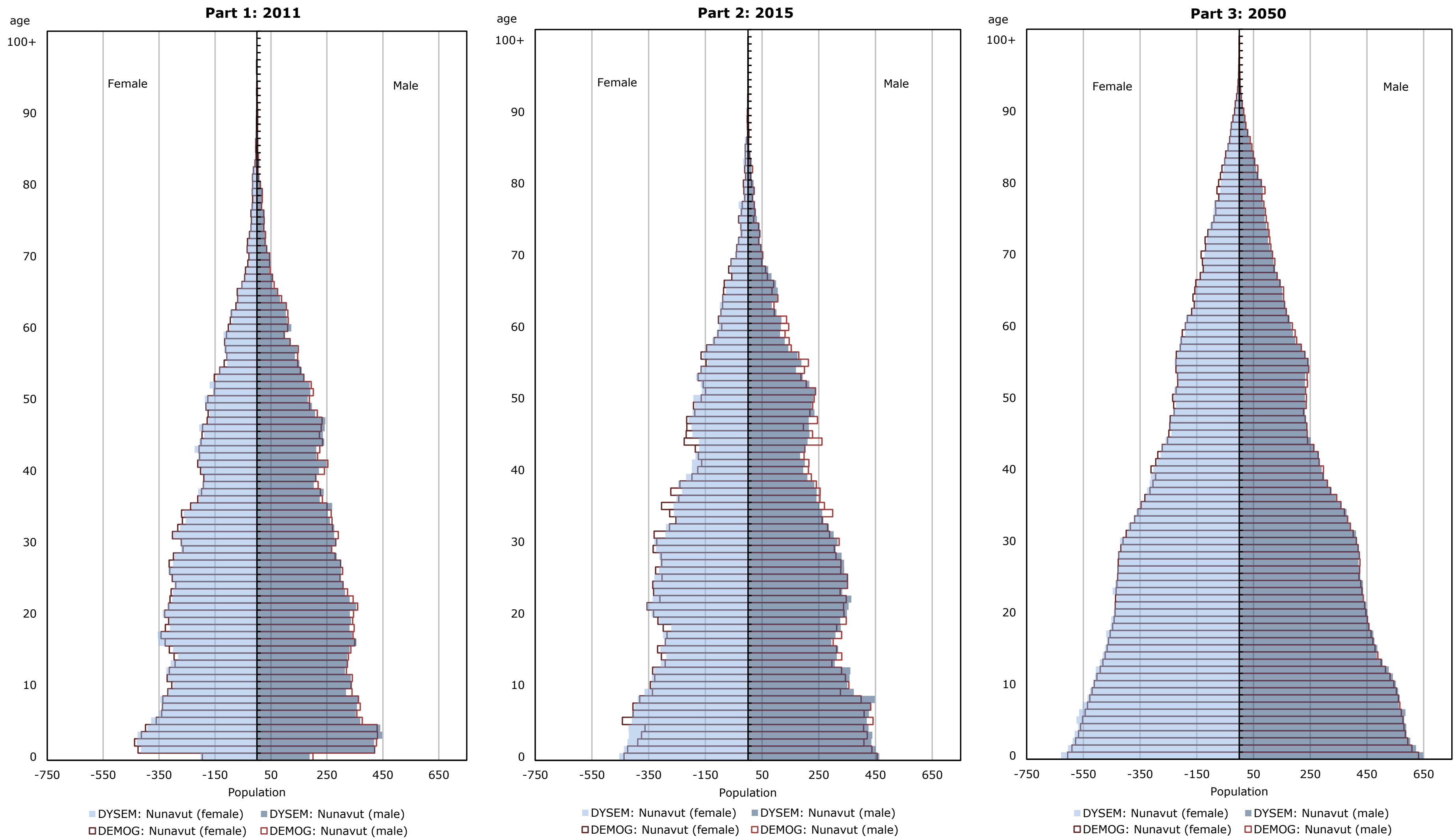
Sources: Statistics Canada, 2015, *Population Projections for Canada (2013 to 2063), Provinces and Territories (2013 to 2038)*, scenario M1, and Statistics Canada, DYSEM version 1.0, custom tabulation.

Chart 3
Population pyramid, 2011, 2015 and 2050, DYSEM demographic estimates and demographic projections, Saskatchewan



Sources: Statistics Canada, 2015, *Population Projections for Canada (2013 to 2063), Provinces and Territories (2013 to 2038),* scenario M1, and Statistics Canada, DYSEM version 1.0, custom tabulation.

Chart 4
Population pyramid, 2011, 2015 and 2050, DYSEM demographic estimates and demographic projections, Nunavut



Sources: Statistics Canada, 2015, *Population Projections for Canada (2013 to 2063), Provinces and Territories (2013 to 2038)*, scenario M1, and Statistics Canada, DYSEM version 1.0, custom tabulation.

4 DYSEM education: Technical details and validation

4.1 Modelling of educational attainment

DYSEM models four levels of educational attainment: less than high school graduation, high school graduation, graduation from postsecondary education below a bachelor's degree, and graduation with a bachelor's degree or above. The goal is to simulate realistic timing for educational attainment; no attempt is made to model school attendance. This model has been adapted from earlier work for the Demosim microsimulation model (Spielauer 2014).

To model educational attainment, the following baseline models were first estimated using the General Social Survey 15 (2001):

- Three logistic regression models for high school graduation (representing graduation at ages 16 to 20, 20 to 25, and older than 25). These were estimated separately because of different cohort trends.
- Two logistic models for first degree or diploma after high school (bachelor's degree or postsecondary diploma below a bachelor's degree).
- A logistic model for a bachelor's degree graduation following receipt of a lower postsecondary diploma.

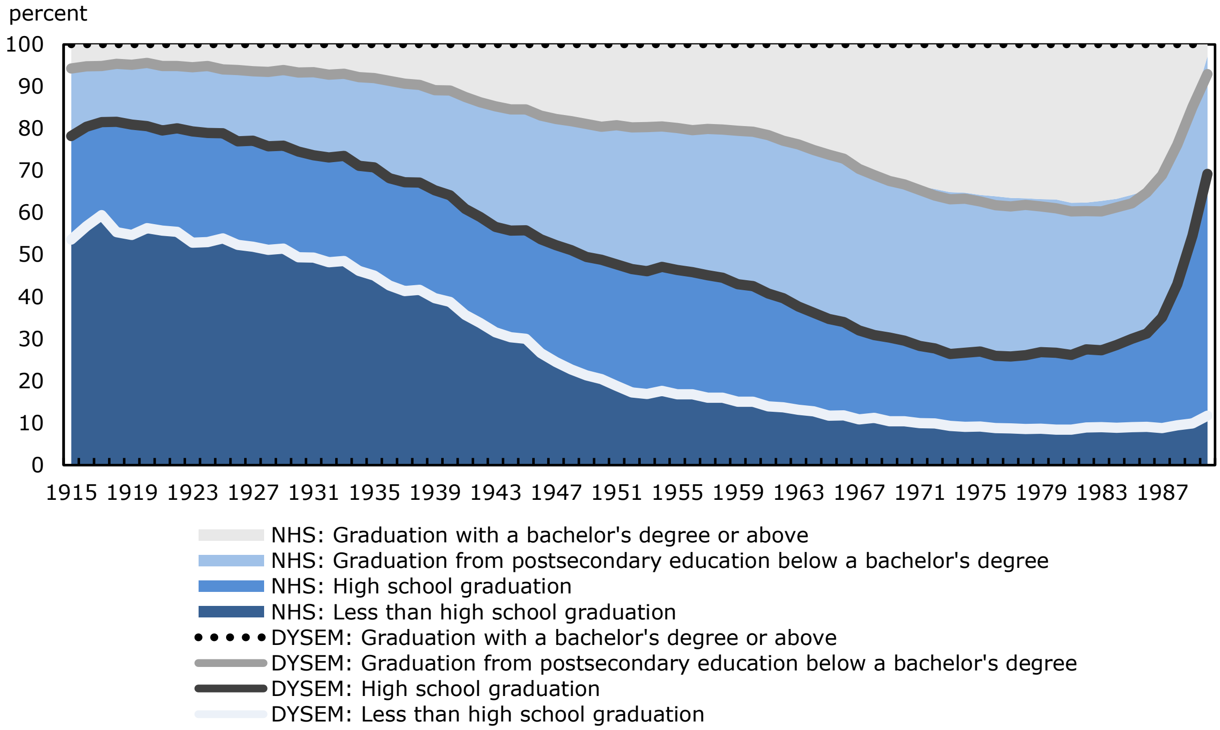
The baseline models were estimated using age, sex, birth cohort, immigrant status, and duration since previous graduation as explanatory variables. Province-specific calibration factors were applied to match cross-sectional outcomes of the 2011 NHS by province of birth (immigrants are assigned "outside Canada" for province of birth).

The estimated cohort trends were extrapolated into the future for some time, then levelled off to prevent unreasonably high bachelor's degree graduation rates, similar to the assumptions in the Demosim model (Spielauer 2014). For this purpose, the average of the 1985-to-1989 birth cohorts was used for high school graduation for those born after 1989, and the average of the 1981-to-1985 birth cohorts was used for postsecondary and bachelor's degree graduation for those born after 1985. Inter-provincial differences were assumed to remain constant.

4.2 Validation of education modelling

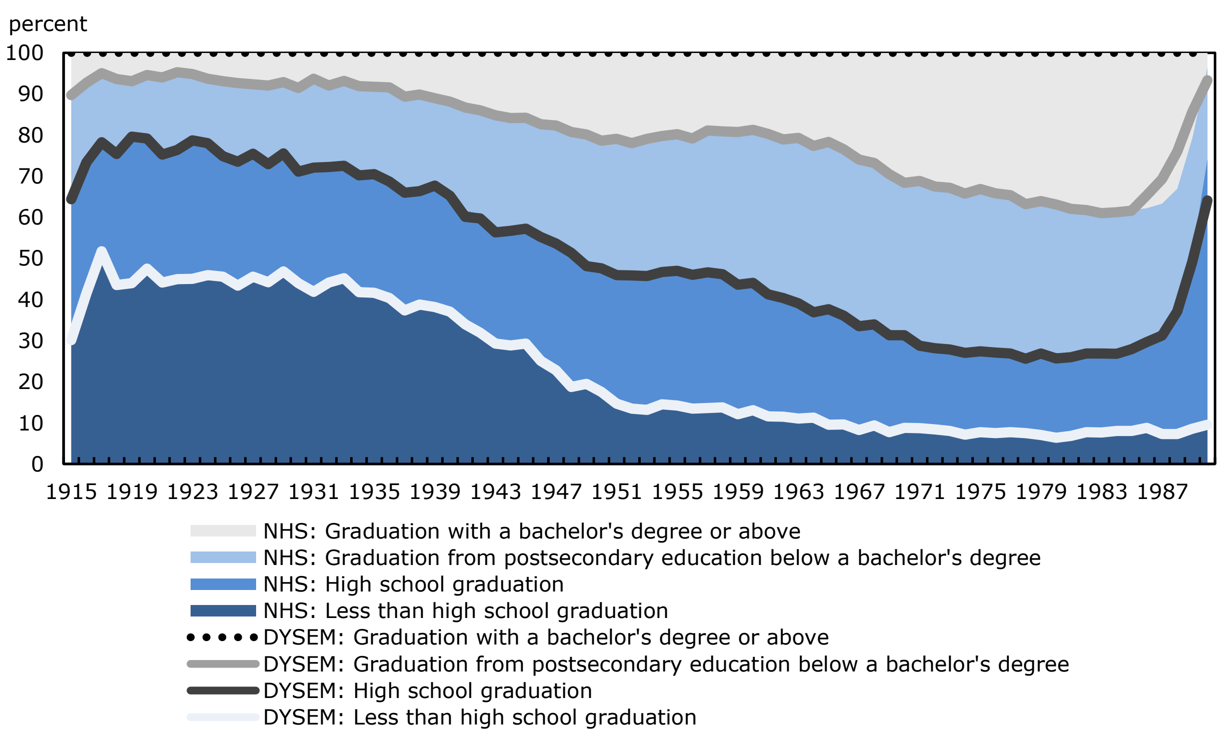
The methodology used in DYSEM produces educational attainment outcomes that closely match those from the 2011 NHS, including provincial variation. To demonstrate, Chart 5 compares the national estimates of educational attainment for women in 2011 by year of birth from DYSEM and the NHS. Charts 6 and 7 compare estimates for women living in Ontario and Manitoba, respectively.

Chart 5
Educational attainment in 2011 by birth year, all women residing in Canada



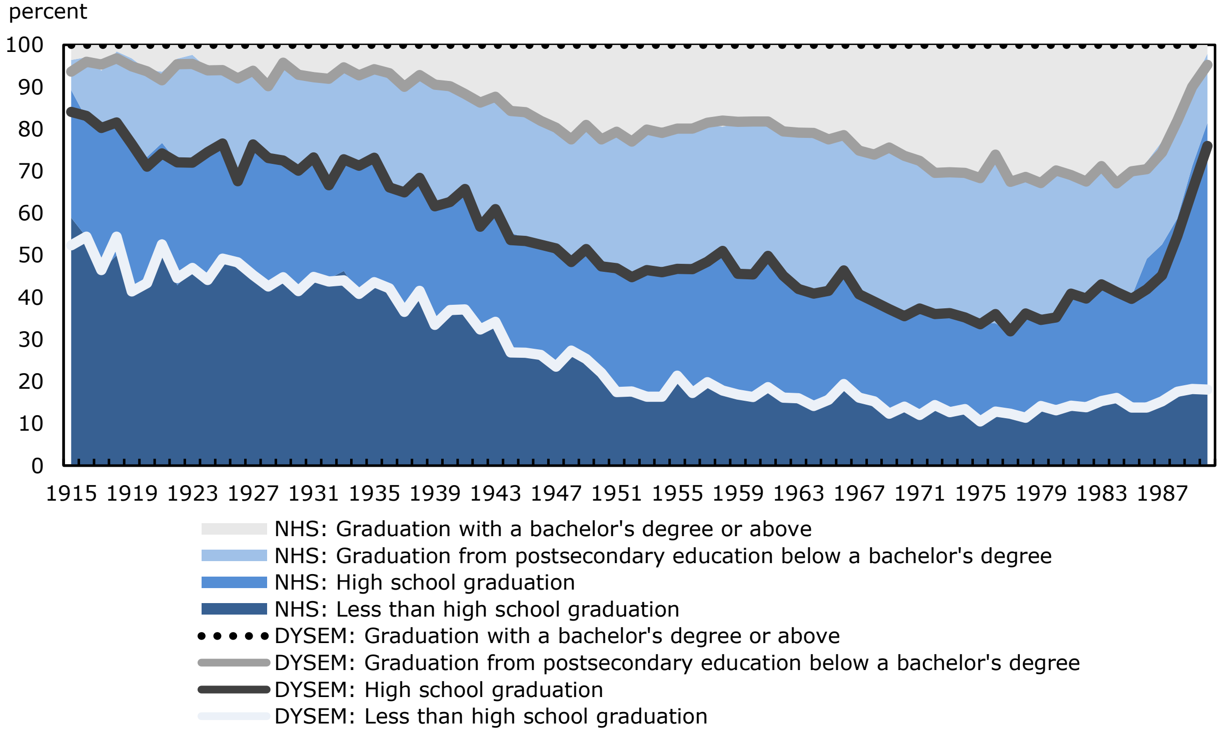
Sources: Statistics Canada, 2011 National Household Survey (NHS), and DYSEM version 1.0, custom tabulation.

Chart 6
Educational attainment in 2011 by birth year, all women residing in Ontario



Sources: Statistics Canada, 2011 National Household Survey (NHS), and DYSEM version 1.0, custom tabulation.

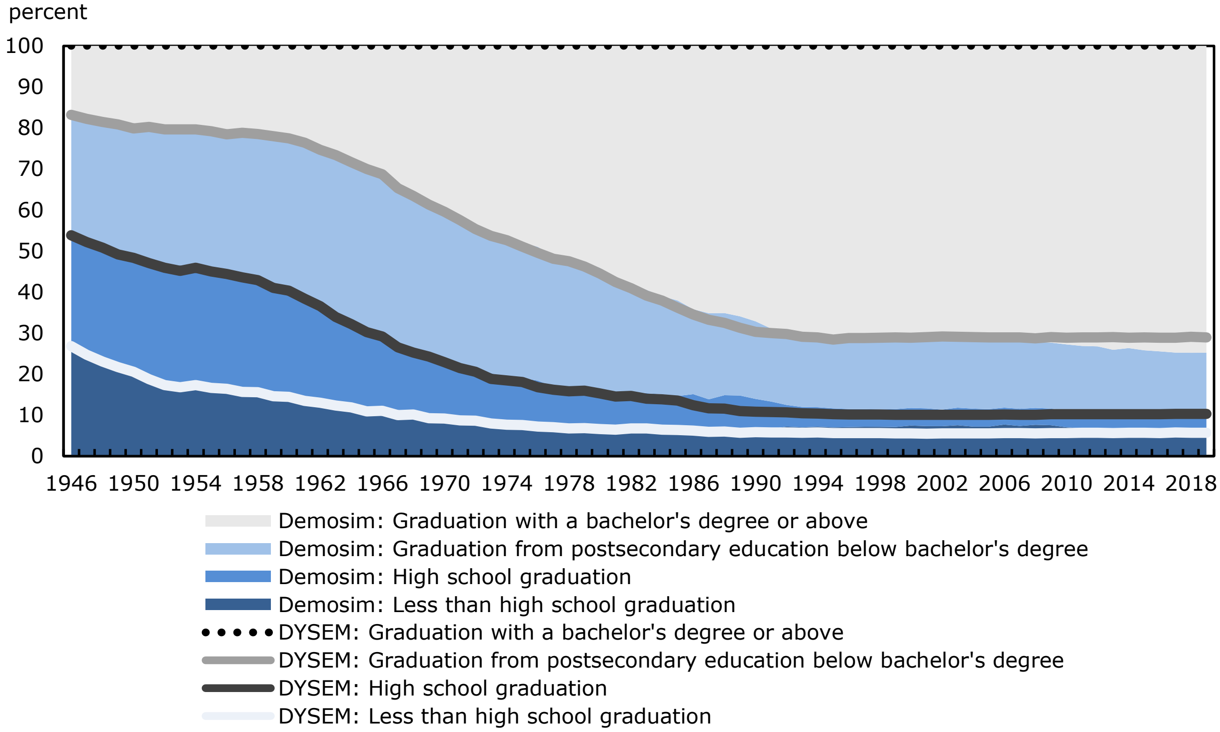
Chart 7
Educational attainment in 2011 by birth year, all women residing in Manitoba



Sources: Statistics Canada, 2011 National Household Survey (NHS), and DYSEM version 1.0, custom tabulation.

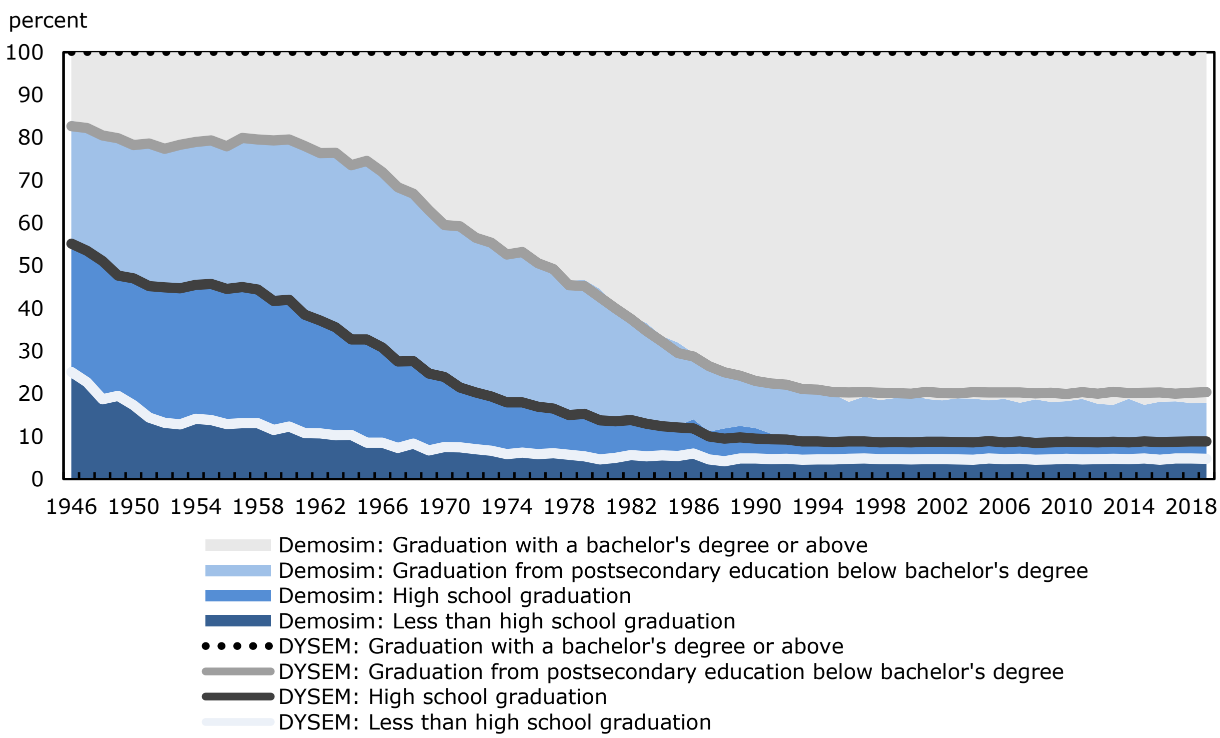
Charts 8 to 10 compare DYSEM and Demosim outcomes, showing the projected highest level of educational attainment at age 65 for women born between 1946 and 2018. The DYSEM results are similar for Canada and Ontario, but less so, for Manitoba. This is as expected—visible minority status and Aboriginal identity are individual characteristics projected in Demosim and used as covariates in its educational attainment model. This is not the case in DYSEM, so its results are insensitive to changes in the composition of the population over time in regard to these characteristics.

Chart 8
Educational attainment at age 65 by birth year, all women residing in Canada



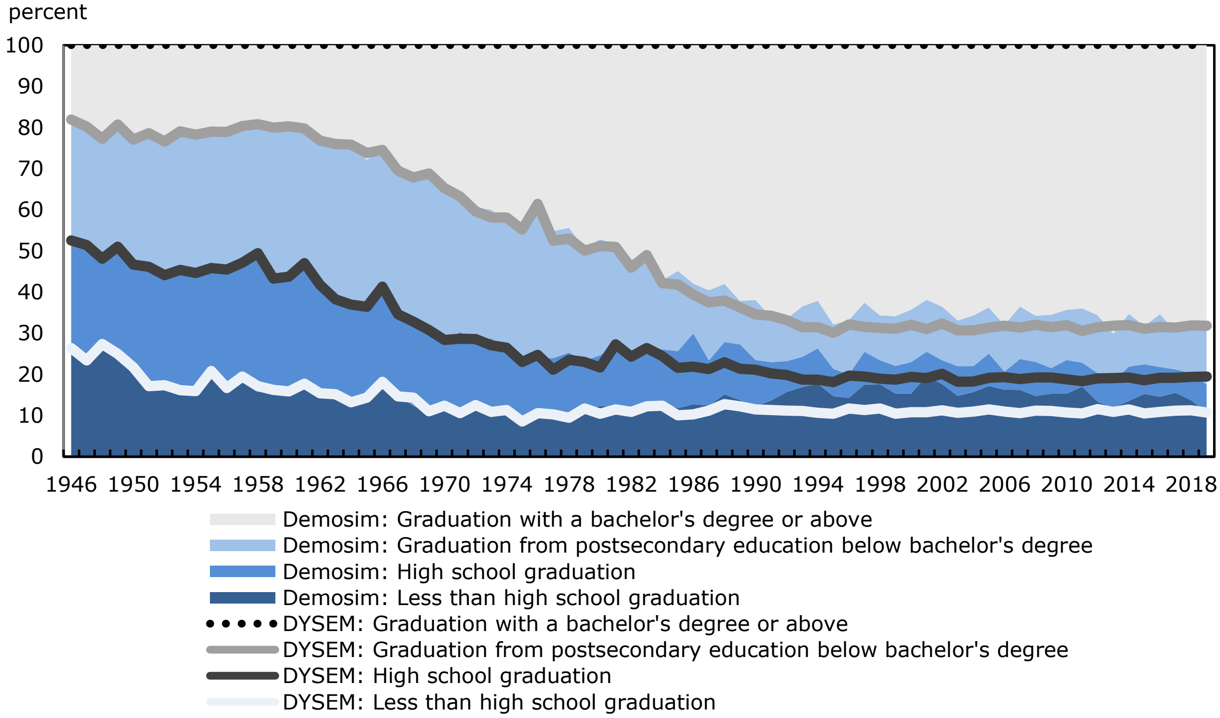
Sources: Statistics Canada, Demosim 2015, custom tabulation, and DYSEM version 1.0, custom tabulation.

Chart 9
Educational attainment at age 65 by birth year, women born in Ontario



Sources: Statistics Canada, Demosim 2015, custom tabulation, and DYSEM version 1.0, custom tabulation.

Chart 10
Educational attainment at age 65 by birth year, women born in Manitoba



Sources: Statistics Canada, Demosim 2015, custom tabulation, and DYSEM version 1.0, custom tabulation.

5 Potential applications

Microsimulation developers can build on the DYSEM platform to incorporate the additional socioeconomic aspects of the actors' simulated lives necessary to address their particular research questions.

For example, an application developed using DYSEM could explore research questions relating to the long-term care of the elderly. The model could be used to examine various scenarios for the projected future use of long-term facilities (or nursing homes), the costs associated with such care, and allocation of these costs between governments and individuals. Such research could explore different scenarios for mortality, nursing home availability or utilization, the cost of nursing home care, the income of seniors, and alternative government cost-sharing policies.

Such an application would require custom development that builds on the DYSEM platform. Specifically, modelling of the marital status and family income of the elderly, as well as individual utilization of nursing homes and home care, and associated provincial policies for user fees, could be added to the model core.

Similarly, microsimulation applications seeking to address research questions in other domains such as financial assistance programs for students, tax and transfer policies, caregiving, or retirement income policy would require custom extensions of the DYSEM core.

6 Conclusion

Dynamic microsimulation models offer uniquely valuable opportunities for socioeconomic research. Among the characteristics that make them unique are the integration of many data sources in their development to provide comprehensive empirical portraits, an emphasis on modelling realistic individual life histories, and the ability to meaningfully represent the complexity of diverse, actual populations through the simulation of millions of realistic individuals. Their focus on the micro (individual) level makes them ideal for framing and exploring policy-oriented “what-if” questions, and allows distributional analysis in all possible dimensions.

The DYSEM platform is a flexible and simple demographic and socio-economic core that can be built upon in the development of dynamic socioeconomic microsimulation models. The demographic events currently modelled are births, immigration, emigration, interprovincial migration, and mortality. The default scenario has been parameterized to reproduce Statistics Canada’s 2015 population projections, M1 scenario. DYSEM also models four levels of educational attainment; further development will include earnings. A series of validation tests have shown that the model performs as expected.

At this point, the DYSEM platform, with custom model extensions, can be used to address research questions in various domains.

More information about the DYSEM microsimulation platform itself and custom microsimulation applications can be obtained by contacting Statistics Canada’s Social Analysis and Modelling Division at statcan.microsimulation-microsimulation.statcan@canada.ca.

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