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Disease burden, lifetime healthcare cost and long-term intervention impact projections among older adults in Singapore

In the format provided by the authors and unedited

Supplementary Information

Singapore FEM Technical Documentation

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1. Supplementary Method

1.1 Functioning of the dynamic model

1.1.1 Overview

The Future Elderly Model (FEM) is a microsimulation model used to project the future population's demographics, health conditions, and costs at an individual level. Goldman and his colleagues [1] initially developed the FEM model at the RAND Corporation to project future trends in health and healthcare costs to aid the decision-making process on the Medicare program in the United States. Since then, the FEM has been applied to analyze social and health issues in aging societies internationally [1-6]. The FEM has been adapted in multiple countries, including Singapore [7], Korea [8], Japan [5], and the US [9]. Research on international comparison of ageing trends projected by FEM was also conducted to investigate the similarities and differences between countries. The future disability prevalence stratified by education for Singapore and Korea older adults population was investigated [8].

The existing literature on applying FEM to the Singapore population focuses merely on Chinese older adults, without considering ethnic differences. This study is beneficial in addressing the disparities in ageing by ethnicity, given that huge ethnic differences exist in Singapore.

The FEM Singapore model was adapted to project comorbidities prevalence and inpatient costs in the next 30 years for Singapore older adults aged 51 and above. We incorporated data from Multi-Ethnic Cohort (MEC), The Well-being of the Singapore Elderly (WiSE) and The Singapore Longitudinal Aging Study (SLAS) in FEM. The FEM Singapore projected chronic diseases including diabetes, hypertension, heart diseases, and stroke; functional status including activities of daily living (ADL) and instrumental activities of daily living (IADL); and the lifetime hospitalization costs for Singapore older adults. The simulation started with a baseline cohort aged 51 and above based on MEC. During the simulation, new individuals aged 51 to 56 are added to each round of the simulation and individuals leave the simulation when deceased. The individuals transited to the next round of simulation based on transitional models, with their age, chronic disease status, disability status, and healthcare cost tracked throughout the simulation. We assumed no immigration effect on Singapore older adults. This technical document provides more information on the FEM-Singapore, the datasets used, estimations, and other efforts made to project ethnic disparities in the next 30 years.

1.1.2 Key components

The key components of FEM include:

a) A baseline cohort was used at the beginning of the simulation. We used the population aged 51 and above from MEC as the main data source, incorporated with disability information from SLAS and inpatient costs from WiSE. Individuals in FEM were characterized and tracked by their health status and socioeconomic status from period to period. At the beginning of each period, a replenishing cohort aged 51 to 56 entered the simulation to fill the age gap as the simulation proceeded.
b) Transitional models estimated the probability of moving into a different health status for every individual in the next simulation cycle. The risk factors accounted for include age, gender, ethnicity, education levels, BMI, smoking status, household income levels, marital status, and lagged chronic disease conditions. Transitional models predicted the probabilities of certain health or financial outcomes with a high level of heterogeneity maintained.
c) The individual-level dynamics were aggregated to the population level at the end of the simulation to obtain overall outcomes. The overall and ethnic-specific prevalence of chronic diseases and disabilities and the lifetime hospitalization costs were obtained.

1.2 Description of Datasets

1.2.1 The Singapore Multi-Ethnic Cohort (MEC)

The Singapore Multi-Ethnic Cohort (MEC) [10] was the main dataset used in our study. The first wave was collected from 2004 to 2010, and the second wave was collected from 2011 to 2016. The cohort was comprised of 14,465 individuals, of which 99.7% were from the three main ethnic groups in Singapore. Participants had a mean age of 46 ± 13 years, with the youngest participant age 21 and the oldest participant age 94. Sociodemographic information including age, gender, ethnicity, education, marital status, and socioeconomic information including monthly household income and housing type were collected. Moreover, lifestyle profiles, such as cigarette smoking and physical activity status, BMI, and self-reported chronic disease conditions were included. The self-reported chronic disease was revealed by participants' responses to the question: "Have you ever been told by a doctor that you have….(e.g. diabetes)?" The chronic conditions from MEC used in this study were diabetes, hypertension, stroke, and heart disease.

1.2.2 The Singapore Longitudinal Ageing Studies (SLAS)

The Singapore Longitudinal Ageing Studies (SLAS) [11] cohort is used to model functional disabilities in our study. The SLAS cohort involved 2800 Singaporean residents aged 55 and above. The data was collected through face-to-face interviews between 2003 and 2005, covering information on demographics, functional disability status, and chronic disease status. Participants' ability to perform the activities of daily living (ADL) and the instrumental activities of daily living (IADL) were used to reflect functional disability status. We used SLAS to predict MEC participants' functional disability status and to build transitional models for projection.

1.2.3 The Well-being of the Singapore Elderly (WiSE)

The Well-being of the Singapore Elderly (WiSE) [12] survey was used to model inpatient costs in our study. WiSE study in 2013 involved 2565 participants aged 60 and above from three main ethnicities. WiSE measured respondents' usage of specific healthcare services 3 months prior to the interview time [13]. We applied the same method used by the Institute of Mental Health to estimate the costs of dementia and depression for the Singapore government[13, 14]. We multiplied each service unit, such as the consultation minutes and number of visits, by the unit cost price for the healthcare costs in the 3 months and multiplied by four for annual costs. Due to variations in local data, an extrapolation method of using United Kingdom (UK) unit costs data to estimate Singapore unit costs (primary and hospital doctors and hospital healthcare workers) was applied. Ratios between Singapore and UK were generated from the World Health Organisation Choosing Interventions that are Cost-Effective (WHO-CHOICE) database[15]. The Unit Cost of Health and Social Care 2013[16] were used as a reliable source of UK unit costs. The cost ratio between UK and Singapore remains unchanged. The average out-of-pocket spendings were used when UK unit costs were unavailable. Self-report chronic diseases, including heart trouble, diabetes, hypertension, and stroke, were collected in WiSE study [13]. We used WiSE to model hospitalization costs, accounting for age, gender, ethnicity, education level, and chronic diseases.

1.2.4 The National Health Survey (NHS)

The National Health Survey (NHS) of the year 1992, 1998, 2004, and 2010 are included in Fig 1. a-d with FEM projections. Information on Singapore residents' demographics, chronic diseases, and lifestyle factors was collected in NHS. We used the prevalence of diabetes (Fig 1. a), hypertension (Fig 1. b), heart disease (Fig 1. c), and stroke (Fig 1.d) of older adults aged 51 and above in NHS.

1.2.5 Missing Data

Several strategies were employed to handle missing data. We assumed that the 2.1% missing chronic disease values as having no disease. For other variables, there were less than 2% missing categorical variables like work and marital status, where we assumed that they belonged to the most prevalent group (work status to be working, marital status to be married). For continuous variables, we used linear regression to predict the 17% missing continuous variables like weight and height. We used age and ethnicity as explanatory variables in the linear regression model for height and weight to impute missing values.

We conducted sensitivity analyses comparing model outcomes with missing values imputed by different methods. The BMI coefficient comparisons include using the complete-case analysis, and also imputed data based on the worst-case scenario, where all missing participants were obese ($BMI \geq 27.5 kg/m^2$). The results showed that the model estimates remained robust across these approaches, with overlapping confidence intervals, suggesting that our imputation strategy did not introduce significant bias.

Furthermore, we examined whether missingness was systematically associated with ethnicity by performing a missingness analysis. The proportion of missing BMI was 18.5% for both Chinese and Malays, while Indians had a slightly lower missing rate of 15.2%. The results did not indicate a significant ethnic-specific pattern in missing values. However, we acknowledge that some degree of bias cannot be entirely ruled out.

1.3 Process of building transitional models

1.3.1 Basic Covariates

We included a set of basic covariates as part of the default structure, including gender (male, female (reference)), ethnicity (Chinese (reference), Malay, Indian, Others), age, marital status (married (reference), single, divorced or separated, widowed), highest attained education (no education (reference), primary school education, secondary or higher education), BMI, income level (average earnings of household per month: less than S$2000 (reference), S$2000 to S$3999, S$4000 to S$5999, more than S$6000) and smoking status (never smoker (reference), ex-smoker and current smoker). We assumed that gender, ethnicity, marital status, and highest attained education remain the same as the baseline condition.

1.3.2 Mixed Stepwise Selection Algorithm

The mixed stepwise selection algorithm combines both forward selection and backward elimination. Each step performs both forward selection, which considers the inclusion of variables, and backward elimination, which determines the removal of variables. The backward stepwise selection drops variables at $p \geq 0.15$, adding those with $p < 0.05$. At each step, the algorithm re-estimates and determines the inclusion and exclusion of variables. The stepwise selection stops when there is no further change in the model structure. Apart from the basic covariates, we included risk factors (diabetes, hypertension hyperlipidemia, stroke, heart diseases, and cancer) in the mixed stepwise selection process to build the final transitional models. The FEM model used the resultant transitional models to determine how likely individuals transit to different health status in each period.

We built transitional models for having any ADL and having any IADL. ADL measures an individual's ability to complete basic tasks, whereas IADL includes higher order tasks to measure an individual's management and engagement of resources. Mixed stepwise selection algorithms were also performed to reveal the relationship between disability and chronic diseases. Basic covariates, including gender, ethnicity, age, marital status, highest education level, BMI, and smoking status were adjusted in the meantime.

1.3.3 Two-part Model For Healthcare Costs

The healthcare cost models were built as two-part models. The covariates included were gender, age, ethnicity, marital status (married, single, divorced or separated or widowed), education, and chronic conditions (diabetes, hypertension, stroke, and heart disease). The first part of the two-part model was probit regression, estimating the probability of having a non-zero healthcare cost, and the second part was a generalized linear model with gamma distribution and log link specified, estimating the inpatient cost in a non-zero case. At each simulation cycle, the FEM predicted individuals' healthcare costs based on one's own characteristics. Healthcare costs used cross-sectional models because healthcare utilizations were driven by the current disease stage.

1.3.4 Estimation of Transition Probabilities in FEM

FEM uses a discrete piecewise linear hazard model on longitudinal data (multiple waves) to estimate transitional probabilities for selected measures of health status. The hazard of getting a disease, dying or becoming disabled depends on risk factors such as gender, education, lifestyle, comorbidities, functional status, and age. The resulting hazards will then be used as parameters in the microsimulation model to determine which individuals transit from period to period. We used probit regression to estimate the transition probability to each health condition, controlling for education, demographic variables and comorbidities in the previous period. We treated all diseases as absorbing in reflection of the question asked: "Have you ever been told by a doctor...".

2. Supplementary Tables

Supplementary Table 1: Mean regression coefficients from bootstrapped transitional models for chronic conditions, income, smoking status, working status, disability, cost and mortality with variable name explanations

Variable name	Explanations
age	Age
anyadl	Have any ADL disability

Variable name	Explanations
anyiadl	Have any IADL disability
diabe	Have diabetes
died	Is died
eduHighEdu	Education is university
eduLowEdu	Education is PSLE
edulowmidhigh	Education is PSLE or O level or A level or university
eduMidEdu	Education is O level or A level
eduMidHighEdu	Education is O level or A level or university
eth_other	Ethnicity is not Chinese, Malay or Indian
female	Gender is female
hearte	Have heart disease
hibpe	Have hypertension
highchole	Have high cholesterol
hospcost	Total healthcare cost
hospprm	Primary healthcare cost
income	Income level
indian	Ethnicity is Indian
l6age	Last cycle's age
l6age6575	Last cycle age spline from 65 to 75
l6age65l	Last cycle age spline below 65
l6age7585	Last cycle age spline from 75 to 85
l6age75l	Last cycle age spline below 75
l6age75p	Last cycle age spline 75 and above
l6age85p	Last cycle age spline 85 and above
l6bmi185_230	Last cycle BMI spline between 18.5 and 23.0
l6bmi185l	Last cycle BMI spline below 18.5
l6bmi185l_cat	Last cycle BMI is below 18.5
l6bmi230_275	Last cycle BMI spline between 23.0 and 27.5
l6bmi230_275_cat	Last cycle BMI is between 23.0 and 27.5
l6bmi230u_cat	Last cycle BMI is above 23.0
l6bmi275u	Last cycle BMI spline above 27.5
l6bmi275u_cat	Last cycle BMI is above 27.5
l6cancre	Last cycle have cancer
l6diabe	Last cycle have diabetes
l6hearte	Last cycle have heart disease
l6hibpe	Last cycle have hypertension
l6highchole	Last cycle have high cholesterol
l6highchole	Last cycle have high cholesterol
l6income2000_3999	Last cycle's income is between S$2000 to S$3999
l6income4000_5999	Last cycle's income is between S$4000 to S$5999
l6income6000u	Last cycle's income is above S$6000
l6logbmi	Last cycle's log of bmi
l6smoken	Last cycle is smoking
l6smokev	Last cycle is an ever smoker
l6stroke	Last cycle have stroke
l6working	Last cycle is working
logbmi	Log of BMI
logdeltaage	Log of the difference in age between the current cycle and last cycle
malay	Ethnicity is Malay
male	Gender is male
mdiv_sep_wid	Marital status is divorced or separated or widowed
mdivorce_sep	Marital status is divorced or separated
msingle	Marital status is single
mwidowed	Marital status is widowed
smoken	Is currently smoking
smokev	Is an ever smoker

Variable name	Explanations
smkstat	Smoking status
stroke	Have stroke
working	Currently working

Transitional models:

probit diabe (diabetes)			
	Mean	95% Confidence Interval	
male	-0.0337	-0.173	0.106
malay	0.179	0.0353	0.324
indian	0.383	0.228	0.539
eth_other	0.336	-0.26	0.932
l6age	0.00707	2.42E-05	0.0141
logdeltaage	0.67	0.457	0.883
mdivorce_sep	0.253	-0.00394	0.509
mwidowed	0.155	-0.0738	0.384
msingle	0.122	-0.138	0.382
edulowmidhigh	0.244	-0.006	0.494
l6logbmi	1.78	1.43	2.12
l6income2000_3999	-0.124	-0.272	0.0246
l6income4000_5999	-0.099	-0.305	0.107
l6income6000u	0.0138	-0.183	0.211
l6smoken	0.266	0.126	0.406
l6smokev	0.0203	-0.256	0.297
l6hibpe	0.292	0.148	0.437
_cons	-9.2	-10.5	-7.85

probit hibpe (hypertension)			
	Mean	95% Confidence Interval	
male	-0.00299	-0.114	0.108
malay	0.141	-0.0199	0.301
indian	0.139	-0.00211	0.281
eth_other	0	0	0
l6age	0.0204	0.0135	0.0272
logdeltaage	0.826	0.622	1.03
mdivorce_sep	-0.116	-0.376	0.145
mwidowed	0.146	-0.0521	0.343
msingle	0.09	-0.142	0.322
eduLowEdu	0.0492	-0.157	0.255
eduMidHighEdu	-0.0436	-0.237	0.149
l6logbmi	1.3	1.01	1.59
l6income2000_3999	0.0734	-0.0677	0.214
l6income4000_5999	0.158	0.00639	0.31
l6income6000u	0.127	-0.0351	0.29
l6smoken	0.199	0.0276	0.371
l6smokev	0.043	-0.189	0.275
l6diabe	0.173	-0.00146	0.347
_cons	-7.83	-9.04	-6.62

probit stroke (stroke)

	Mean	95% Confidence Interval	
male	-0.124	-0.486	0.238
malay	-0.163	-0.529	0.203
indian	0.0475	-0.275	0.37
eth_other	0	0	0
l6age	0.00301	-0.0115	0.0175
logdeltaage	0.912	0.229	1.59
mdivorce_sep	0.476	-0.121	1.07
mwidowed	0.441	-0.00482	0.886
msingle	0.0702	-0.234	0.374
eduMidHighEdu	-0.475	-0.759	-0.191
l6bmi230_275_cat	0.175	-0.175	0.524
l6bmi275u_cat	0.164	-0.333	0.662
l6smoken	0.701	0.252	1.15
l6smokev	0.892	0.478	1.31
l6hibpe	0.153	-0.156	0.462
_cons	-3.61	-5.24	-1.97

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probit hearte (heart disease)			
	Mean	95% Confidence Interval	
male	0.474	0.253	0.696
malay	-0.0195	-0.259	0.22
indian	0.411	0.251	0.571
eth_other	1.23	0.377	2.08
l6age	0.0148	0.00541	0.0242
logdeltaage	0.456	0.116	0.796
mdivorce_sep	0.414	0.0927	0.735
mwidowed	0.246	-0.075	0.567
msingle	0.243	-0.112	0.599
eduLowEdu	0.238	-0.11	0.586
eduMidHighEdu	0.066	-0.279	0.411
l6logbmi	0.532	0.0202	1.04
l6income2000_3999	-0.0977	-0.32	0.124
l6income4000_5999	0.17	-0.107	0.447
l6income6000u	0.279	-0.00832	0.566
l6smoken	0.443	0.207	0.68
l6smokev	0.277	0.0268	0.527
l6diabe	0.508	0.302	0.713
l6hibpe	0.266	0.102	0.43
l6highchole	0.249	0.0621	0.437
_cons	-6.17	-8.48	-3.86

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probit anyadl (any ADL disability)			
	Mean	95% Confidence Interval	
male	-0.2	-0.587	0.188
malay	0.508	-0.0249	1.04
indian	0.426	-0.0521	0.904
l6age75l	0.0239	-0.00557	0.0534
l6age7585	0.0772	0.0238	0.131
l6age85p	0.119	0.022	0.216
mdivorce_sep	-0.105	-0.653	0.443
mwidowed	0.0468	-0.328	0.422
msingle	0.375	-0.0459	0.796

eduMidHighEdu	0.00785	-0.274	0.289
l6bmi185l	-0.0579	-0.227	0.111
l6bmi185_230	-0.0662	-0.186	0.0538
l6bmi230_275	-0.0178	-0.113	0.0779
l6bmi275u	0.0931	0.00938	0.177
smokev	0.353	0.0557	0.65
smoken	0.365	-0.183	0.913
l6diabe	0.344	0.0434	0.644
l6stroke	1.44	1.1	1.78
l6hearte	0.441	-0.0288	0.911
_cons	-2.22	-5.84	1.4

probit anyiadl (any IADL disability)			
	Mean	95% Confidence Interval	
male	0.892	0.74	1.04
malay	0.664	0.342	0.985
indian	0.473	0.0476	0.898
l6age75l	0.0414	0.0283	0.0545
l6age7585	0.0686	0.0335	0.104
l6age85p	0.0545	-0.0418	0.151
mdivorce_sep	0.0846	-0.239	0.408
mwidowed	0.0149	-0.154	0.184
msingle	0.478	0.259	0.698
eduLowEdu	-0.45	-0.621	-0.278
eduMidHighEdu	-0.588	-0.764	-0.413
smokev	0.207	0.0357	0.379
l6stroke	0.895	0.689	1.1
_cons	-3.46	-4.35	-2.57

probit logbmi (log of BMI)			
	Mean	95% Confidence Interval	
male	-0.0129	-0.0171	-0.00869
malay	0.0135	0.00764	0.0194
indian	0.00839	0.00441	0.0124
eth_other	0.0544	0.00386	0.105
l6age	-0.000995	-0.00127	-0.000718
logdeltaage	0.00688	-0.00052	0.0143
mdivorce_sep	-0.000595	-0.0128	0.0116
mwidowed	0.00222	-0.00728	0.0117
msingle	0.00102	-0.00925	0.0113
eduLowEdu	-0.000736	-0.00857	0.0071
eduMidHighEdu	0.000285	-0.00696	0.00753
l6logbmi	0.904	0.892	0.917
l6income2000_3999	0.00233	-0.0027	0.00736
l6income4000_5999	-0.000856	-0.00663	0.00492
l6income6000u	0.00319	-0.00386	0.0102
l6smoken	-0.0071	-0.0124	-0.00178
l6smokev	-0.000741	-0.00776	0.00628
l6diabe	-0.0213	-0.0269	-0.0158
l6hibpe	0.00435	-0.000964	0.00967
l6highchole	0.00359	-0.000292	0.00748
l6stroke	-0.0216	-0.0443	0.00119
_cons	0.372	0.328	0.416

probit died (died)			
	Mean	95% Confidence Interval	
male	0.16	0.00644	0.313
malay	0.177	0.00403	0.349
indian	0.0246	-0.189	0.239
eth_other	0	0	0
l6age65l	0.0408	0.0277	0.0539
l6age6575	0.135	0.0952	0.174
l6age75p	0.177	0.0269	0.327
mdivorce_sep	-0.773	-1.28	-0.261
mwidowed	-1.12	-1.51	-0.744
msingle	-0.831	-1.29	-0.375
eduLowEdu	-0.0256	-0.301	0.25
eduMidHighEdu	-0.186	-0.444	0.0728
l6bmi185l_cat	0.328	0.0407	0.615
l6bmi230u_cat	0.135	-0.0664	0.336
l6income2000_3999	0.0295	-0.117	0.176
l6income4000_5999	-0.31	-0.579	-0.0404
l6income6000u	-0.234	-0.569	0.101
l6smoken	0.498	0.248	0.749
l6diabe	0.556	0.365	0.746
l6cancre	0.733	-0.0932	1.56
l6stroke	0.707	0.0467	1.37
_cons	-4.13	-4.93	-3.33

probit hospcost (total healthcare cost)			
	Mean	95% Confidence Interval	
female	0.235	0.112	0.357
age	0.00465	-0.00205	0.0113
malay	-0.259	-0.387	-0.131
indian	0.0702	-0.0584	0.199
eth_other	0.312	-0.172	0.796
msingle	-0.38	-0.64	-0.119
mdiv_sep_wid	-0.13	-0.3	0.0399
eduLowEdu	0.0793	-0.0973	0.256
eduMidEdu	0.161	-0.0225	0.345
eduHighEdu	0.0566	-0.173	0.286
diabe	0.57	0.419	0.721
hearte	0.443	0.233	0.652
stroke	0.233	-0.0295	0.495
hibpe	0.141	0.0206	0.262
_cons	-0.0881	-0.615	0.439

GLM margin hospcost (total healthcare cost)			
	Mean	95% Confidence Interval	
female	-242	-755	270
age	57.8	38	77.6
malay	49.3	-611	710
indian	344	-159	847
eth_other	496	-1220	2210
msingle	3.22	-1130	1140

mdiv_sep_wid	-99.5	-675	476
eduLowEdu	-520	-1150	115
eduMidEdu	-6.74	-709	695
eduHighEdu	-251	-1180	681
diabe	547	111	983
hearte	1020	542	1490
stroke	711	-91.5	1510
hibpe	149	-105	402
_cons	2080	1880	2290

probit hospprm (primary healthcare cost)			
	Mean	95% Confidence Interval	
female	0.161	0.047	0.275
age75p_cat	0.0519	-0.0264	0.13
malay	-0.169	-0.296	-0.0426
indian	0.0314	-0.0849	0.148
msingle	-0.341	-0.591	-0.0917
mdiv_sep_wid	-0.157	-0.279	-0.036
eduHighEdu	-0.149	-0.309	0.012
diabe	0.281	0.163	0.398
hibpe	0.146	-0.000629	0.292
_cons	0.0723	-0.0849	0.229

GLM margin hospprm (primary healthcare cost)			
	Mean	95% Confidence Interval	
female	64	21.3	107
age75p_cat	14.8	-10.9	40.5
malay	28.6	-23.2	80.4
indian	7.03	-47.7	61.7
msingle	0.449	-89.2	90.1
mdiv_sep_wid	-5.66	-58.8	47.5
eduHighEdu	74.1	0.444	148
diabe	23.3	-8.29	55
hibpe	18.5	-9.25	46.3
_cons	446	422	470

ordered probit income (income level)			
	Mean	95% Confidence Interval	
male	0.079	-0.0176	0.176
malay	-0.192	-0.287	-0.0975
indian	-0.239	-0.321	-0.158
eth_other	-0.251	-1.26	0.753
l6age	-0.0271	-0.0314	-0.0229
logdeltaage	0.0885	-0.0204	0.197
mdivorce_sep	-0.581	-0.762	-0.401
mwidowed	-0.191	-0.333	-0.0489
msingle	-0.62	-0.792	-0.449
edulowmidhigh	-0.0205	-0.141	0.0998
l6logbmi	-0.159	-0.343	0.026
l6income2000_3999	0.575	0.484	0.666
l6income4000_5999	1.03	0.891	1.17

l6income6000u	1.61	1.48	1.75
l6smoken	-0.19	-0.312	-0.0684
l6smokev	0.0234	-0.117	0.164
l6working	0.14	0.0594	0.221
cutoff_1	-2.19	-2.93	-1.45
cutoff_2	-0.691	-1.43	0.0443
cutoff_3	-0.0447	-0.775	0.686

ordered probit smkstat (smoking status)			
	Mean	95% Confidence Interval	
male	1.19	1.03	1.34
malay	0.228	0.0674	0.389
indian	-0.0231	-0.168	0.122
eth_other	0.193	-1.1	1.49
l6age	0.000226	-0.00645	0.00691
logdeltaage	-0.0722	-0.301	0.156
mdivorce_sep	0.364	0.0431	0.684
mwidowed	-0.0902	-0.42	0.24
msingle	-0.0828	-0.406	0.24
eduLowEdu	-0.122	-0.357	0.113
eduMidHighEdu	-0.174	-0.381	0.0326
l6logbmi	0.118	-0.32	0.555
l6income2000_3999	-0.0531	-0.201	0.0947
l6income4000_5999	0.0665	-0.115	0.248
l6income6000u	-0.137	-0.367	0.0931
l6smoken	3.76	3.47	4.05
l6smokev	2.16	1.99	2.34
cutoff_1	2.9	1.36	4.45
cutoff_2	4.7	3.11	6.29

probit working (working status)			
	Mean	95% Confidence Interval	
male	0.498	0.388	0.607
malay	-0.142	-0.271	-0.0131
indian	0.0548	-0.053	0.163
eth_other	-0.475	-1.26	0.308
l6age	-0.0461	-0.0527	-0.0396
logdeltaage	-0.44	-0.612	-0.268
mdivorce_sep	-0.0279	-0.287	0.231
mwidowed	-0.184	-0.379	0.0112
msingle	-0.206	-0.39	-0.0227
eduLowEdu	-0.0977	-0.28	0.0844
eduMidHighEdu	-0.0896	-0.245	0.0659
l6logbmi	-0.193	-0.484	0.0986
l6smoken	0.0479	-0.121	0.217
l6smokev	-0.125	-0.294	0.0453
l6hearte	-0.334	-0.676	0.00807
l6working	1.32	1.22	1.42
_cons	3.34	2.39	4.29

probit highchole (high cholesterol)			
	Mean	95% Confidence Interval	

male	-0.0789	-0.208	0.0501
malay	0.107	-0.0232	0.237
indian	0.139	0.0062	0.272
eth_other	0.523	-0.375	1.42
l6age	0.0269	0.0198	0.0341
logdeltaage	0.412	0.239	0.585
mdivorce_sep	-0.296	-0.556	-0.0369
mwidowed	-0.261	-0.479	-0.0418
msingle	-0.0263	-0.288	0.235
eduLowEdu	0.168	0.00455	0.331
eduMidHighEdu	0.148	-0.0307	0.326
l6logbmi	0.975	0.691	1.26
l6income2000_3999	-0.0457	-0.2	0.108
l6income4000_5999	0.036	-0.118	0.19
l6income6000u	0.0013	-0.193	0.196
l6smoken	0.189	0.0339	0.344
l6smokev	-0.0973	-0.302	0.107
l6diabe	0.347	0.15	0.544
l6hibpe	0.321	0.188	0.455
_cons	-5.99	-7.16	-4.81

3. Supplementary Figures

3.1 Chronic Disease Projections

The percentage of Chinese older adults having diabetes was 9.95% (95% CI: 8.84-11.1) in 2020 and 11.3% (95% CI: 8.55-14.0) in 2050. Diabetes was more prevalent among Malay older adults, with the prevalence rate being 23.1% (95% CI: 21.2-25.1) in 2020 and 39.0% (95% CI: 34.7-43.3) in 2050. Indian older adults had the highest diabetes prevalence of 32.3% (95% CI: 30.3-34.4) in 2020 and 41.3% (95% CI: 36.2-46.4) in 2050 (Fig. 1a).

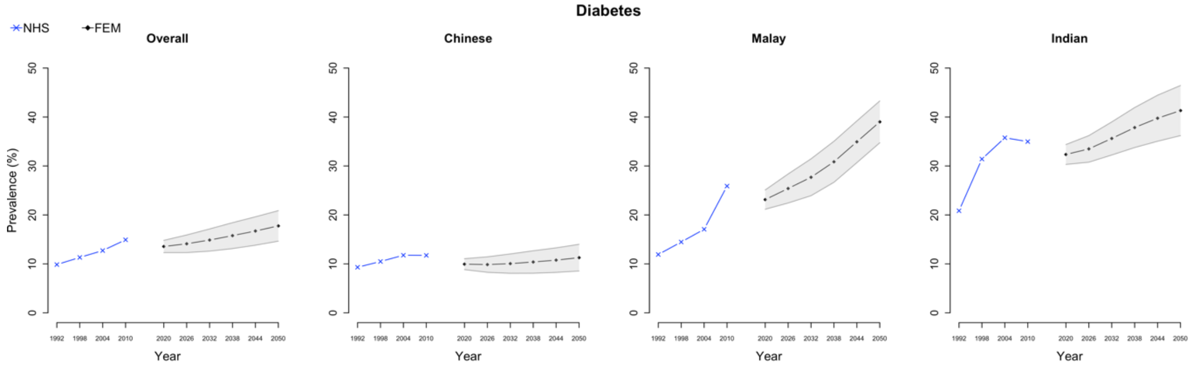
Chinese older adults had the lowest hypertension prevalence of 33.5% (95% CI: 31.8-35.1) in 2020, projected to be 35.5% (95% CI: 31.2-39.7) in 2050. The proportion of Malay older adults having hypertension was projected to be 46.8% (95% CI: 44.9-48.8) in 2020 and 58.6% (95% CI: 54.4-62.8) in 2050. 42.1% (95% CI: 40.3-43.9) of Indian older adults were projected with hypertension in 2020, and the proportion kept increasing, reaching 58.7% (95% CI: 54.4-63.0) in 2050 (Fig. 1b).

Heart disease was projected to be the least prevalent in Chinese older adults, with 4.52% (95% CI: 2.88-6.17) in 2020 and 5.88% (95% CI: 2.45-9.30) in 2050. Malay heart disease prevalence was 5.21% (95% CI: 3.59-6.83) in 2020, rising to 8.62% (95% CI: 4.76-12.5) in 2050. The steepest rise occurred among Indians, with prevalence being 13.1% (95% CI: 10.0-16.2) in 2020 and 22.7% (95% CI: 15.4-30.1) in 2050 (Fig. 1c).

In 2020, the stroke prevalence rate was 2.36% (95% CI: -0.288-5.01) for Chinese, 2.15% (95% CI: 0.472-3.82) for Malays, and 2.32% (95% CI: 0.0160-4.62) for Indians. In 2050, the prevalence was projected to be 3.05% (95% CI: 0.0824-6.00) for Chinese, 3.21% (95% CI: 0.874-5.54) for Malays, and 2.93% (95% CI: -0.937-6.80) for Indians (Fig. 1d).

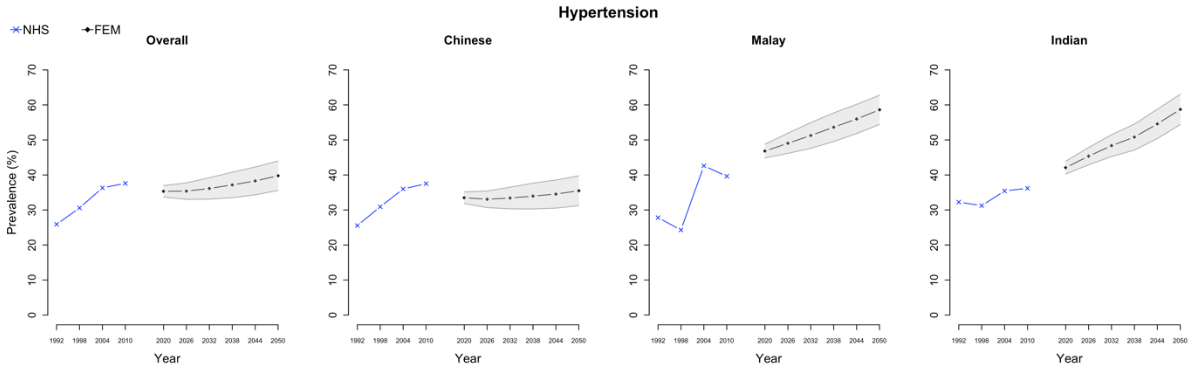
Current smoker prevalence was projected to drop from 9.48% (95%CI: 7.32-11.7) in 2020 to 4.75% (95%CI: 2.71-6.80) in 2050 for Chinese. Similar trend was projected in Indian older adults, with 9.19% (95%CI: 7.32-11.1) current smokers in 2020 and 5.05% (95%CI: 2.50-7.59) in 2050. Malays were projected with the highest prevalence of current smokers, 16.2% (95%CI: 13.4-19.0) in 2020 and 13.1% (95%CI: 9.49-16.8) in 2050 (Fig. 1e).

Obesity was projected to be the least prevalence in Chinese, 21.3% (95%CI: 17.5-25.1) in 2020 to 20.7% (95%CI: 14.8-26.7) in 2050. The proportion of Malays being obese was projected to be 51.9% (95%CI: 48.8-54.9) in 2020, reaching 58.9% (95%CI: 51.1-66.6) in 2050. Indian older adults were projected with 44.7% (41.5-47.8) obese in 2020 and 52.2% (95%CI: 43.2-61.2) in 2050 (Fig. 1f).



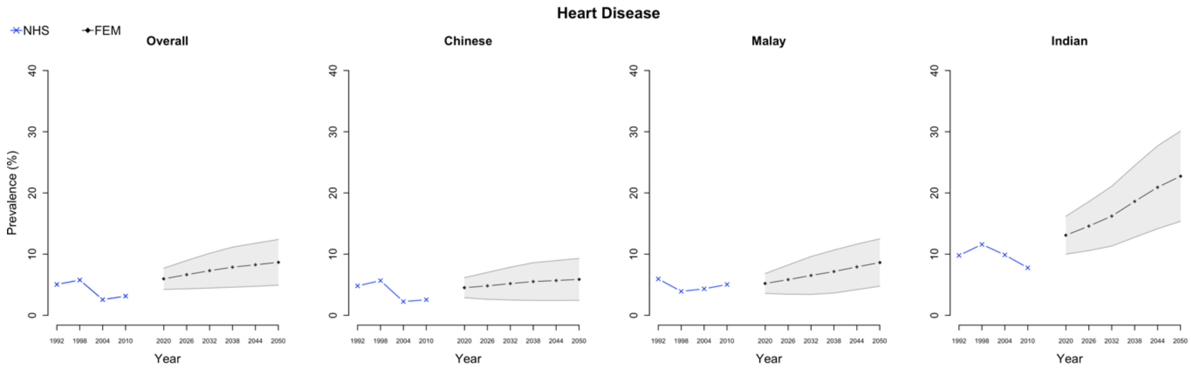
Supplementary Fig 1a. NHS and FEM projections of diabetes prevalence for three ethnic groups aged more than 51 years old.

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



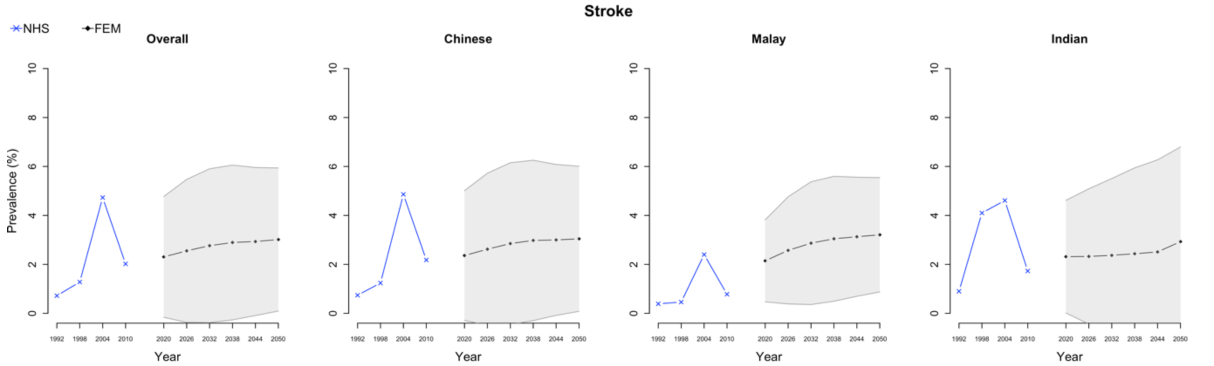
Supplementary Fig 1b. NHS and FEM projections of hypertension prevalence for three ethnic groups aged more than 51 years old.

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



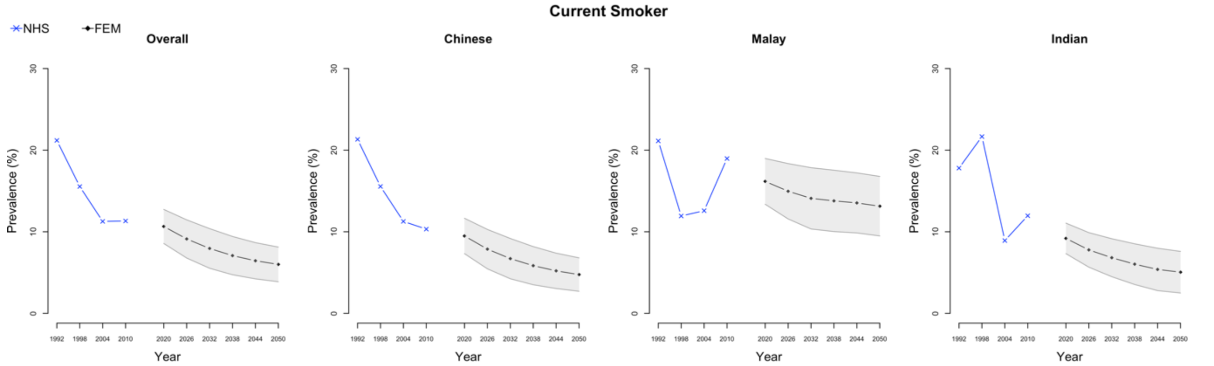
Supplementary Fig 1c. NHS and FEM projections of heart disease prevalence for three ethnic groups aged more than 51 years old.

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



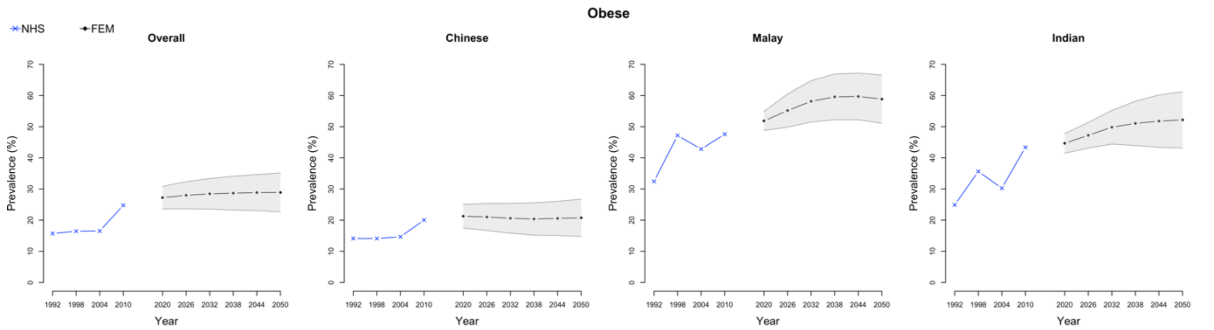
Supplementary Fig 1d. NHS and FEM projections of stroke prevalence for three ethnic groups aged more than 51 years old.

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



Supplementary Fig 1e: NHS and FEM projections of current smoker prevalence for three ethnic groups aged more than 51 years old.

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



Supplementary Fig 1f: NHS and FEM projections of obesity prevalence for three ethnic groups aged more than 51 years old.

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

3.2 Intervention effects on chronic diseases

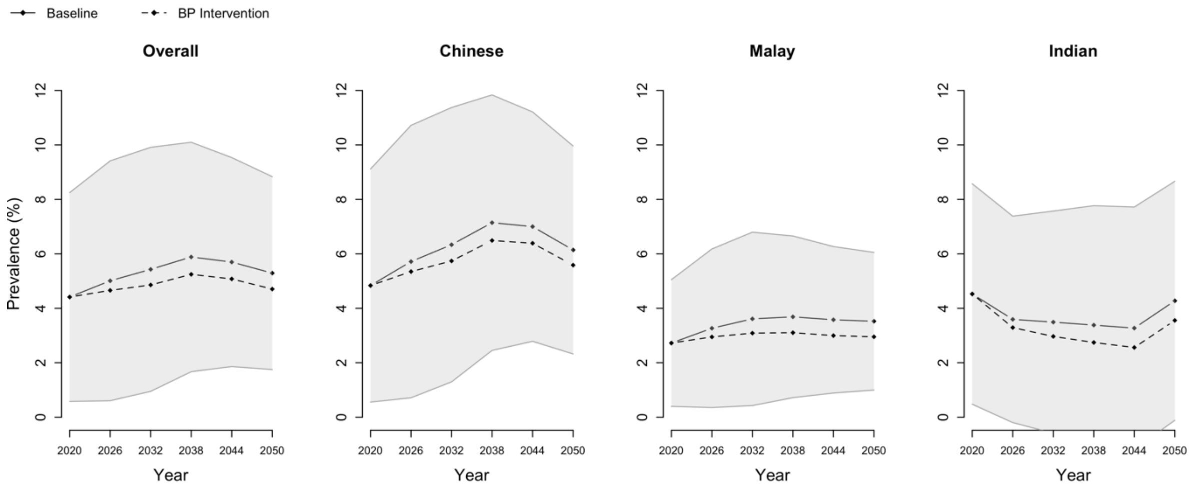
The following four intervention scenarios were designed and simulated to mimic the effects of HealthierSG in bending the curves on chronic diseases and savings in healthcare costs. We have incorporated the available ethnic differences where possible:

1. Improved Blood Pressure (BP) management intervention
2. Increased Physical Activity (PA) intervention

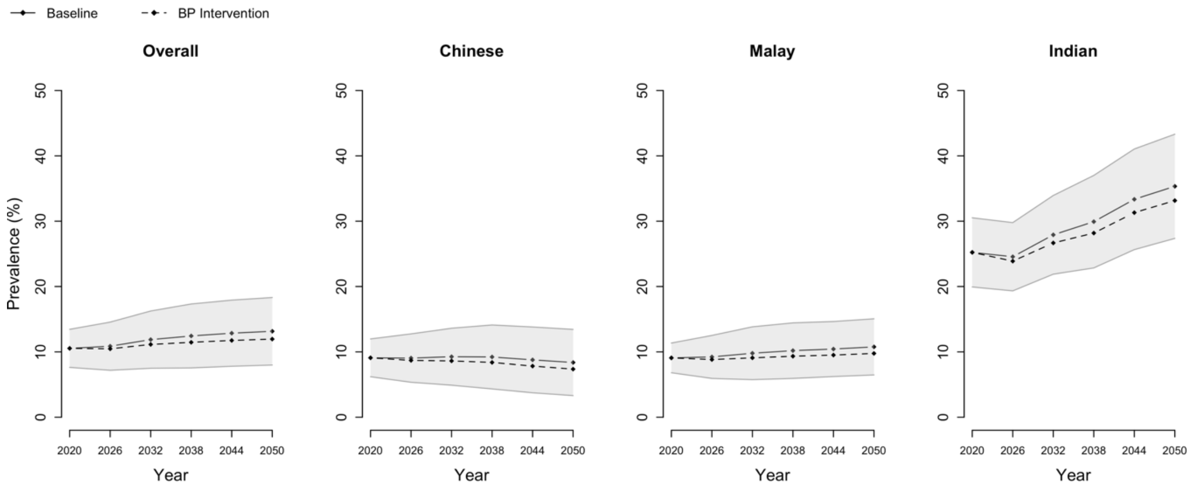
3. Sodium reduction intervention
4. All of the above interventions

Intervention 1. Improved Blood Pressure (BP) management

The stroke prevalence was reduced by 0.558% for Chinese, 0.571% for Malays, and 0.721% for Indians in 2050 (Fig. 2a). With the intervention, 1.01% less Chinese was projected with heart disease. Malays heart disease prevalence was reduced by 1.00%, and Indians' reduced by 2.19% in 2050 (Fig. 2b).



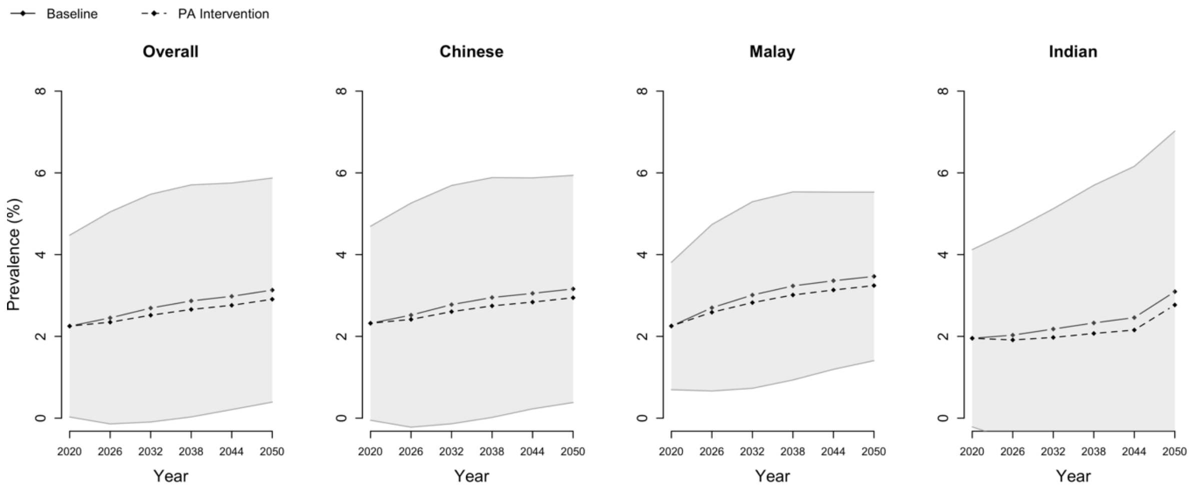
Supplementary Fig 2a: Prevalence of stroke of eligible individuals in baseline and BP intervention
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



Supplementary Fig 2b: Prevalence of heart disease of eligible individuals in baseline and BP intervention
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

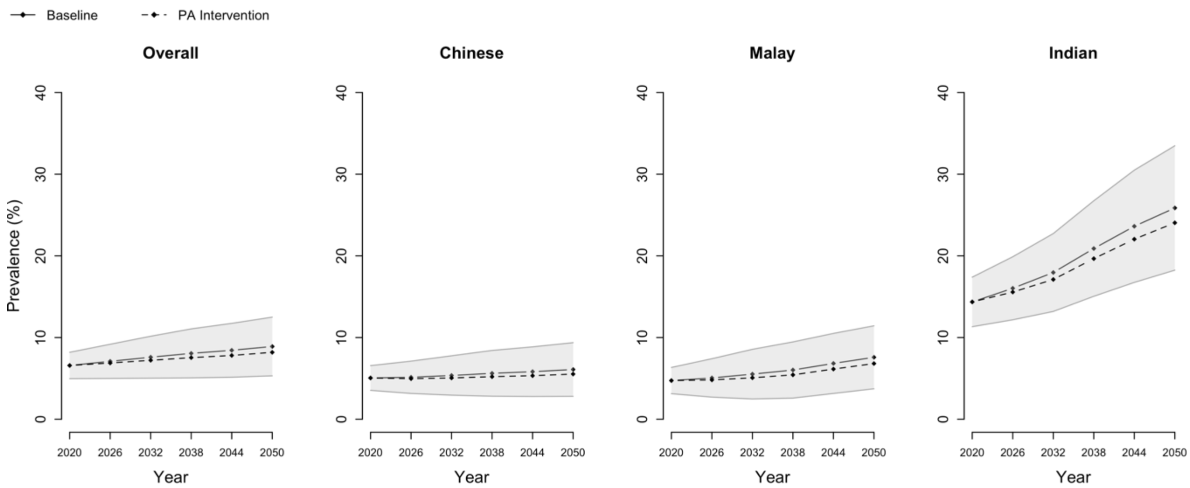
Intervention 2. Increased Physical Activity (PA)

The intervention helps reduce stroke prevalence by 0.216% for Chinese, 0.225% for Malays and 0.326% for Indians (Fig. 3a). A reduction of 1.82% in heart disease prevalence was projected in Indians, higher than 0.558% reduction in Chinese and 0.767% in Malays (Fig. 3b). Diabetes prevalence was reduced by 0.607% in Chinese, 1.08% in Malays and 1.38% in Indians (Fig. 3c).



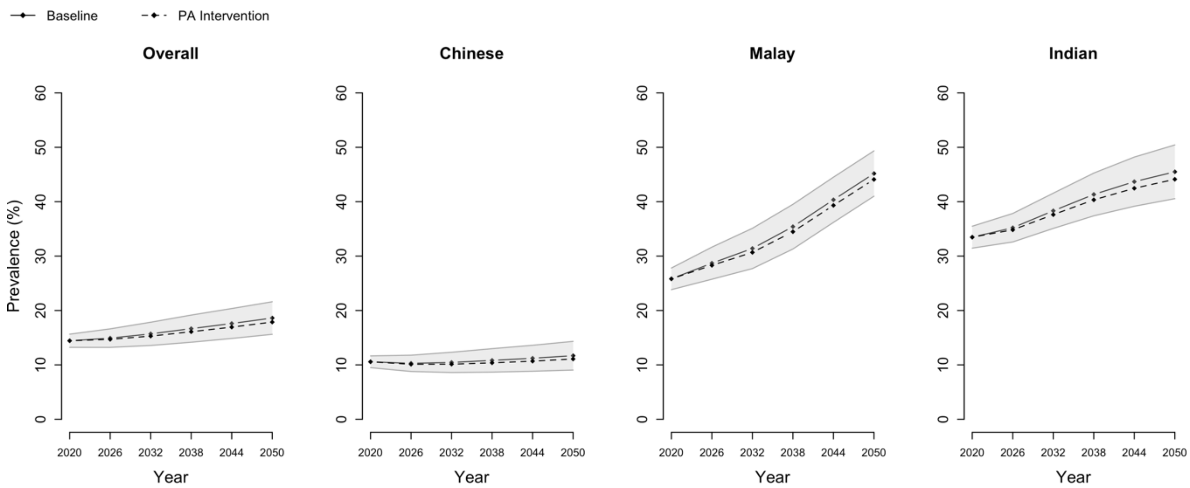
Supplementary Fig 3a: Prevalence of stroke of eligible individuals in baseline and PA intervention

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



Supplementary Fig 3b: Prevalence of heart disease of eligible individuals in baseline and PA intervention

The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

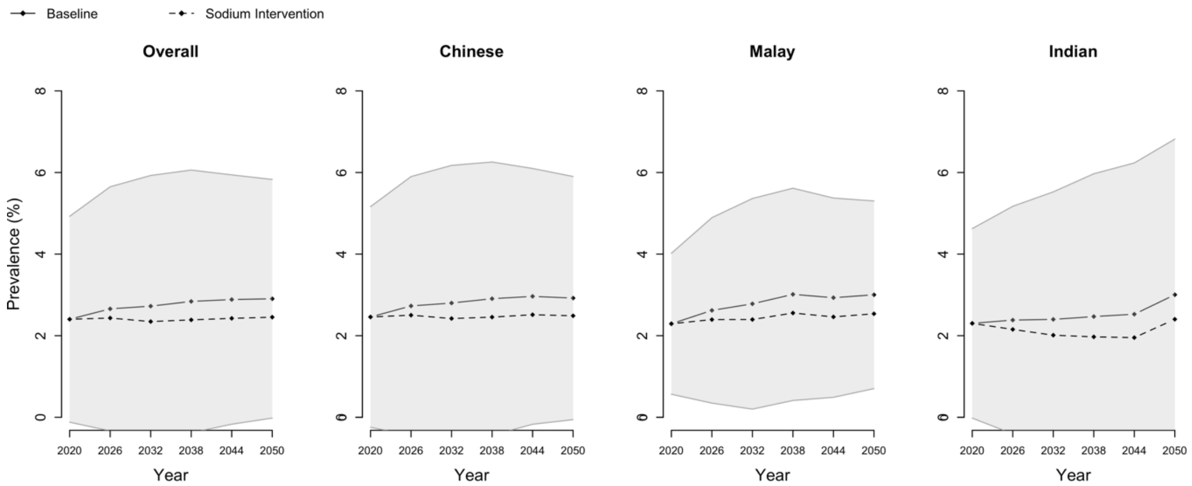


Supplementary Fig 3c: Prevalence of diabetes of eligible individuals in baseline and PA intervention

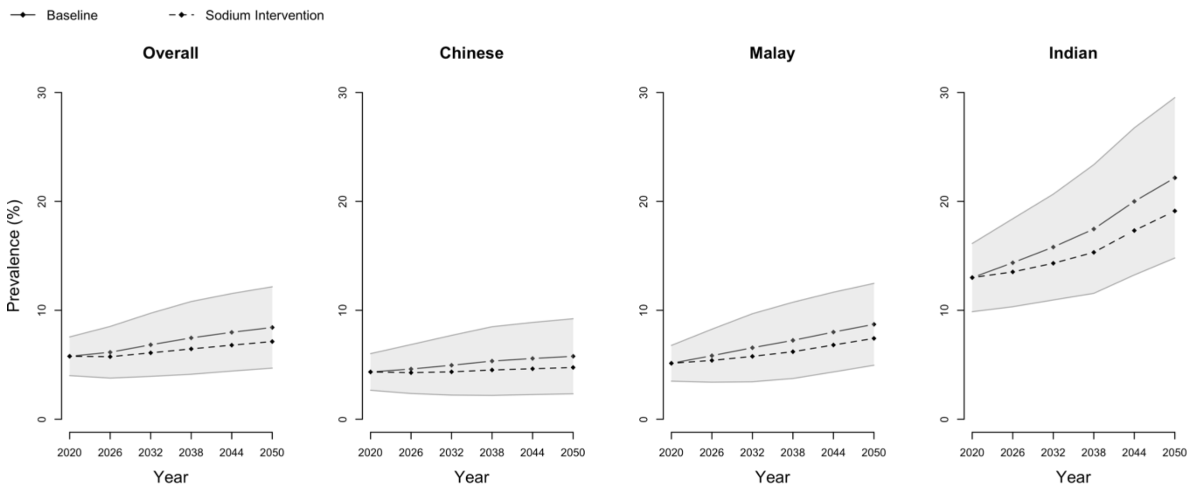
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

Intervention 3. Sodium reduction

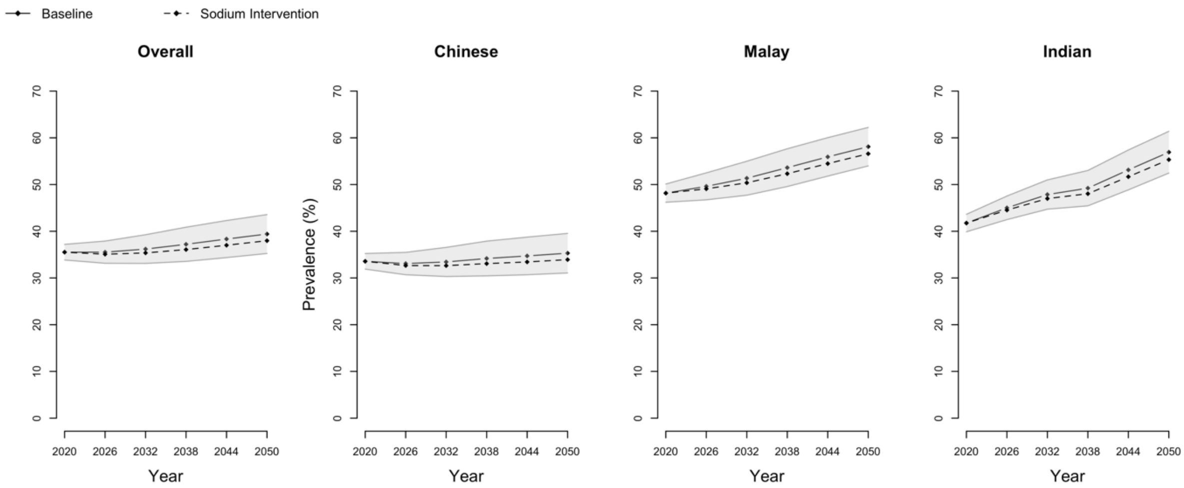
Reduction in sodium intake help reduce stroke prevalence by 0.434% for Chinese, 0.466% for Malays and 0.601 for Indians (Fig. 4a). Heart disease prevalence was reduced most in Indians, with a drop of 3.04%, higher than 1.03% for Chinese and 1.29% for Malays (Fig. 4b). With the intervention, 1.38% less Chinese, 1.51% less Malays and 1.60% less Indians were projected with hypertension (Fig. 4c).



Supplementary Fig 4a: Prevalence of stroke of eligible individuals in baseline and Sodium reduction
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



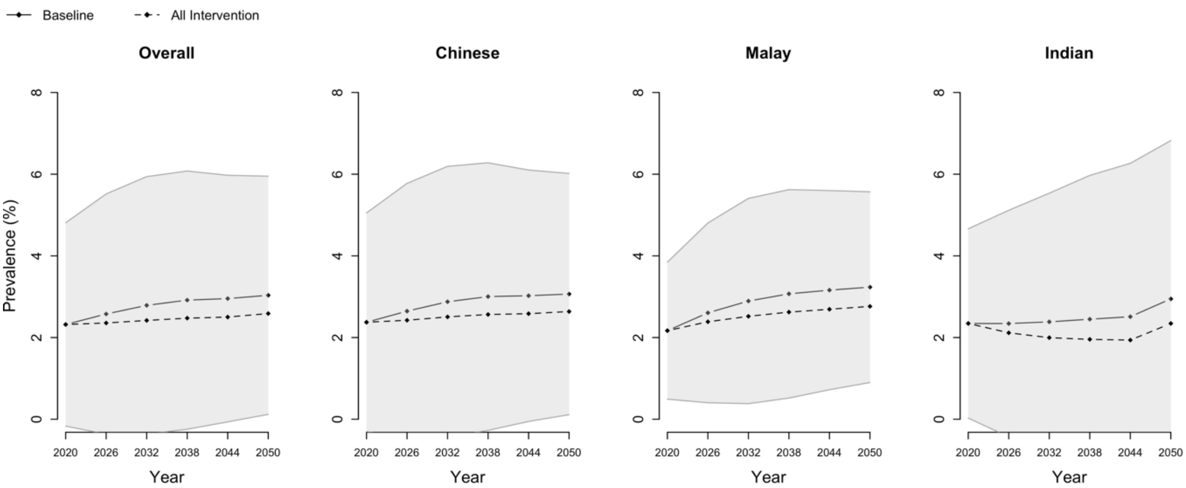
Supplementary Fig 4b: Prevalence of heart disease of eligible individuals in baseline and Sodium reduction
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



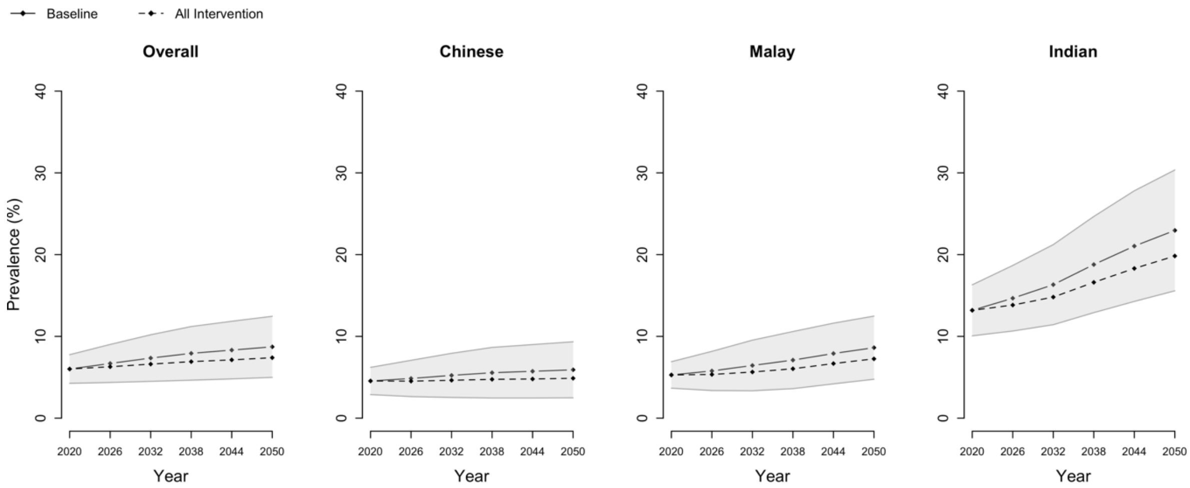
Supplementary Fig 4c: Prevalence of hypertension of eligible individuals in baseline and Sodium reduction
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

Intervention 4. All interventions

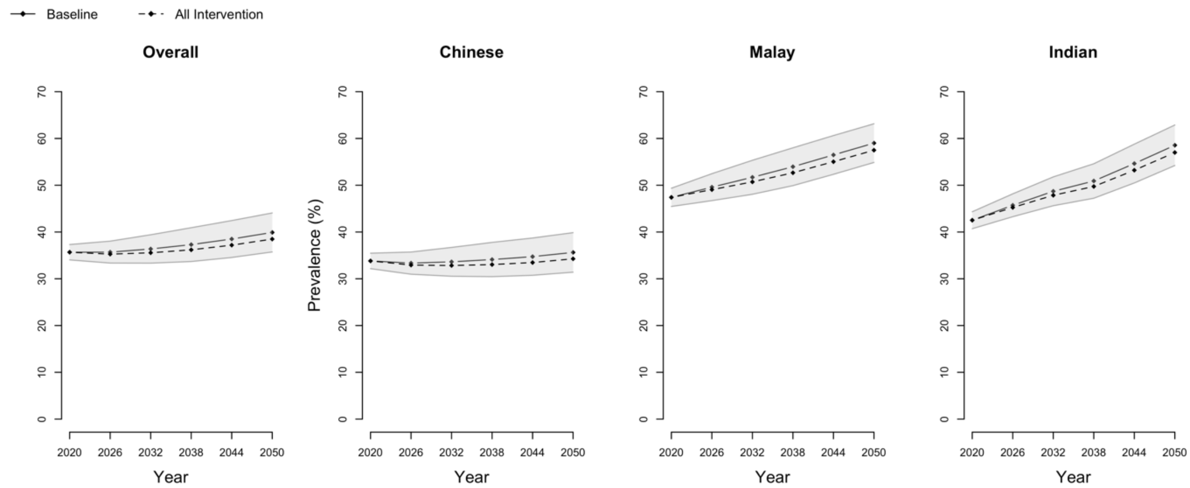
All interventions reduced stroke prevalence by 0.428% for Chinese, 0.470% for Malays and 0.602% for Indians in 2050 (Fig. 5a). Indians were projected with the greatest reduction of 3.13% in heart disease, followed by 1.37% for Malays and 1.04% for Chinese (Fig. 5b). Hypertension prevalence was projected to be 1.37% lower for Chinese, 1.52% lower for Malays, and 1.55% lower for Indians (Fig. 5c). Diabetes prevalence was projected to drop 1.49% for Indians, 1.14% for Malays and 0.652% for Chinese (Fig. 5d).



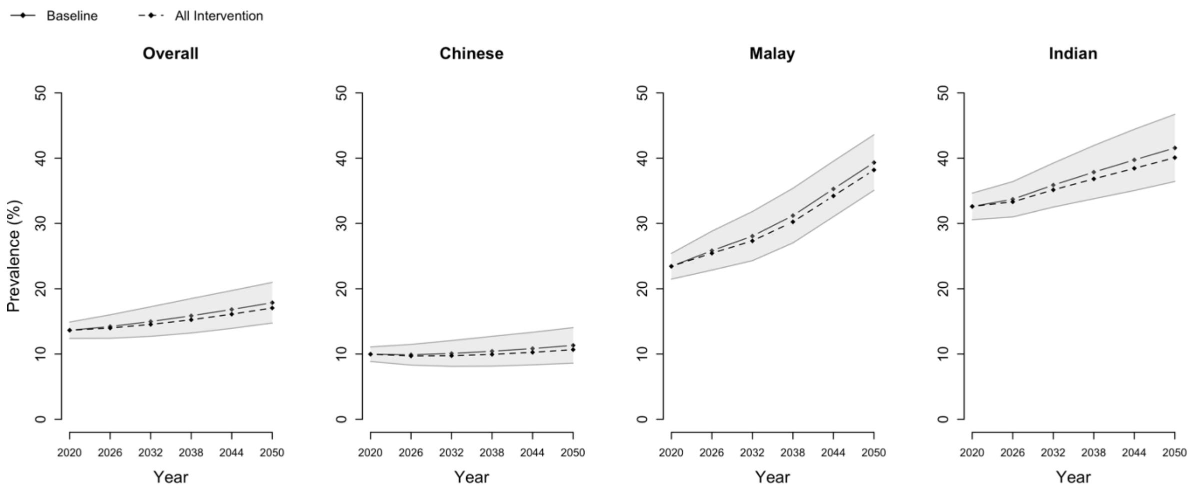
Supplementary Fig 5a: Prevalence of stroke of eligible individuals in baseline and all interventions
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



Supplementary Fig 5b: Prevalence of heart disease of eligible individuals in baseline and all interventions
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

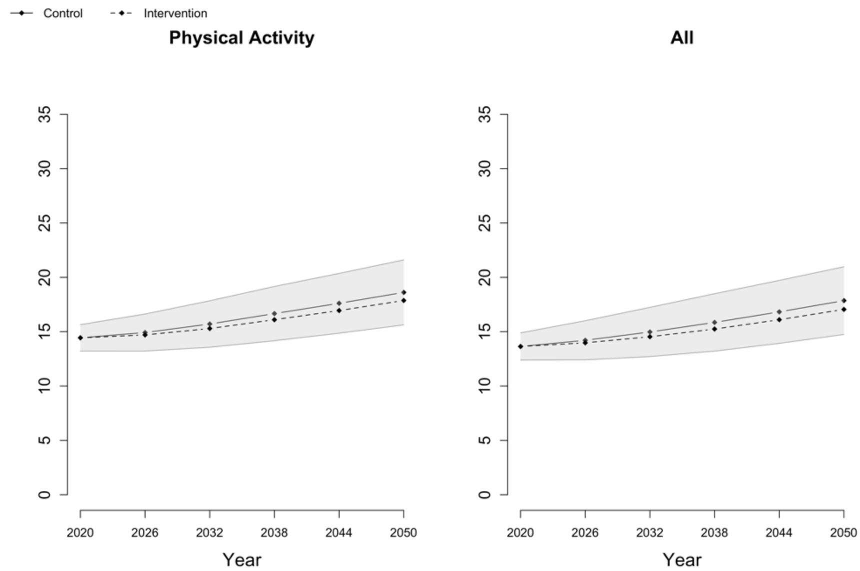


Supplementary Fig 5c: Prevalence of hypertension of eligible individuals in baseline and all interventions
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

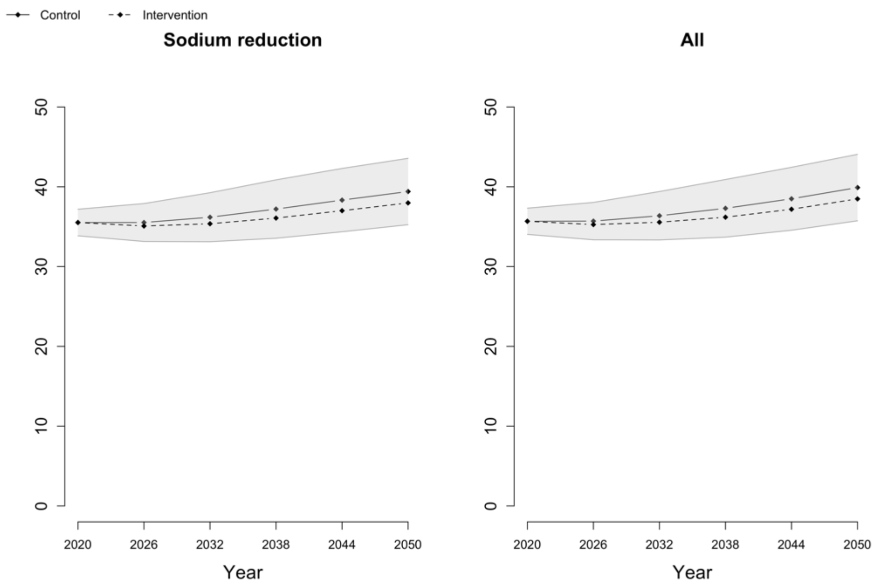


Supplementary Fig 5d: Prevalence of diabetes of eligible individuals in baseline and all interventions
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

The largest reduction in diabetes prevalence was observed in all interventions scenario, with a decrease of 0.810%, followed by the physical activity intervention, 0.745% (Fig. 5e). Moreover, all interventions and sodium reduction intervention had comparable effects in reducing hypertension prevalence, with reductions of 1.42% and 1.43%, respectively (Fig. 5f).

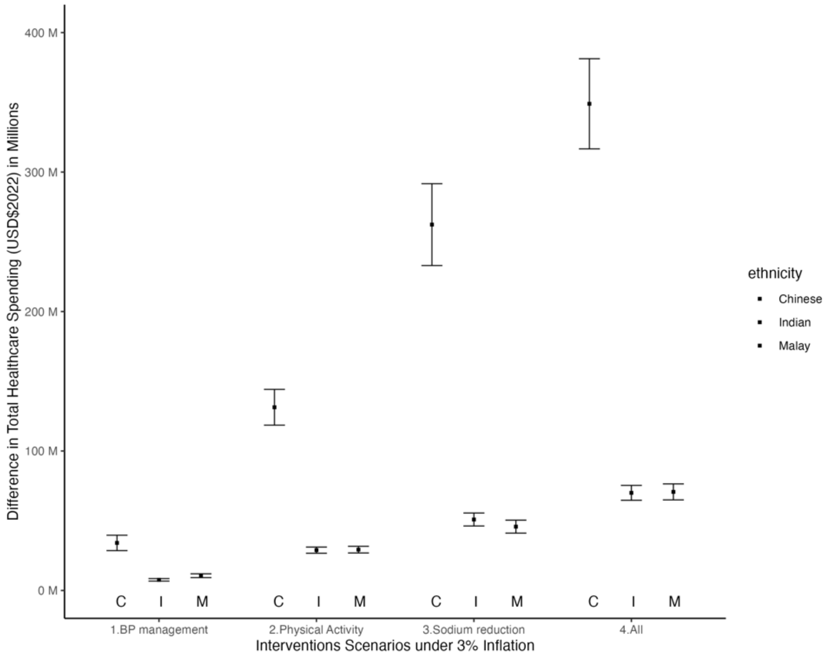


Supplementary Fig 5e: Prevalence of diabetes of eligible individuals in baseline and interventions
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test



Supplementary Fig 5f: Prevalence of hypertension of eligible individuals in baseline and interventions
The center point represents the mean and the shaded area represents 95% credible interval with a significance level of 5% based on two-sided test

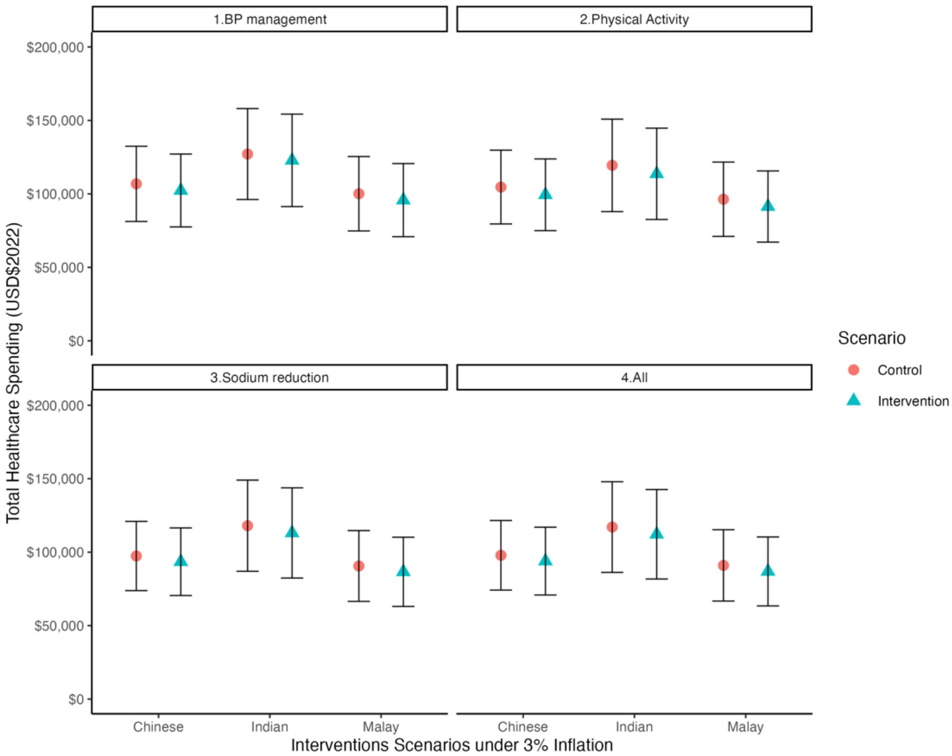
With improved BP management, Chinese saved US$34.1 (95%CI 28.6-39.6) million, Malay saved US$10.6 (95%CI 9.25-11.9) million, and Indian saved US$7.64 (95%CI 6.74-8.54) million in total healthcare costs. PA intervention helped save US$131 (95%CI 119-144) for Chinese, US$29.3 (95%CI 26.9-31.7) for Malays and US$28.9 (95%CI26.7-31.1) for Indians. By reducing sodium intake, US$262 (95%CI 233-292) saved for Chinese, US$45.8 (95%CI 41.1-50.4) for Malays, and US$50.9 (95%CI 46.2-55.5) for Indians. In all interventions scenario, Chinese saved US$349 (95%CI 317-381), Malay saved US$70.7 (95%CI 65.0-76.4) and Indian saved US$70.0 (95%CI 64.7-75.3). (Fig. 6)



Supplementary Fig 6: Difference in healthcare spending compared to baseline, by intervention scenarios and ethnicity

Intervention 1 targeted 22.4% of the cohort (Chinese: n = 267,257; Malay: n = 66,400; Indian: n = 32,992). Intervention 2 targeted 72.2% of the cohort (Chinese: n = 939,765; Malay: n = 130,398; Indian: n = 84,316). Intervention 3 targeted 89.9% of the cohort (Chinese: n = 1,166,059; Malay: n = 169,500; Indian: n = 110,781). Intervention 4 included 98.1% of the cohort eligible for any of the above (Chinese: n = 1,267,219; Malay: n = 184,664; Indian: n = 121,992). The center point represents the mean and the black lines represent 95% credible interval with a significance level of 5% based on two-sided test.

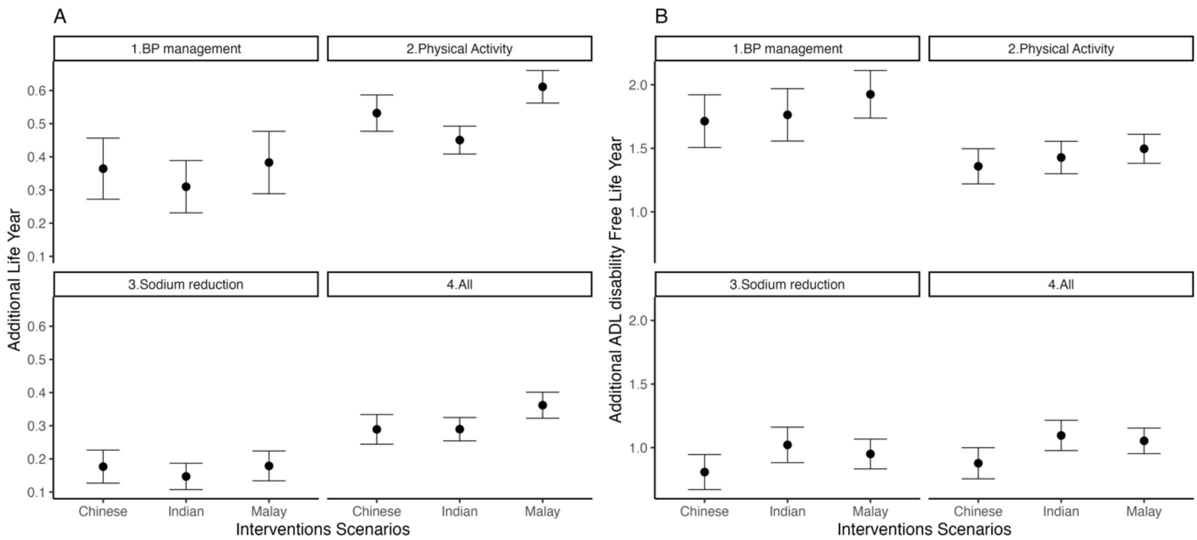
At the individual level, among those with different health conditions in intervention and control, the improved BP management saved US$4510 (4.23%) for Chinese, US$4280 (3.37%) for Indians and US$4360 (4.35%) for Malays. PA intervention saved US$5260 (5.02%) for Chinese, US$5750 (4.82%) for Indians and US$4960 (5.14%) for Malays. With sodium intake reduction, US$3890 (4.00%) saved for Chinese, US$4920 (4.17%) for Indians and US$3970 (4.38%) for Malays. Moreover, all interventions saved US$3950 (4.03%) for Chinese, US$4910 (4.20%) for Indians and US$4120 (4.53%) for Malays. (Fig. 7)



Supplementary Fig 7: Individual cost-savings of by intervention scenarios and ethnicity

Intervention 1 targeted 22.4% of the cohort (Chinese: n = 267,257; Malay: n = 66,400; Indian: n = 32,992). Intervention 2 targeted 72.2% of the cohort (Chinese: n = 939,765; Malay: n = 130,398; Indian: n = 84,316). Intervention 3 targeted 89.9% of the cohort (Chinese: n = 1,166,059; Malay: n = 169,500; Indian: n = 110,781). Intervention 4 included 98.1% of the cohort eligible for any of the above (Chinese: n = 1,267,219; Malay: n = 184,664; Indian: n = 121,992). The center point represents the mean and the black lines represent 95% credible interval with a significance level of 5% based on two-sided test.

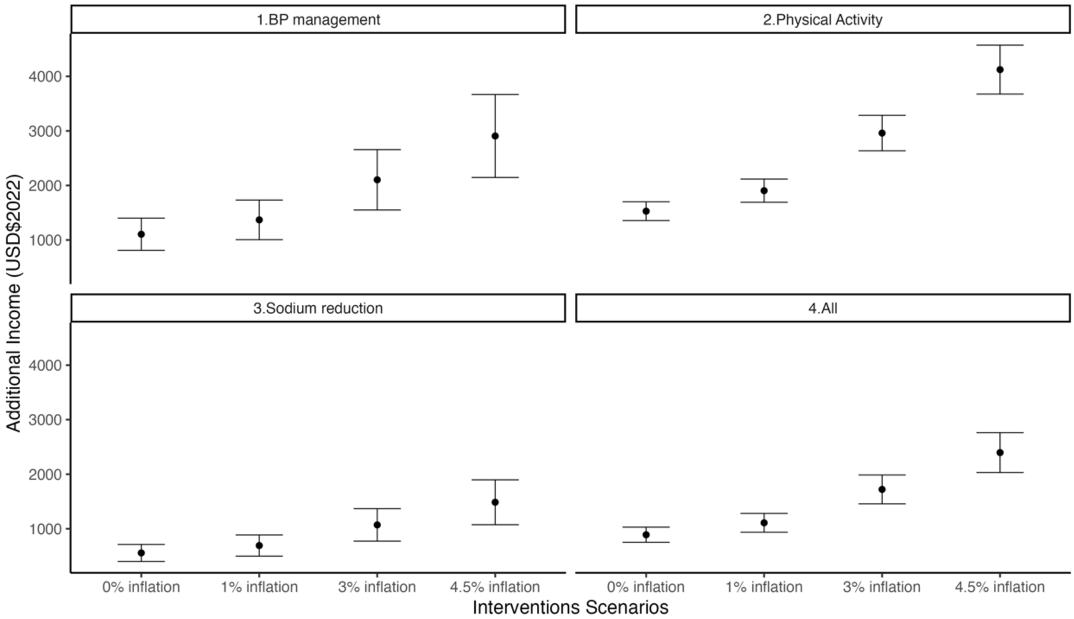
The average life-year extended was longest in Malays, with 0.383 years in improved BP management, 0.611 years in PA intervention, 0.179 years in Sodium reduction intervention and 0.362 in all interventions. The average ADL disability-free life year extended was longest in Malays with improved BP management, 1.920 years and PA intervention, 1.500 years, and in Indians with Sodium reduction intervention, 1.020 years and all interventions, 1.100 years. (Fig. 8) Malays had longer life-year extension than Indians with PA intervention. No other significant differences across ethnicities were observed.



Supplementary Fig 8: Ethnicity-specific (a) life-year gains and (b) ADL disability-free life-year gains

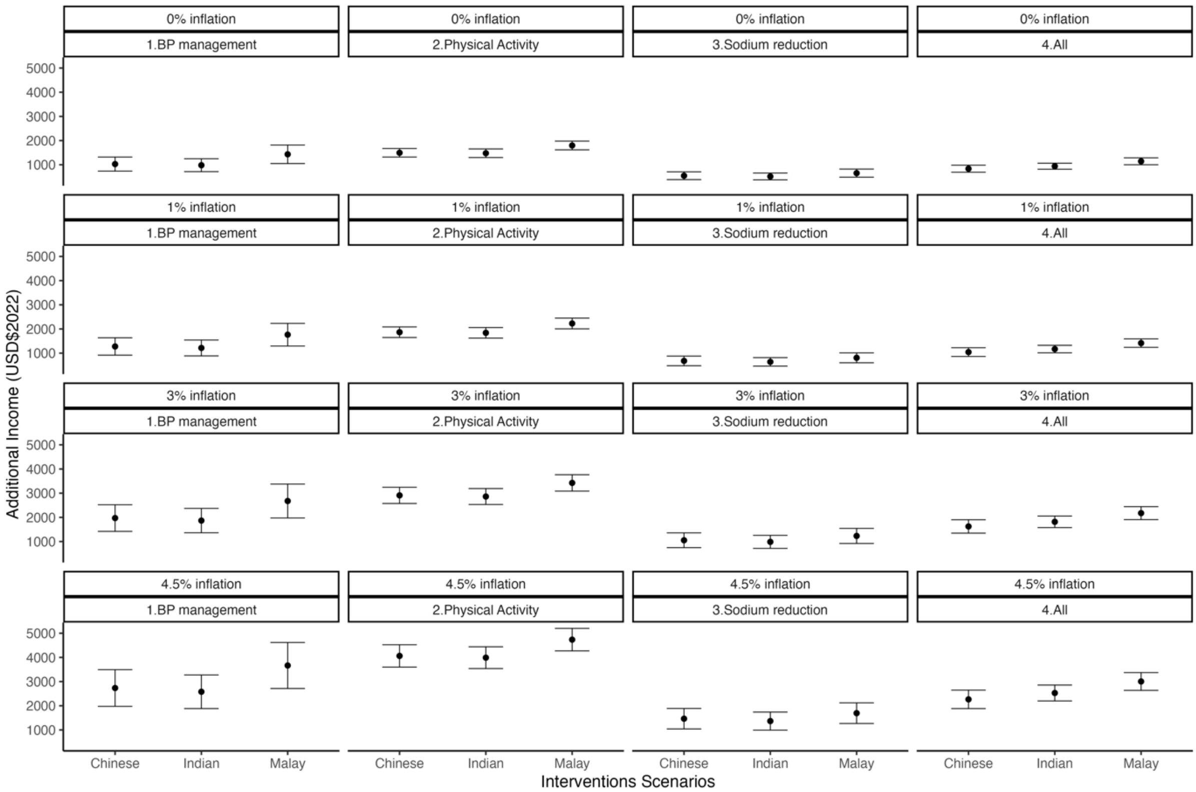
Intervention 1 targeted 22.4% of the cohort (Chinese: n = 267,257; Malay: n = 66,400; Indian: n = 32,992). Intervention 2 targeted 72.2% of the cohort (Chinese: n = 939,765; Malay: n = 130,398; Indian: n = 84,316). Intervention 3 targeted 89.9% of the cohort (Chinese: n = 1,166,059; Malay: n = 169,500; Indian: n = 110,781). Intervention 4 included 98.1% of the cohort eligible for any of the above (Chinese: n = 1,267,219; Malay: n = 184,664; Indian: n = 121,992). The center point represents the mean and the black lines represent 95% credible interval with a significance level of 5% based on two-sided test.

We estimated the additional income generated by interventions. The monthly economic gain of an older adult is estimated by the monthly income multiplied by labor force participation rates, according to specific age group and gender.[17] The yearly gain was the monthly gain multiplied by 12. The average economic gains of improved BP management was US$2100 (95%CI 1550-2660), PA intervention was US$2960 (95%CI 2630-3290), Sodium reduction was US$1070 (95%CI 773-1370) and all interventions was US$1720 (95%CI 1460-1990) under 3% inflation (Fig. 9). The economic gains for improved BP management were US$1970 (95%CI: 1420-2520) for Chinese, US$1870 (95%CI: 1360-2370) for Indians and US$2680 (95%CI: 1980-3380) for Malays. With PA intervention, Chinese earned US$2910 (95%CI: 2570-3240) more, Indians earned US$2860 (95%CI: 2530-3190) more and Malays earned US$3430 (95%CI: 3090-3760) more. Sodium reduction intervention helped bring additional income by US$1050 (95%CI:747-1360) for Chinese, US$987 (717-1260) for Indians and US$1230 (95%CI: 920-1540) for Malays. With all interventions, the economic gains were US$1620 (95%CI: 1350-1900) for Chinese, US$1820 (95%CI: 1580-2050) for Indians and US$2170 (95%CI: 1910-2440) for Malays under 3% inflation (Fig. 10).



Supplementary Fig 9 Economic gains with interventions

Intervention 1 targets 22.4% of the cohort (n = 366,649) with uncontrolled BP management, Intervention 2 targets 72.2% of the cohort (n= 1,180,774) with lower physical activity level, Intervention 3 targets 89.9% of the cohort (n=1,470,382) with high sodium intake and Intervention 4 targets 98.1% of the cohort (n=1,604,909) eligible for Intervention 1-3. The center point represents the mean and the black lines represent 95% credible interval with a significance level of 5% based on two-sided test.

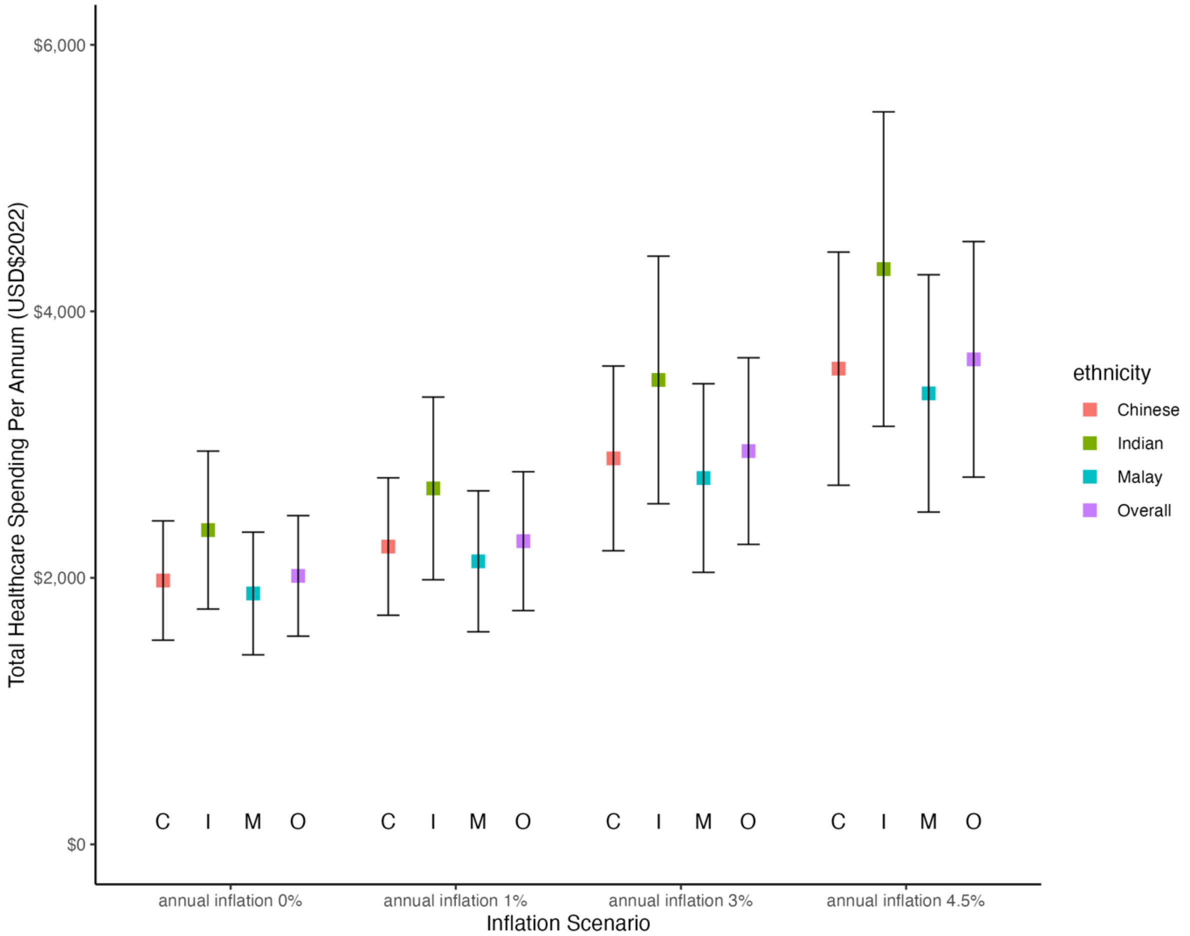


Supplementary Fig 10: Ethnicity-specific economic gain

Intervention 1 targeted 22.4% of the cohort (Chinese: n = 267,257; Malay: n = 66,400; Indian: n = 32,992). Intervention 2 targeted 72.2% of the cohort (Chinese: n = 939,765; Malay: n = 130,398; Indian: n = 84,316). Intervention 3 targeted 89.9% of the cohort (Chinese: n = 1,166,059; Malay: n = 169,500; Indian: n = 110,781). Intervention 4 included 98.1% of the cohort eligible for any of the above (Chinese: n = 1,267,219; Malay: n = 184,664; Indian: n = 121,992). The center point represents the mean and the black lines represent 95% credible interval with a significance level of 5% based on two-sided test.

3.3 Total Healthcare Costs Projection

Healthcare cost per annum in Fig 11 was obtained using lifetime hospitalization cost divided by ethnic-specific life expectancy at age 51. Under 3% inflation scenario, US$2880 was the overall healthcare cost per annum. Among the three main ethnic groups, Chinese is projected to spend US$2820 per annum, followed by Malays with US$2700 and Indians US$3410 per annum. Under the three inflation scenarios with different assumptions: (a) inflation assumed to be 1%, (b) higher inflation rate of 3%, and (c) highest inflation rate of 4.5%. In the scenario with the highest inflation rate, the overall healthcare spending per annum is US$3480, and US$3330, US$4220, for Chinese, Malay, and Indian older adults respectively.



Supplementary Fig 11. Healthcare spending per annum of older adults aged 51 and above, by ethnicity. *Ethnicity-specific sample sizes: Chinese (n = 1,291,402), Malay (n = 188,230), Indian (124,377). The center point represents the mean and the black lines represent 95% credible interval with a significance level of 5% based on two-sided test.*

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