

Motivation

Singapore, like many other countries in Asia, is getting older, and more rotund. These rises bode ill for the future burden of type two diabetes (T2DM) in Singapore, a disease that is associated with aging and obesity.

We built an individual-level model of Singapore's population from 1990 to 2050, with individual BMI trajectories and genetic risk factors, to forecast the T2DM burden.

Data

Data come from official national statistics (<http://www.singstat.gov.sg>), the National Health Surveys (NHS) of 1992, 1998, 2004 and 2010, and the Singapore Prospective Study Programme (SP2):

- Census of 1990, 2000 and 2010: population count.
- Yearbook of Statistics Singapore (1990–2010): resident population by age group, sex & race; age-group mortality & fertility rates.
- Complete life tables 2003–2010 for resident population.
- Report on registration of birth and death 1990–2010.
- Obesity status and DM status by age group, sex & race.
- Longitudinal BMI and DM status (1992/1998 & 2005).
- Hazard ratio estimates of mortality by T2DM status for different races (Ma et al 2003 AJE 158:543).

Framework

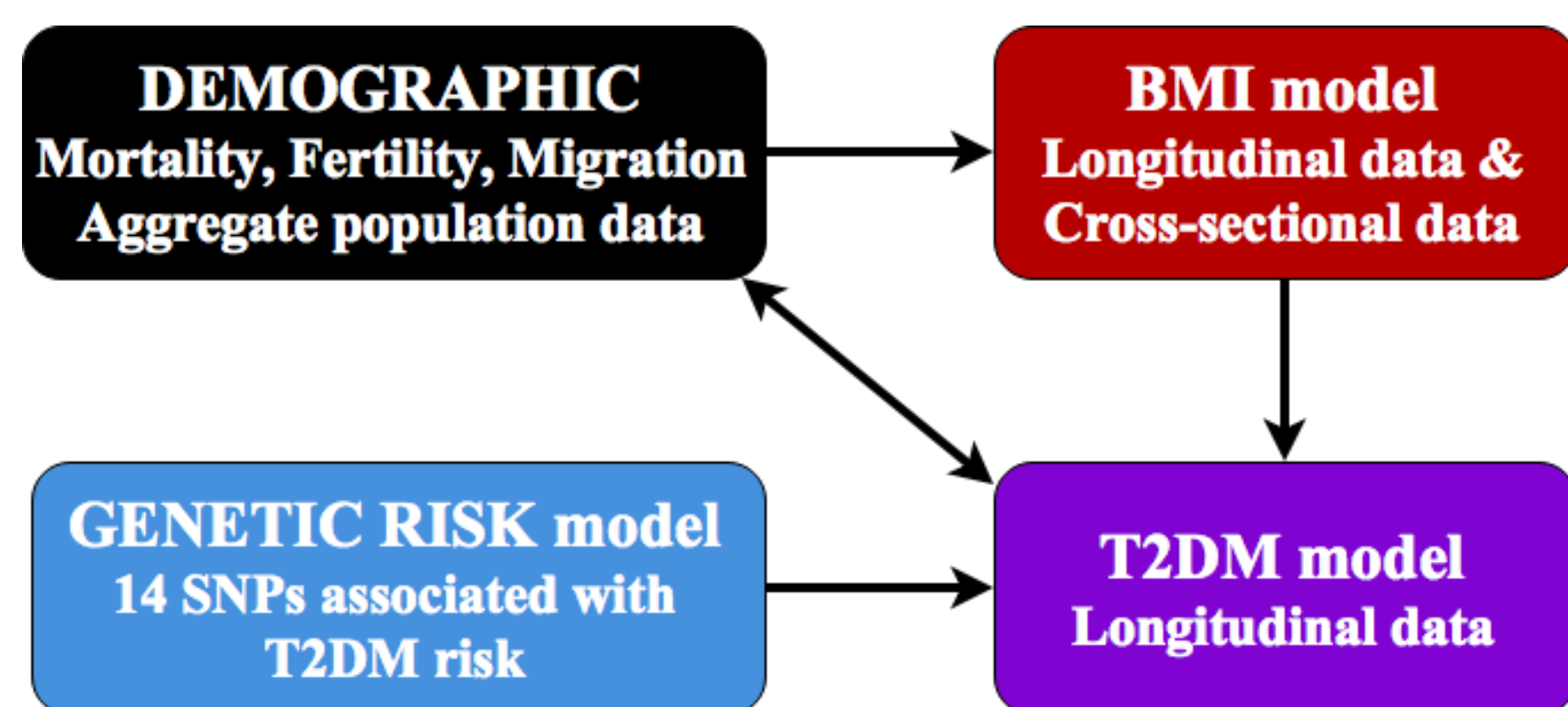


Figure 1: Overview of model structure.

Rates of demographic sub-models were disaggregated using Markov chain Monte Carlo (MCMC) techniques. A BMI model was parameterised using Approximate Bayesian Computation (ABC). A T2DM model was parameterised using importance sampling & MCMC.

After parameter estimation, a combined C++ routine brought together all the components to simulate individual life histories of all Singapore residents from 1990 to 2050.

Demographic model

This contained three subcomponents:

Mortality submodel

Mortality rate was parameterised using the Lee–Carter model, stratified by gender with secular trend of change in mortality rate as random walk with drift.

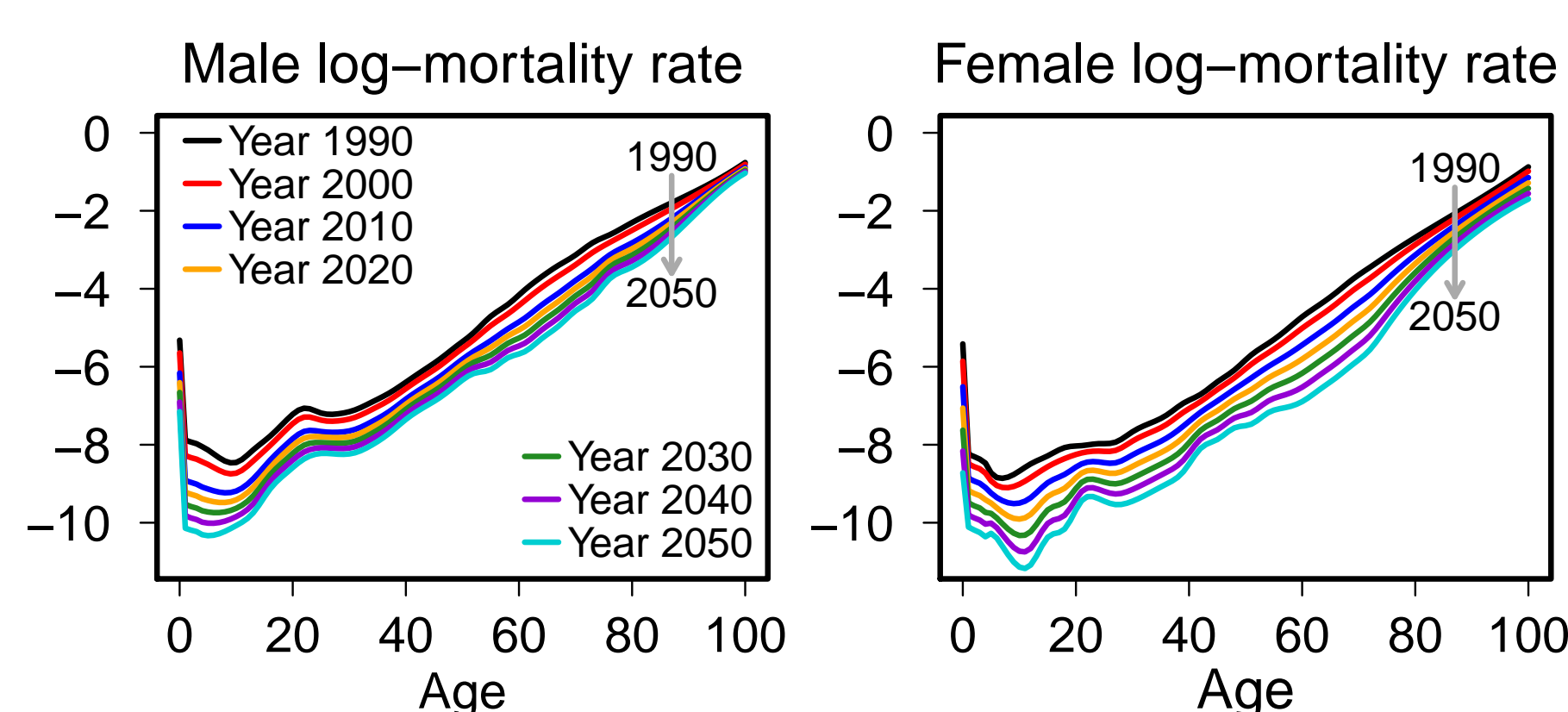


Figure 2: Overall mortality. Estimated by MCMC.

Race-specific mortality rates were modelled as proportional to the baseline mortality rate.

Fertility submodel

Fertility rates by age were modelled to follow a Gaussian function with secular trends on the peak age (linearly) and peak rate (random walk with drift), assuming proportional hazards for the effect of ethnicity. Projected fertility rates after 2010 assumed fertility rates remain at 2010 levels.

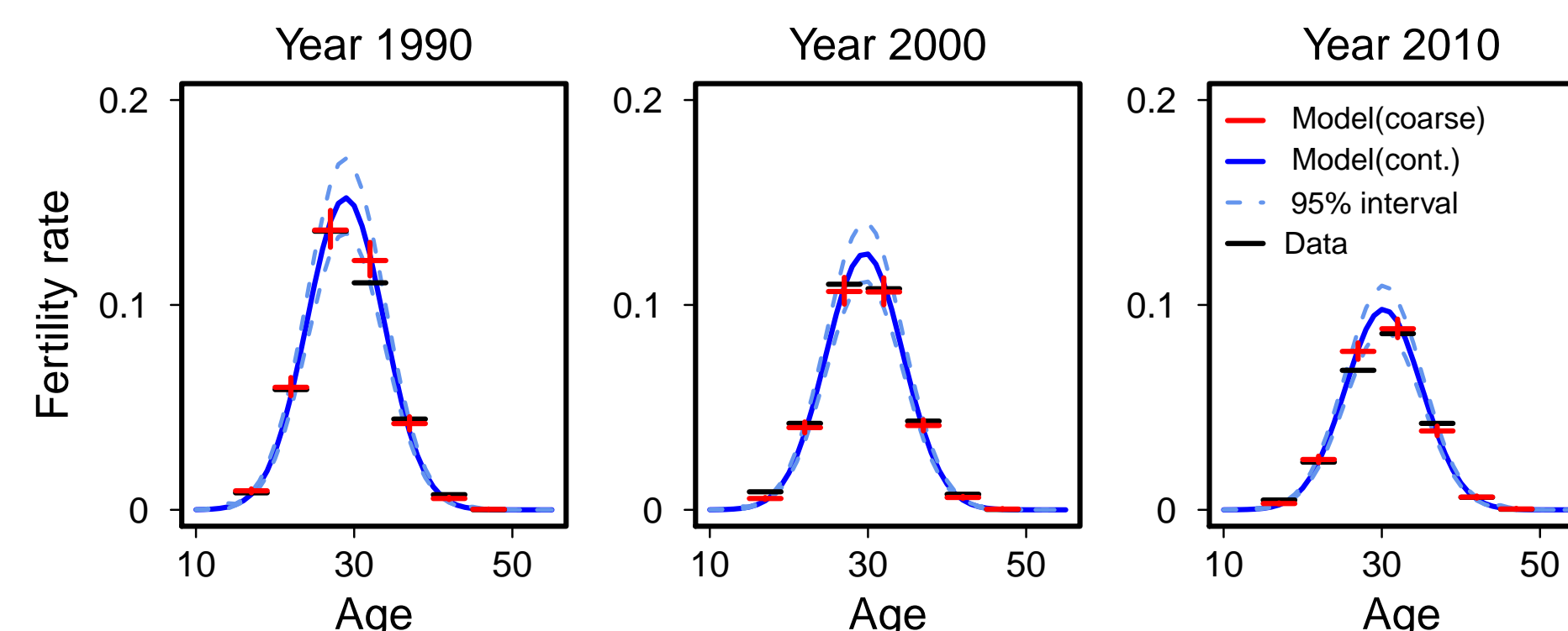


Figure 3: Overall fertility. Estimated by MCMC. These do not depend on parity but depend on age & time.

Migration submodel

A baseline migrant age profile curve was modelled based on the migration schedule model of Castro and Rogers stratified by ethnicity and gender, with a random effect applied to each year to reflect the economic situation and government policy changes.

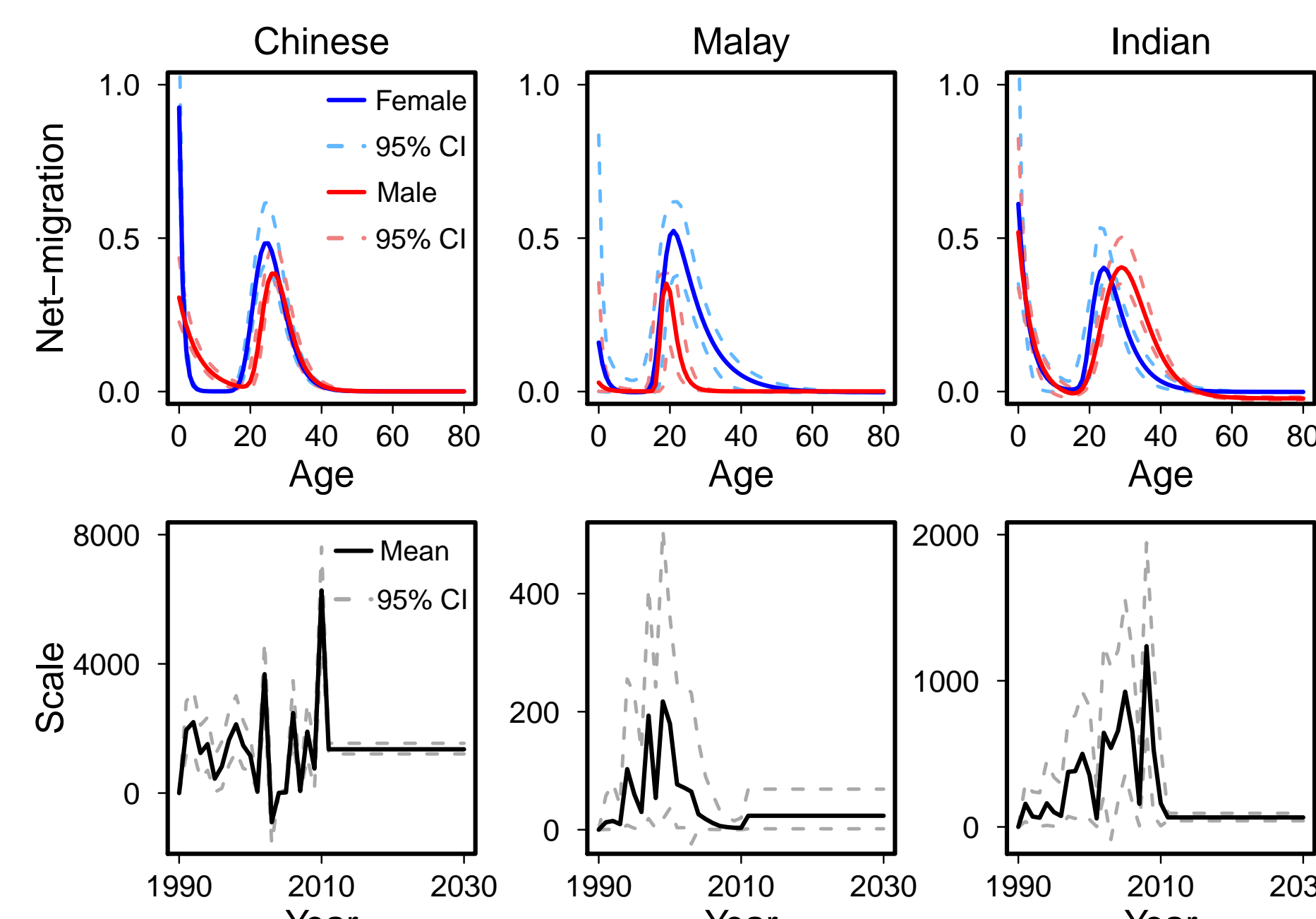


Figure 4: Migration profile. The inferred net age profile of migrants by race is top. The time effect is bottom.

BMI model

Individuals' BMI was fluctuated with Gaussian errors around an overall trend, generated from a cubic spline through BMI at age 18, 35, 55 and 75. To estimate BMI values at those points, parameters were drawn from a multivariate normal distribution with hyperparameters estimated independently for each race and sex combination.

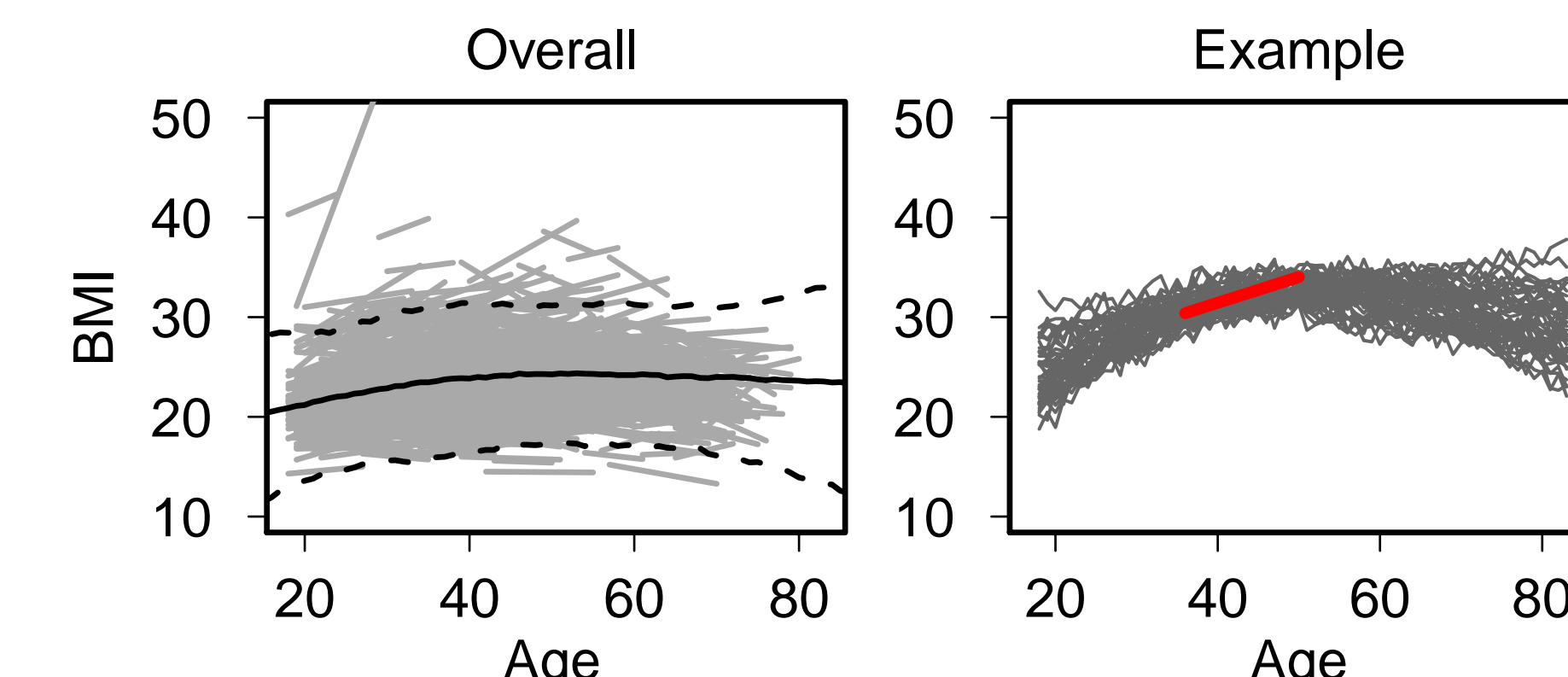


Figure 5: BMI model of Chinese Male group.

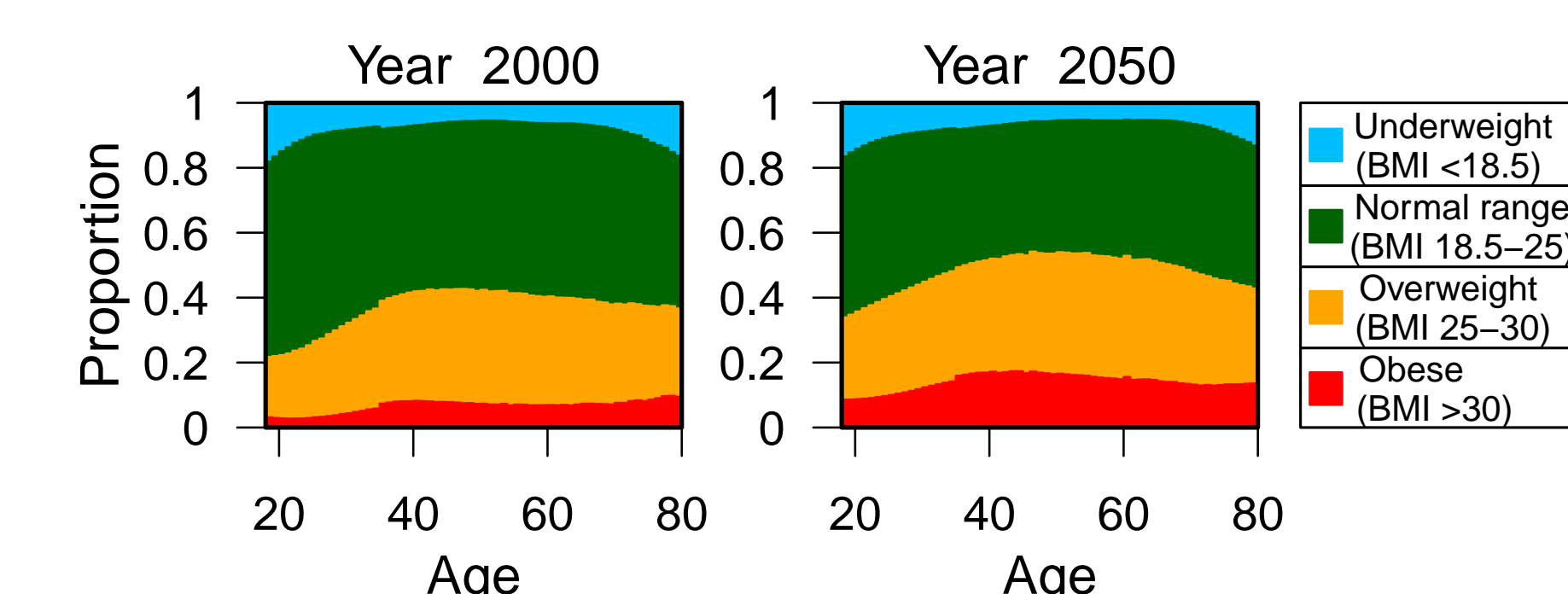


Figure 6: BMI distribution over time.

Genetic model

The joint distribution of 14 major SNPs associated with T2DM in the three main races of Singapore were determined from several cohort studies run by the SSHSPH. The frequency of all 16 000 odds ratios was then obtained for each race, with individuals' genetic risk randomly selected from this distribution.

T2DM model

An annual risk of developing T2DM for each non-diabetic was modelled with a logit link for the current BMI, age, race and sex. This risk was then estimated using MCMC on imputed BMI trajectories for participants in SP2, where the imputation was done using importance sampling.

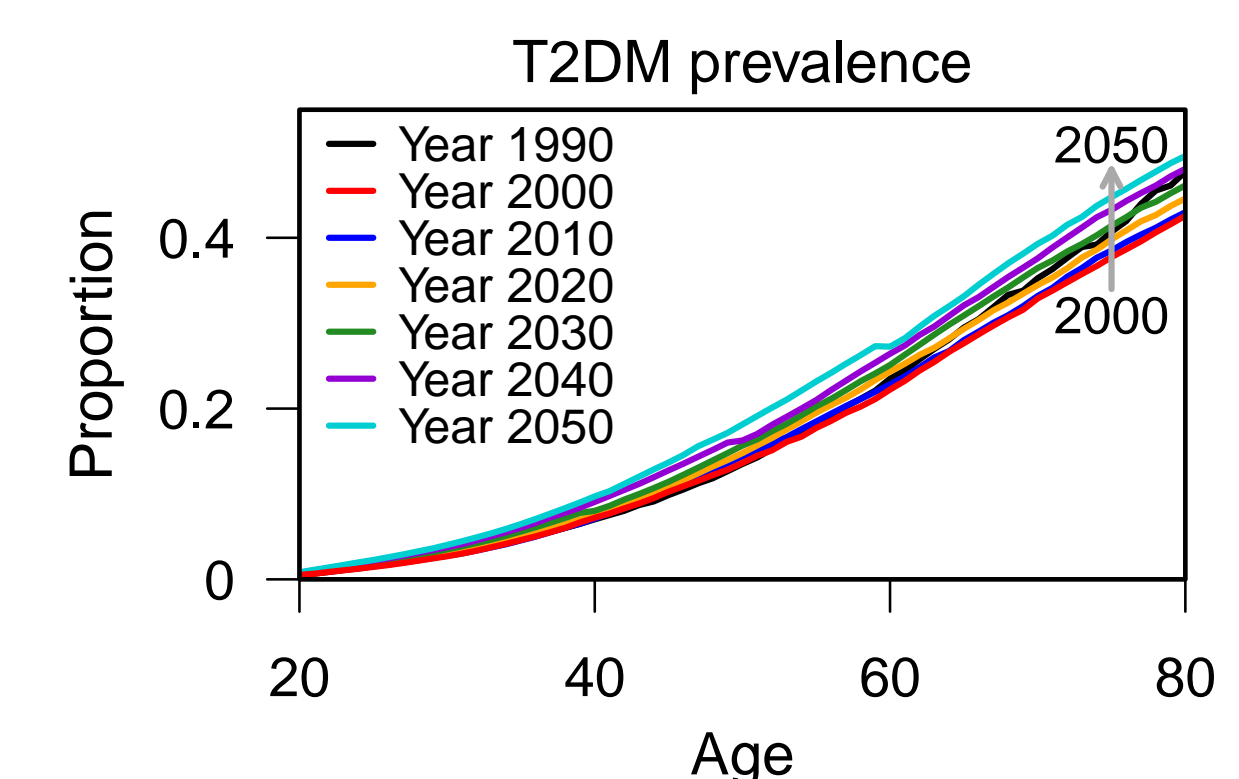


Figure 7: Proportion diabetic by age.

An alternative model in which the risk of DM is a function of age, race and sex alone is used as a sensitivity analysis.

Projection

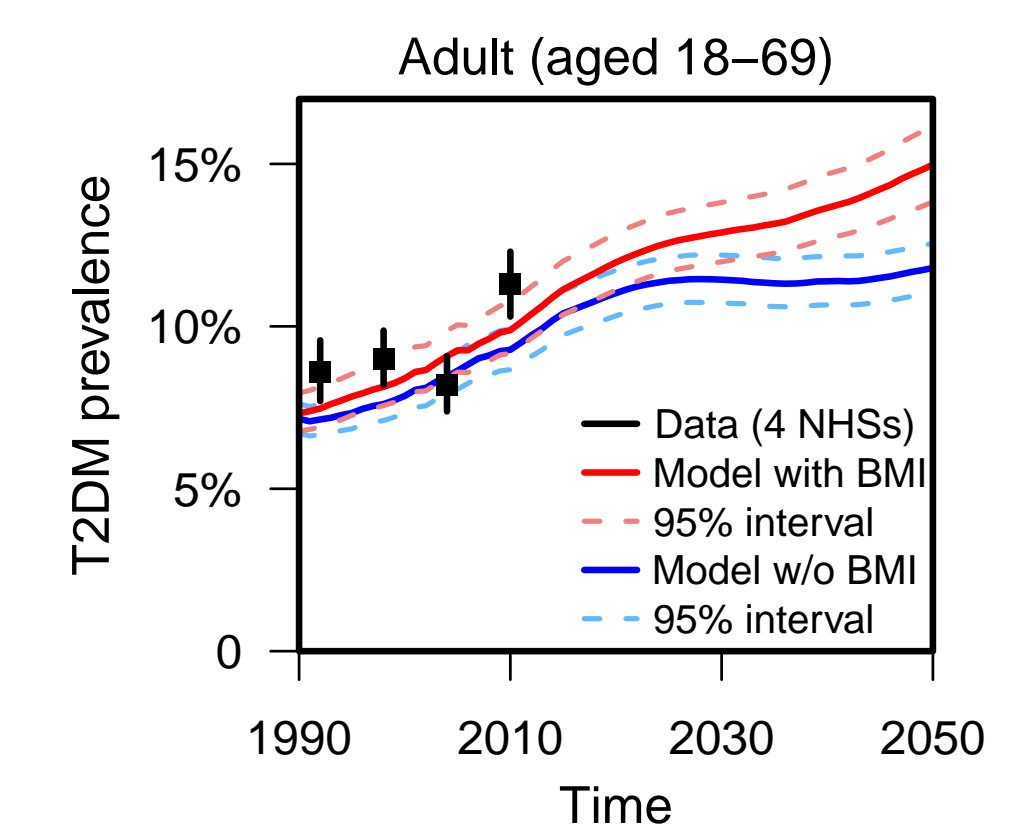


Figure 8: forecast DM prevalence for working age.

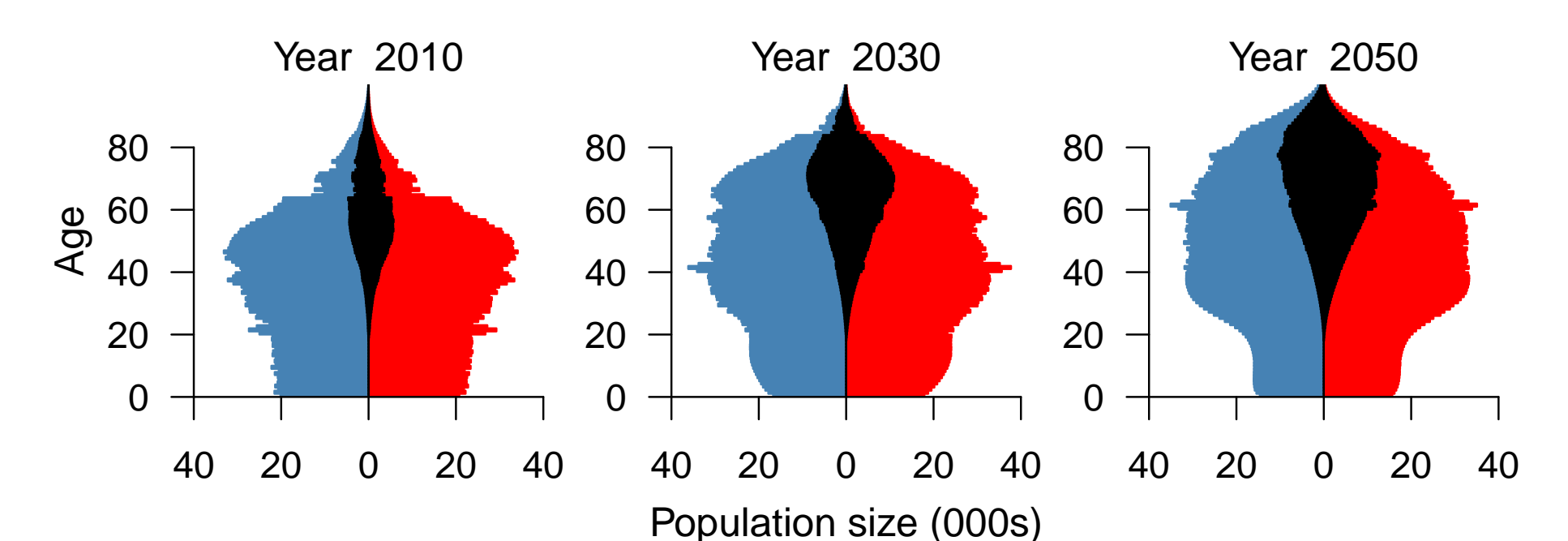


Figure 9: Evolving risk of DM in Singapore. Women in blue, men in red, diabetics in black.

Take-home message

- By 2050, of 100 adults who survive to age 70, about 50 will have developed T2DM.
- Accounting for the recent rises in obesity levels, we anticipate the diabetic population rising threefold from 360 000 to 950 000.

Reference

Phan, T., Alkema, L.,... Cook, A. (2014). Forecasting the burden of type 2 diabetes in Singapore using a demographic epidemiological model of Singapore. *BMJ Open Diabetes Research & Care*, 2(1): e000012.

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