SUPPLEMENT MATERIAL

Socioeconomic inequalities in obesity: modelling future trends in Australia

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Section 1: Supplement Methods

1.1 Prediction equations for annual weight (BMI) gain, by age, sex and SEP

The study populations for deriving equations for annual weight (BMI) gain included data on 7508 persons aged between 20 and 59 from the 1995 National Nutrition Survey (NNS) and 9850 persons aged between 37 and 76 from the 2011/12 National Health survey who had full data on height, weight and education and were not pregnant. The 1995 NNS was the first nationally representative survey in Australia in which height and weight were objectively measured. The NHS administered by the Australian Bureau of statistics (ABS) use a stratified multistage area sampling design including private dwelling in all states and territories across Australia, and are designed to be population representative.

Further details are shown below.

Characteristics of birth cohorts used to derive weight (BMI) gain equations

	Mean (95%CI) BMI					
	NNS 1995			NHS 2011/12		
Birth cohort	Low SEP	High SEP	Missing Education	Low SEP	High SEP	Missing Education
1936-45	26.9 (26.2 – 27.6)	27.3 (26.8 – 27.8)	56.3%	29.1 (28.6 - 29.5)	27.5 (26.86 -28.17)	0%
1946-55	26.7 (26.3 – 27.2)	26.2 (25.8 – 26.6)	33.2%	29.6 (29.2 - 30.1)	27.7 (27.2 - 28.1)	0%
1956-65	26.5 (26.1 – 26.9)	25.4 (25.1 – 25.7)	22.0%	29.0 (28.5 - 29.4)	27.7 (27.3 - 28.1)	0%
1966-75	25.11 (24.6 – 25.6)	24.4 (24.0 – 24.7)	13.6%	28.7 (28.3 - 29.2)	27.2 (26.9 - 27.5)	0%

In discrete-time simulation with annual cycles, the BMI of person i at time t, is determined from their BMI at the end of the previous year plus BMI gained during the current year.

$$BMI_{it} = BMI_{it-1} + \Delta\, BMI_{it}$$

Annual BMI gain ($\Delta\, BMI_{it}$) is a function of a number of covariates x_1-x_3 including age, BMI at the end of the previous year and socioeconomic position.

$$\Delta\, BMI_{it} = c + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \epsilon$$

Estimates of annual BMI change for different sectors of the population were derived using a synthetic cohort technique (1) which matches members of national level cross-sectional health surveys by birth year to estimate change in BMI over longitudinal time for different age and sex cohorts, stratified by socio-economic position and quantiles of BMI. BMI in all surveys was based on objectively measured height and weight. Socio-economic position was defined by completion of senior school education. When analysing data on adults, this is a fixed, time invariant measure, and thus particularly suited to synthetic cohort methodology. The synthetic cohorts were constructed between 1995 and 2012 for men and women aged 20-29, 30-39, 40-49, and 50-59 years in 1995, representing 4 birth cohorts 1936-45, 1946-55, 1956-65 and 1966-75, centred around 1940, 1950, 1960 and 1970, respectively. To capture BMI growth at different positions across the BMI spectrum, we determined BMI change over time in each decile of BMI within synthetic cohorts.

Annual weight gain based on age, sex, SEP and position on the BMI spectrum was then determined by assuming a fixed annual rate within the 17 years span. Using age and BMI from the mid–point of the matched surveys, this provided 40 estimates (10 from each of 4 synthetic cohort) of BMI change across matched deciles within each synthetic cohort and by SEP group. Finally we used multiple linear regression analysis and followed methods described in (2) to derive separately for men and women, prediction equations for annual change in BMI based on age, current BMI and SEP. For older adults (>75 years) we assumed a small annual weight loss, informed by observations of BMI change from a large Australian longitudinal study (3).

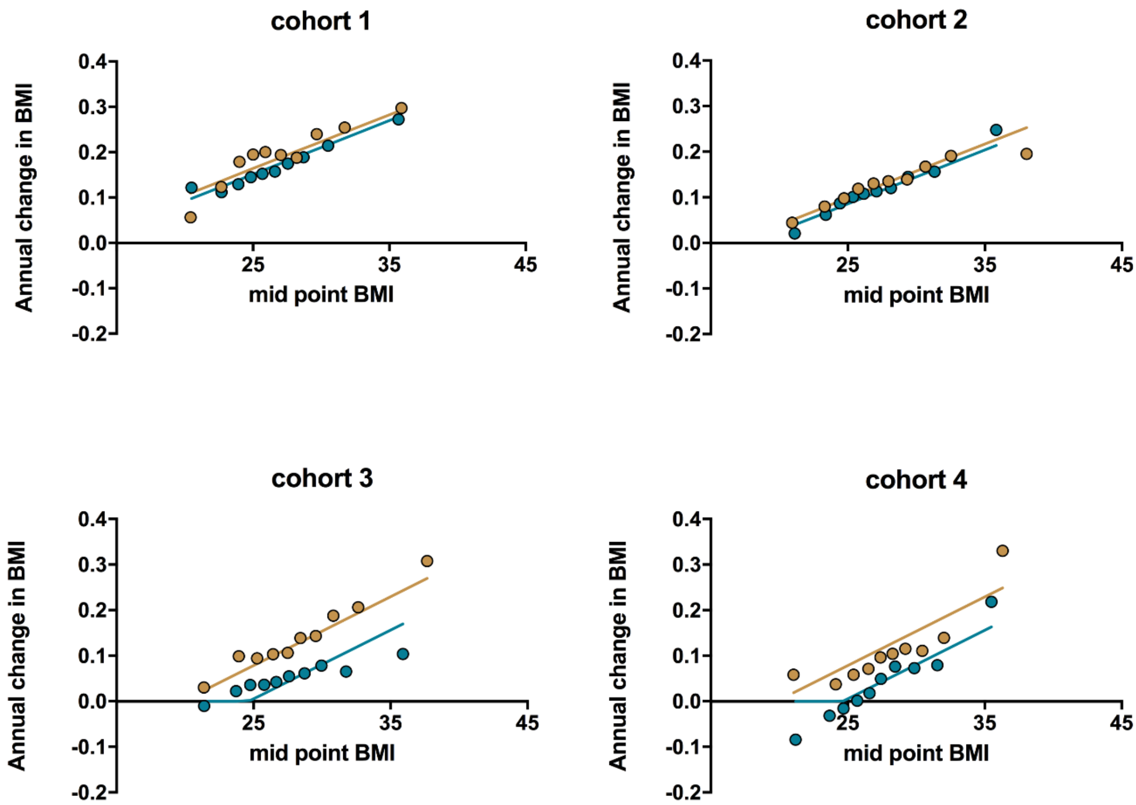
A summary of all the BMI gain equations for men and women are shown below:

Weight gain equations for men

	Men under 50		**Men over 50**	
	Coefficient (95% CI)	**p-value**	**Coefficient (95% CI)**	**p-value**
Age	-0.0065 (-0.0078, -0.0054)	<0.001	-	**-**
BMI	0.0118 (0.0104, 0.0132)	<0.001	0.0151 (0.0013, 0.0176)	<0.001
School completion	-0.0129 (-0.025, -0.0008)	0.038	-0.0731 (-0.0935, -0.0527)	<0.001
Constant	0.0909 (0.0317,0.150)	0.004	-0.2987 (-0.3701, -0.2273)	<0.001
Adjusted R^2	0.91		0.85	

Some examples of annual weight gain by SEP

Example 1: For a man aged 25, who completed high school and has BMI of 30;
Annual weight gain = 0.0909 – 0.0065*25 + 0.0118*30 – 0.0129 = 0.2695units BMI
Example 2: For a man aged 25, who did not complete high school and has a BMI of 30;
Annual weight gain = 0.0909 – 0.0065*25 + 0.0118*30 = 0.2824 units BMI
Example 3: For a man aged 60, who completed high school and has a BMI of 35;
Annual weight gain = -0.2987 + 0.0151*35 – 0.0731 = 0.1567 units BMI
Example 4: For a man aged 60, who did not complete high school and has a BMI of 35;
Annual weight gain = -0.2987 + 0.0151*35 = 0.2298 units BMI



Annual weight gain in 4 synthetic cohorts centred around age 34 (synthetic cohort 1), age 44 (synthetic cohort 2), age 54 (synthetic cohort 3), and age 64 (synthetic cohort 4).
Brown circles = low SEP group; Turquoise circles = high SEP group; Each point represents annual BMI change in deciles of BMI. Brown lines = annual BMI change from regression equation(s) for low SEP; Turquoise lines = annual BMI change from regression equation(s) for low SEP

Weight gain equations for women

As there was no significant difference in BMI gain between the high and low SEP groups for younger females (p=0.58), an equation already derived and not stratified by SEP (1) was used to predict annual change in BMI for young women. For older females, equations for high and low SEP groups were derived separately. Polynomial splines (curves that are defined by two or more points) were used to account for the plateauing of BMI gain for people in higher BMI range the upper part of the BMI spectrum.

Weight gain equations for women

	Women under 50 (High and low SEP)		**Women over 50 (High SEP group)**		**Women over 50 (Low SEP group)**	
	Coefficient (95% CI)	**p-value**	**Coefficient (95% CI)**	**p-value**	**Coefficient (95% CI)**	**p-value**
Age	-0.0050 (-0.0055,-0.0046)	<0.001	-0.0059 (-0.0076, -0.0042)	<0.001	-	-
BMI under 30	0.0185 (0.0170, 0.0200)	<0.001	0.0080 (0.0055, 0.0105)	<0.001	0.0187 (0.0158, 0.0216)	<0.001
BMI over 30	-	-	-	-	0.0066 (0.0032, 0.010)	0.001
Constant	-0.0861 (-0.1268, -0.0454)	<0.001	0.2091 (0.0932, 0.3251)	0.001	-0.3478 (-0.4231, -0.2725)	<0.001
Adjusted R^2	0.92		0.82		0.95	

Some examples of annual weight gain by SEP

Example 1: For a woman aged 25, and has BMI of 28;

Annual weight gain = -0.0861 – 0.0050*25 + 0.0185*28 = 0.3069 units BMI (regardless of SEP status)

Example 2: For a woman aged 25, who has a BMI of 35;

Annual weight gain = -0.0861 – 0.0050*25 + 0.0185*30 = 0.3439 units BMI (regardless of SEP status)

Example 3: For a woman aged 60, who completed high school and has a BMI of 28;

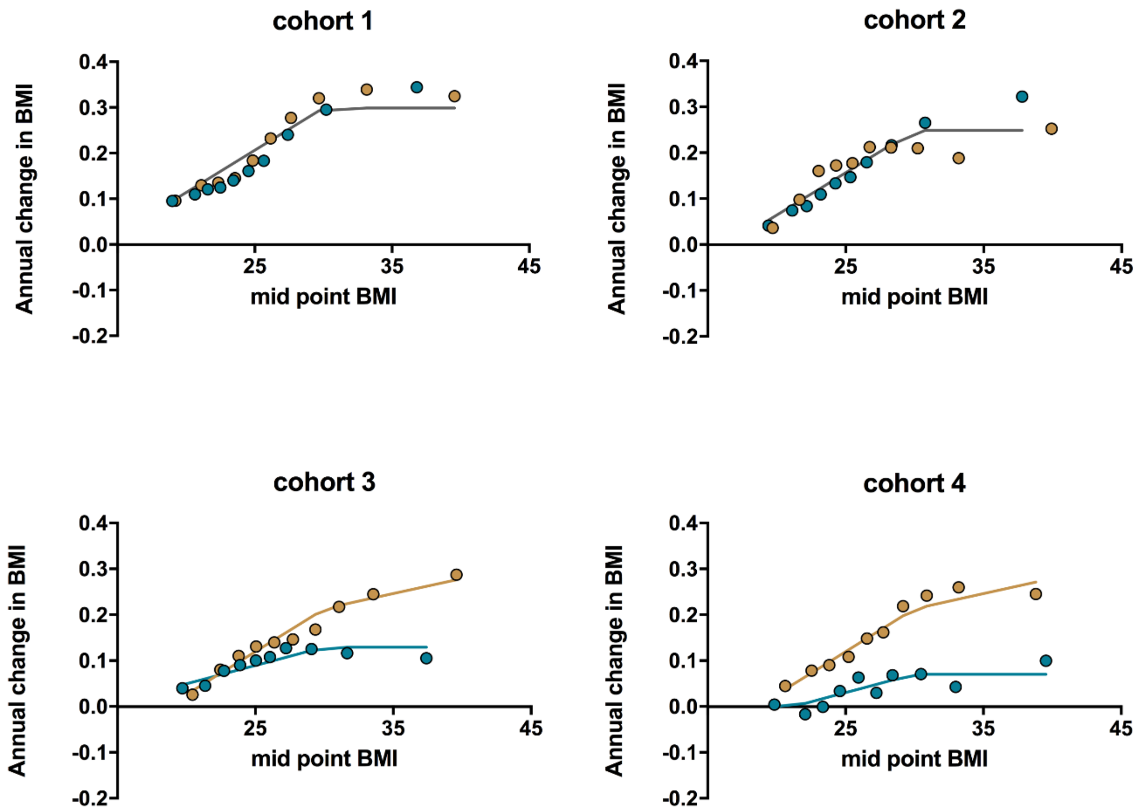
Annual weight gain = 0.2091 – 0.0059*60 + 0.0080*28 = 0.0791 units BMI

Example 4: For a woman aged 60, who completed high school and has a BMI of 33;

Annual weight gain = 0.2091 – 0.0059*60 + 0.0080*30 = 0.0951 units BMI

Example 5: For a woman aged 60, who did not complete high school and has a BMI of 33;

Annual weight gain = -0.3478 + 0.0187*30 + 0.0066*(33-30) = 0.233 units BMI



Predictions of equation for weight (BMI) gain among women for four synthetic cohorts centred on ages 34, 44, 54 and 64 years.

Brown circles = low SEP; Turquoise circles = high SEP; Each point represents annual BMI change in deciles of BMI. Grey lines = BMI change from regression equation independent of SEP; Brown lines = annual BMI change from regression equation for low SEP; Turquoise lines = annual BMI gain from regression equation for high SEP.

1.2 Modelling annual mortality

The modelling of age- and SEP- specific mortality is based on the 2011/12 Australian life table (4), a published meta-analysis of the association of BMI and all-cause mortality (5), and the published relative risk of mortality in lower and higher educated groups from a large Australian cohort study (6). The following table shows the age-specific association of BMI and SEP with mortality.

Hazard ratios of increased mortality associated with BMI and socioeconomic position

Age at risk (years)	Hazard ratio per 5 kg/m^2 increase in BMI between 25 and 50 kg/m^2 (5)	Hazard ratio of low compared with high socioeconomic position (6)
20-34	1*	1.39 (95% CI 1.08 – 1.79)
35-59	1.37 (95% CI 1.31 – 1.42)	1.39 (95% CI 1.08 – 1.79)
60-69	1·32 (95% CI 1·27–1·36)	1.39 (95% CI 1.08 – 1.79)
70-79	1·27 (95% CI 1·23–1·32)	1.39 (95% CI 1.08 – 1.79)
80+	1·16 (95% CI 1·10–1·23)	1.39 (95% CI 1.08 – 1.79)

* No association was found between BMI and mortality for those less than 35 years of age (5).

The model accounts for an increase in mortality for individuals in higher weight categories, compared with healthy weight for adults aged 35 years and over. This was based on a large meta-analysis and estimated different hazard ratios for different age groups (5). The model also includes an increase in mortality for individuals with low SEP, compared to individuals with high SEP at any age. This was informed by published data (6) from the Australian Diabetes Obesity and Lifestyle (AusDiab) study, a national population based survey of 11,247 adults aged 25 years or older in Australia. The measure of SEP was secondary school education, which matched our study's measure of SEP.

Deriving q_xs

Conditional probabilities of death (q_x) for men and women in single years of age (from the lifetable) were adjusted by SEP and weight status. For each year of age, we took into account the prevalence of 6 weight status and 2 socioeconomic groups. The calculations apportion the conditional probability of death for the entire population of men age x years, into 12 q_xs, using the method described in (7). For example, considering just the two SEP groups,

$$q_x = q_{xl} * P_l + q_{xh} * P_h \,;$$

where q_x = conditional probability of death at age x for the whole male population
q_{xl} = conditional probability of death at age x for the low SEP male subgroup;
q_{xh} = conditional probability of death at age x for the high SEP male subgroup;
P_l = prevalence of low SEP among men
P_h = prevalence of high SEP among men

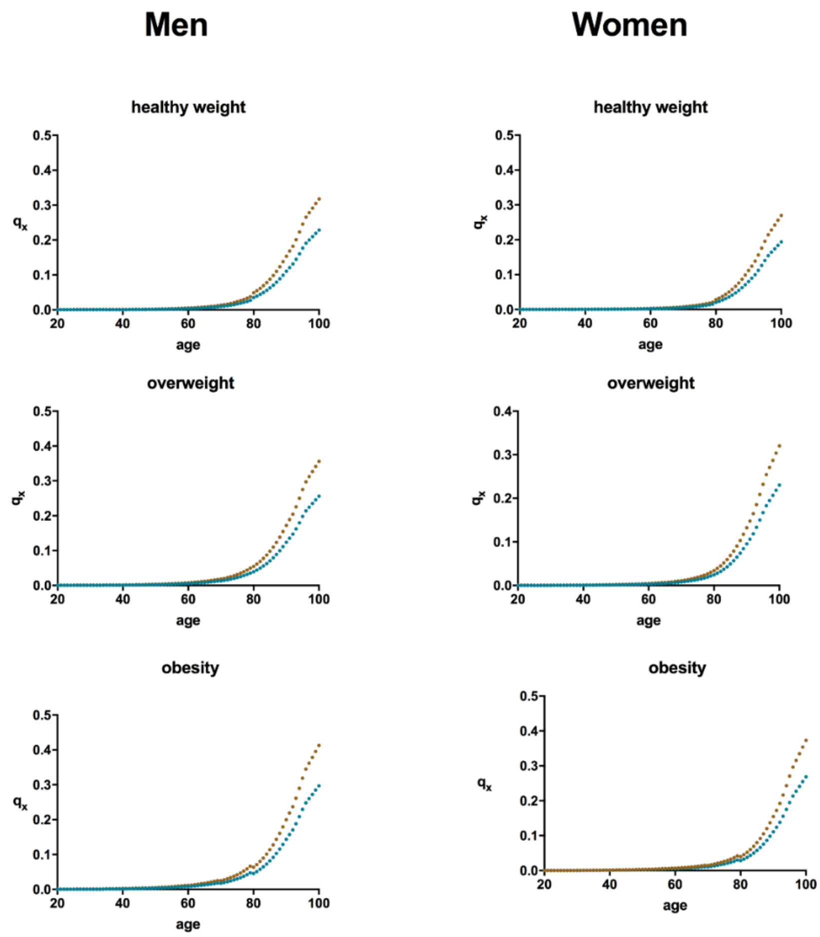
Since q_x, P_l and P_h are known, and we also know that $q_{xl} = 1.39 * q_{xh}$ (6) it is possible to solve for q_{xh}.

Example: For example, for a 40 year old man, the q_x from the 2011/12 life table is 0.00134. This was firstly partitioned into 6 q_xs representing healthy, overweight and obese I-IV categories, taking into account the prevalence of each BMI class for this age using data from the National Health Survey 2011/12. Then the q_xs each of the 6 BMI are apportioned to high and low SEP (see following table) shows the 12 q_xs derived.

qxs for men aged 40 years for different BMI classes and SEP, 2011/12.

	Healthy BMI<25	Overweight BMI 25-25.99	Obese class I BMI 30-34.99	Obese class 2 BMI 35-39.99	Obese class 3 BMI 40-44.99	Obese class 4 BMI>45
HR for mortality cf healthy weight	1	1.37	1.37^2	1.37^3	1.37^4	1.37^5
Prevalence (2011/12)	24.6%	45.2%	20.7%	6.6%	2.5%	0.4%
q_x	0. 00088	0. 00121	0. 00165	0. 00226	0. 00310	0. 00425
HR for mortality cf high SEP	1.39	1.39	1.39	1.39	1.39	1.39
Proportion high SEP (2011/12)	52.6%	56.7%	47.7%	45.0%	59.2%	59.2%
q_x high SEP	0.00074	0.00103	0.00136	0.00185	0.00266	0.00365
q_x low SEP	0.00103	0.00143	0.00190	0.00258	0.00370	0.00507

The following graphs, show q_xs for men and women by age and SEP for selected weight status groups.



qxs by high and low SEP groups and weight status
Healthy weight (BMI<25); overweight (25<BMI<30); obesity (30<BMI<35); brown circles = low SEP; turquoise circles = high SEP.

Simulation of mortality

In each year of simulation, probability of dying is determined by the q_xs for individual years of age and sex, by SEP and weight status. The number of people alive at any time is calculated from the number alive at the start of the year minus the number who have died since the start of the year. Thus:

$$X_t = \sum_{i=1}^{i=n} (x_{it} - (x_{it} * pr(d_{it})))$$

where X_t= Number of people alive at the end of time t for the whole population
x_{it}= survey weight for ith individual in the simulated data at time t, representing the number of similar people alive at a population level
$pr(d_{it})$= Probability of death for *i*th person at time t, conditional upon age, sex, BMI and SEP

The total number of people dying each year is determined from the sum across all simulated individuals of the annual probability of dying multiplied by the survey weights. Individual survey weights are adjusted at each time step of the simulation to reflect the number still alive at a population level.

1.3 Sensitivity analysis

We carried one-way sensitivity analysis of major model parameters by changing to their upper and lower 95% confidence limits and observing the change in the projected prevalence of mean BMI, overall obesity and severe obesity at age 60 years, when compared with the base model. These sensitivity analyses were carried out for men and women of high and low SEP, for 4 different age and birth cohorts, centred around: 1940, 1950, 1960 and 1970.

Parameters investigated in the sensitivity analysis were:

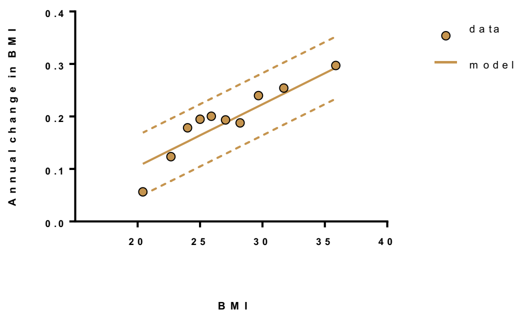
a. changing constants in the weight gain equations by upper and lower 95% confidence limits
b. changing the hazard ratio for mortality (1.39 (95% CI 1.08 to 1.79) of low compared to high education groups by the upper and lower 95% confidence limits.

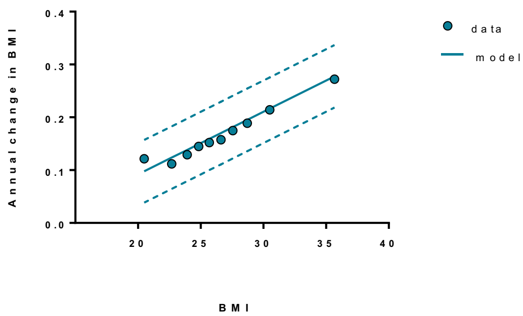
Sensitivity analysis of annual weight gain

Details of the sensitivity analysis of weight gain equations are shown graphically. Changing the constants by upper and lower CI has the result of increasing or decreasing annual weight gain, but not impacting on the slope of the relationship with baseline BMI.

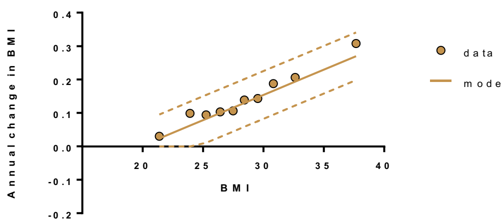
Example: For young men aged 35 the graphs below show the base model prediction for annual weight gain for men of different BMI, and the dashed lines show the upper and lower CI of those predictions, used in the sensitivity analysis.

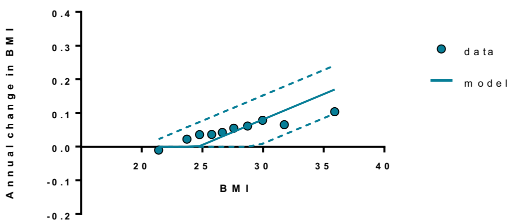
Men aged 35 (brown = low SEP; blue = high SEP)





Men aged 55 (brown = low SEP; blue = high SEP)





Sensitivity analysis of mortality

In this sensitivity analysis we investigated changing HR of mortality by low cf high SEP by its upper and lower limits (1.79 & 1.08) – this increases or decreases the risk of mortality of low SEP compared high SEP at all ages, and BMI classes.

Results of the one-way sensitivity analyses in the tables below, for men and women of 4 birth cohorts. Sensitivity analysis of upper and lower CI of annual weight change has major impacts on BMI, obesity and severe obesity at age 60 and these impacts are more pronounced for the youngest cohort.

Conversely, changing hazard of mortality by SEP to upper and lower 95% CI had little or no effect on projected mean BMI, obesity and severe obesity at age 60 years. The sensitivity analyses did not affect the pattern of obesity being higher with each successive generation and the conclusion that the youngest 3 cohorts would have much higher socioeconomic inequality at age 60, when compared with the 1940 birth cohort.

Sensitivity analysis for males, showing simulated outcomes and absolute difference (inequality) in outcomes between lower and higher SEP groups

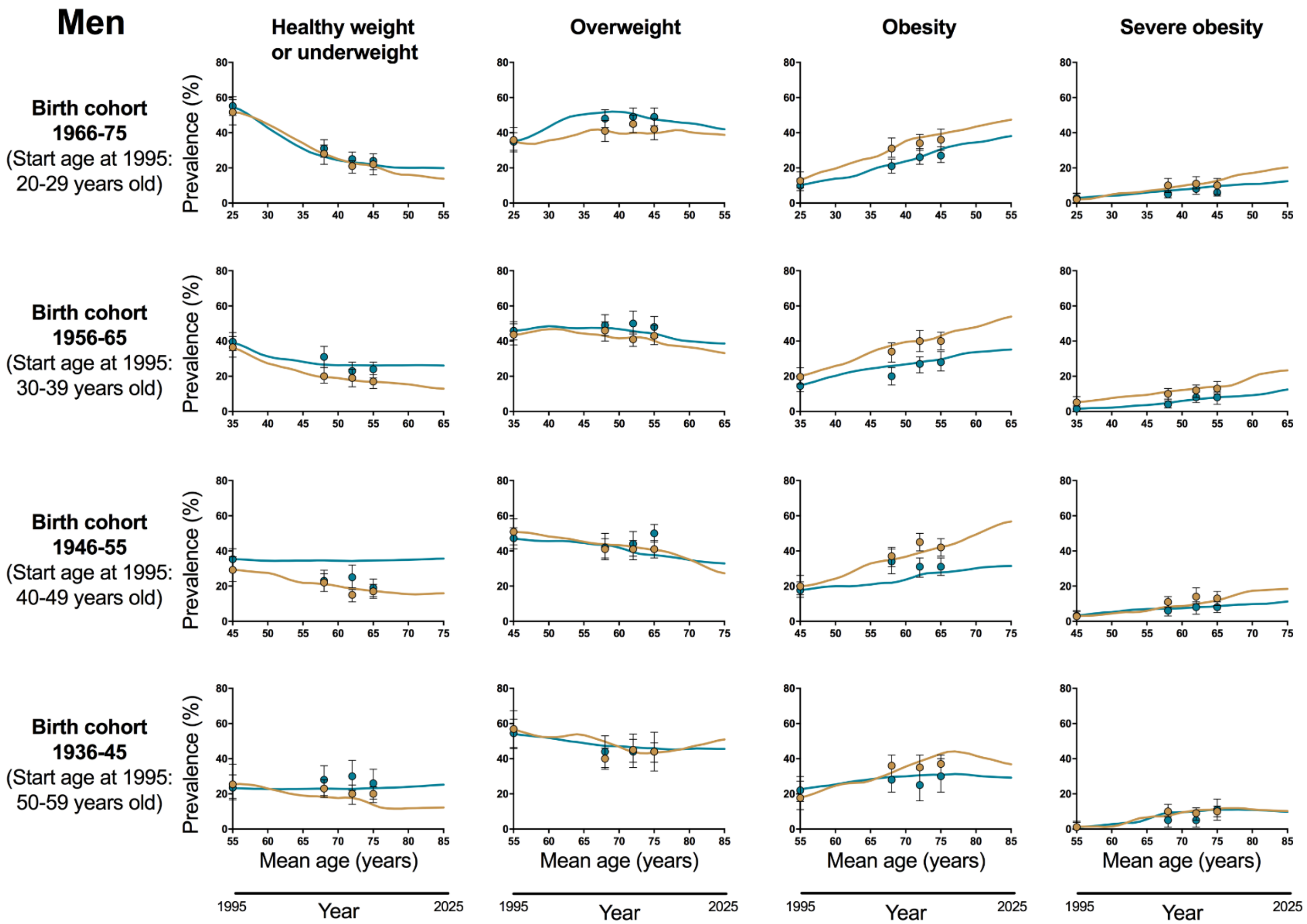
	Mean BMI at age 60			Obesity prevalence at age 60 (%)			Predicted severe obesity at age 60 (%)		
SEP	Low	High	Inequality (High minus Low)	Low	High	Inequality (High minus Low)	Low	High	Inequality (High minus Low)
Base model									
Birth cohort 1940	27.6	27.7	0.1	24.5	25.6	1.1	1.4	2.6	1.2
1950	28.9	27.6	-1.3	36.3	23.1	-13.2	8.3	7.3	-1.0
1960	30.7	28.5	-2.2	47.9	33.6	-14.3	20.3	9.4	-10.9
1970	31.4	29.7	-1.7	50.7	41.1	-9.6	24.6	13.9	-10.7
a) lower 95% CI estimate of the constants in all weight gain equations									
Birth cohort 1940	27.2	27.5	0.2	20.5	23.2	2.8	1.4	2.1	0.7
1950	27.9	27.0	-0.8	27.4	19.2	-8.2	5.2	6.5	1.3
1960	28.8	27.2	-1.6	36.8	22.6	-14.2	12.6	4.9	-7.8
1970	28.7	27.5	-1.2	37.2	21.7	-15.5	15.3	9.2	-6.1
b) upper 95% CI estimate of the constants in all weight gain equations									
Birth cohort 1940	27.9	28.0	0.1	26.3	28.6	2.3	2.1	3.7	1.6
1950	30.1	28.7	-1.4	46.1	35.0	-11.1	12.5	9.7	-2.8
1960	32.6	30.4	-2.2	63.7	48.0	-15.7	28.1	16.6	-11.5
1970	34.2	32.4	-1.8	73.5	66.0	-7.5	39.5	24.4	-15.1
c) lower 95% CI estimate of the hazard ratio of mortality by SEP									
Birth cohort 1940	27.6	27.7	0.1	24.5	25.6	1.1	1.4	2.6	1.1
1950	28.9	27.6	-1.3	36.3	23.0	-13.3	8.3	7.2	-1.1
1960	30.7	28.5	-2.2	47.9	33.4	-14.5	20.3	9.4	-10.9
1970	31.4	29.7	-1.7	50.7	40.9	-9.8	24.7	13.8	-10.9
d) upper 95% CI estimate of the hazard ratio of mortality by SEP									
Birth cohort 1940	27.6	27.7	0.1	24.5	25.6	1.2	1.4	2.6	1.2
1950	28.9	27.6	-1.3	36.3	23.1	-13.1	8.3	7.3	-0.9
1960	30.7	28.5	-2.1	47.9	33.7	-14.2	20.2	9.5	-10.7
1970	31.4	29.7	-1.7	50.6	41.2	-9.4	24.6	14.0	-10.6

Sensitivity analysis for females, showing simulated outcomes and absolute difference (inequality) in outcomes between lower and higher SEP groups

	Mean BMI at age 60			Obesity prevalence at age 60 (%)			Predicted severe obesity at age 60 (%)		
SEP	Low	High	Inequality (High minus Low)	Low	High	Inequality (High minus Low)	Low	High	Inequality (High minus Low)
Base model									
Birth cohort 1940	27.5	27.5	0.0	26.5	24.0	-2.5	9.4	10.4	1.0
1950	28.7	27.0	-1.7	38.3	22.1	-16.2	13.9	9.2	-4.7
1960	30.4	28.0	-2.4	43.4	30.4	-13.0	22.7	11.0	-11.7
1970	31.7	29.7	-2.0	53.7	42.3	-11.4	25.8	18.1	-7.7
a) lower 95% CI estimate of the constants in all weight gain equations									
Birth cohort 1940	27.2	27.1	-0.1	24.8	22.2	-2.6	9.4	8.2	-1.2
1950	27.7	25.9	-1.8	34.7	16.3	-18.4	11.2	6.6	-4.6
1960	28.9	26.5	-2.4	36.0	22.3	-13.7	18.3	8.2	-10.1
1970	29.6	27.5	-2.0	42.0	28.8	-13.3	21.6	12.2	-9.4
b) upper 95% CI estimate of the constants in all weight gain equations									
Birth cohort 1940	27.9	28.1	0.2	27.0	29.3	2.3	9.4	10.7	1.3
1950	29.7	28.4	-1.3	44.3	28.1	-16.3	15.4	11.9	-3.5
1960	31.9	29.9	-2.0	56.1	42.0	-14.0	29.3	16.7	-12.6
1970	33.8	32.1	-1.7	69.2	57.9	-11.3	36.7	25.2	-11.6
c) lower 95% CI estimate of the hazard ratio of mortality by SEP									
Birth cohort 1940	27.5	27.5	0.0	26.5	24.0	-2.5	9.4	10.3	1.0
1950	28.7	27.0	-1.7	38.4	22.0	-16.4	13.9	9.1	-4.8
1960	30.4	28.0	-2.3	43.4	30.3	-13.1	22.8	11.0	-11.8
1970	31.7	29.7	-2.0	53.8	42.2	-11.6	25.8	18.0	-7.9
d) upper 95% CI estimate of the hazard ratio of mortality by SEP									
Birth cohort 1940	27.5	27.5	0.0	26.5	24.0	-2.4	9.4	10.4	1.0
1950	28.7	27.0	-1.7	38.3	22.1	-16.2	13.9	9.2	-4.7
1960	30.4	28.0	-2.3	43.4	30.5	-12.9	22.7	11.1	-11.6
1970	31.7	29.7	-2.0	53.7	42.4	-11.3	25.8	18.2	-7.6

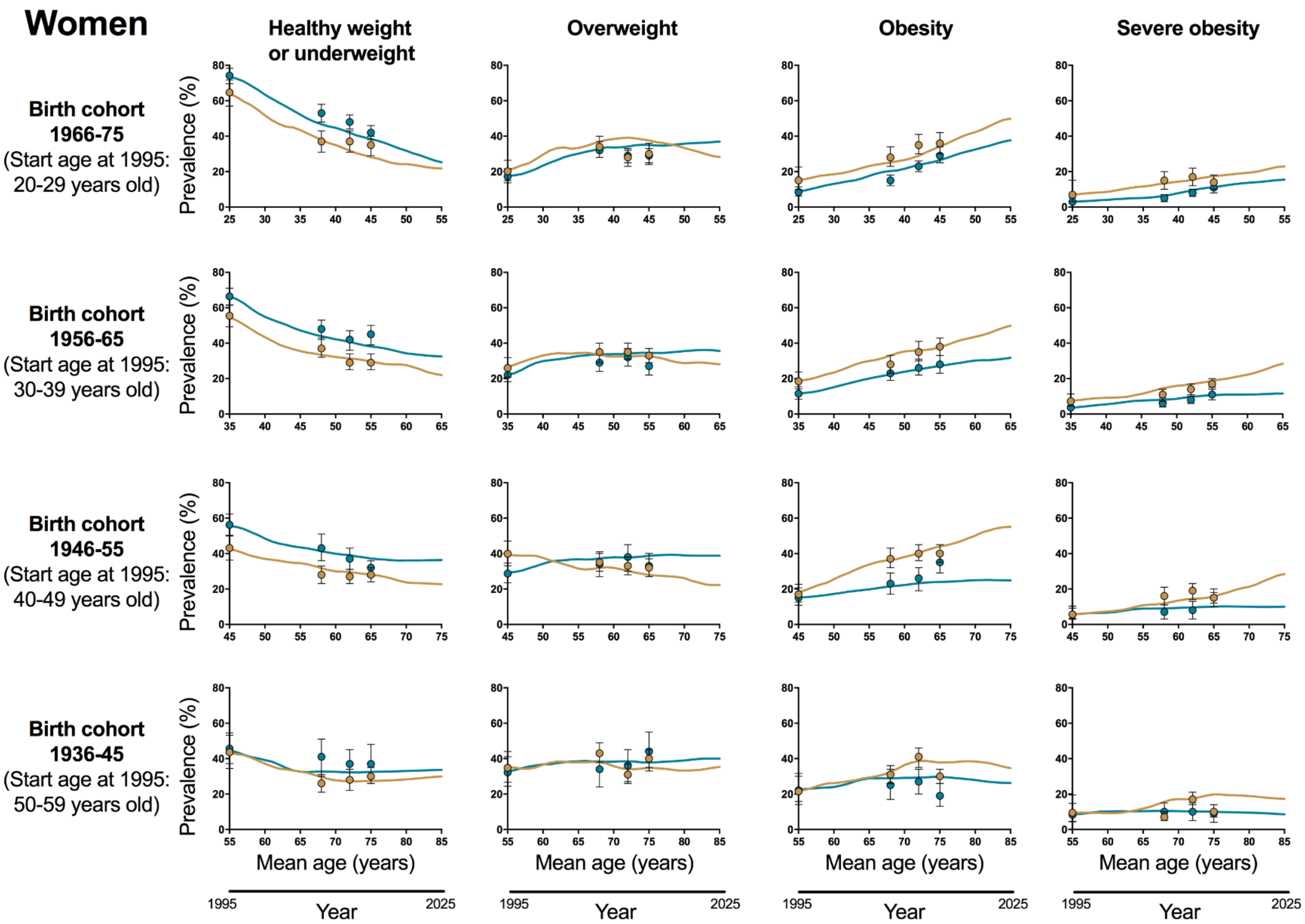
Section 2: Supplement Figures

Supplement Figure 1. Simulated compared with actual weight status, for men by birth cohort and SEP



Lines = simulated prevalence; circles = prevalence from NHS; turquoise = high SEP; brown = low SEP. Healthy and underweight prevalence BMI<25; overweight 30>BMI>25; obesity BMI>30; severe obesity BMI>35.

Supplement Figure 2. Simulated compared with actual weight status, for women, by birth cohort and SEP



Lines = simulated prevalence; circles = prevalence from NHS; turquoise = high SEP; brown = low SEP. Healthy and underweight prevalence BMI<25; overweight 30>BMI>25; obesity BMI>30; severe obesity BMI>35.

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