Modeling and Forecasting Premature Cardiovascular Mortality: The Role of Obesity and Education

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Modeling and Forecasting Premature Cardiovascular Mortality:

The Role of Obesity and Education

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CONTENTS

Executive Summary **4**

Section 1: Background and Literature Review **6**
- 1.1 Trends in CVD mortality in high-income countries 6
- 1.2 Obesity and CVD mortality 6
- 1.3 Education and CVD mortality 7
- 1.4 Education and obesity prevalence 8

Section 2: Data **9**
- 2.1 The National Center for Health Statistics (NCHS) 9
- 2.2 Survey of Epidemiology and End Results (SEER) 10
- 2.3 CDC National Health and Nutrition Examination Survey (NHANES) 11
- 2.4 American Community Survey (ACS) 11

Section 3: Modeling Framework **13**
- 3.1 Data collection and visualization 13
- 3.2 Inputs 13
- 3.3 Stochastic mortality modeling 13
- 3.4 Mean-level and interval projection 14
- 3.5 Output and Excel tool 14

Section 4: Empirical Results **15**
- 4.1 Trend in CVD mortality rate 15
- 4.2 Trend in education attainment levels 17
- 4.3 Trend in obesity prevalence rate 20
- 4.4 Trend in proportion of obesity-related CVD mortality 21
- 4.5 Trend in conditional CVD mortality given obesity status and education attainment level 27
- 4.6 Forecast of conditional CVD mortality to 2029 34
- 4.7 An actuarial perspective 41

Section 5: Conclusions **43**
- 5.1 Summary of key results 43
- 5.2 Limitations 43

Section 6: Acknowledgment **44**

References **45**

About The Society of Actuaries Research Institute **48**

Modeling and Forecasting Premature Cardiovascular Mortality:

The Role of Obesity and Education

Executive Summary

Cardiovascular disease (CVD) mortality in high-income countries has experienced a sustained reduction since the 1960s, which has contributed to improvements in population life expectancy. However, for several high-income countries, including the U.S., recent data from vital statistics indicates a deceleration in CVD mortality declines, particularly below age 75 years. To better understand the potential future trajectory of CVD mortality, we need to examine and model recent historical data on premature CVD mortality, i.e. at ages 35–74 years, in particular the key risk factors that affect its trends.

This project aims to model and forecast premature cardiovascular mortality, with a focus on two main risk factors - obesity status and education attainment level. A key contribution of this research is to investigate the role of obesity and education in determining age-sex-specific premature cardiovascular mortality. There is a strong link between obesity status and CVD deaths, with numerous studies affirming how obesity heightens the risk of CVD mortality. In this report, we identify obesity-related CVD deaths as deaths with CVD being reported as a cause of death, along with one or more of obesity, diabetes, chronic kidney disease, lipidemias or hypertensive heart disease. As such, they are a strong proxy for CVD mortality due to obesity. It is also important to consider socioeconomic factors when modeling CVD mortality. This report utilizes education attainment level as a proxy for socioeconomic status in CVD mortality modeling, assessing the impact of low, medium, and high education attainment levels and examining inequality in CVD mortality across these groups.

Collecting and consolidating data across several different sources for the U.S. population, we estimate the conditional probability of premature cardiovascular deaths given obesity status and education attainment level. Data on U.S. mortality, obesity status, and education attainment are considered over the period 2003–2019 by collecting both individual-level and macro-level information. Based on the computed conditional premature CVD mortality, we find that during the period 2003–2019:

- CVD mortality has been either increasing, especially in younger age groups, or has remained stable in more recent years.
- The prevalence of obesity has been increasing across all age groups and education levels.
- The proportion of individuals with higher educational attainment has been increasing over time.
- The proportion of CVD deaths that are obesity-related has been increasing over all education attainment levels.

In this report, we have also estimated conditional premature CVD mortality given obesity status and education attainment for 2003-2019 and forecast it for the 10-year period 2020–2029[1]. Our main findings can be summarized as follows.

- There has been, and is forecast to be, a divergence in CVD mortality trends for obese vs non-obese populations across all education levels.
- The obese population has been experiencing, and is forecast to experience, either an increase or stabilization in CVD mortality, depending on the sex, age and education attainment, with worse outcomes for males in particular.
- The non-obese highly educated population has been experiencing, and is projected to experience, a decrease in CVD mortality, while for those of low and middle education attainment it has been, and is projected to, remain stable in most age groups while is projected to decline slightly in other age groups.
- In the most recent years and projected into the future, the conditional CVD mortality for the obese population of middle education attainment exceed those of the non-obese population with low education, demonstrating that obesity more than offsets lower CVD mortality due to higher education.

[1] Note that our projections are based on modeling of the historical trend in conditional CVD mortality and do not consider the effect of new semaglutide drugs such as Ozempic and Wegovy that have been found to lead to weight loss. They also do not account for the effect of COVID-19.

Section 1: Background and Literature Review

As the leading cause of death globally, cardiovascular disease (CVD) experienced a long-term decline in mortality from the 1960s. In fact, the improvements in population life expectancy over the last few decades were largely driven by the decreasing trend in premature CVD mortality (Klenk et al., 2016). However, for many high-income countries, recent evidence from national vital statistics shows that CVD mortality rates are now either decreasing at a much slower speed, or in some cases increasing (Sidney et al., 2016; Lopez & Adair, 2019), especially for younger age groups. Furthermore, obesity, which has high prevalence in many high-income countries, has been a key driver of recent adverse CVD mortality trends in the U.S. (Adair & Lopez, 2020). Also, educational attainment is a leading predictor of CVD mortality, including in the U.S. (Khan et al., 2023). Given this background, this project focuses on premature CVD mortality in the U.S. and the role of obesity status and education attainment. Considering the recent poor trends in CVD mortality improvement, we also provide predictions for future CVD mortality rates given obesity status and education attainment level.

1.1 TRENDS IN CVD MORTALITY IN HIGH-INCOME COUNTRIES

CVD has been a leading cause of death in high-income countries, including the U.S., for the last few decades. Globally, around 32.2 million deaths, accounting for 80% of all noncommunicable diseases (NCDs), are caused by CVD, cancers, chronic respiratory disease, and diabetes. Sustainable Development Goal (SDG) 3.4 aims for a one-third reduction in mortality between ages 30 and 70 years due to these four NCD causes from 2015 to 2030. However, less than 20% of countries are expected to achieve this goal according to their existing rate of mortality decline (Bennett et al., 2018).

Given that CVD is the leading cause of NCD-related deaths, both its epidemiology and surveillance are recognized as major factors influencing effective health policy intervention and the reduction of premature mortality. It is therefore essential to describe the trends and patterns of both the risks and mortality due to CVD. CVD is the leading cause of global premature mortality (GBD, 2020).

Despite the introduction of many modern therapies to treat CVD, the rate of decline in CVD mortality seems to be slowing down in the last decade across many high-income countries. For U.S. males and females, Lopez and Adair (2019) found that the average rate of decline in age-standardized CVD mortality from 2010 to 2016 was about 1% per annum, which is around 2.5% lower compared to the previous decade. They also found that since 2014, age-standardized CVD mortality rates have even started increasing, especially in ages 35–74 and at all ages for lower socioeconomic groups. Similar experience has been observed in Australia, and the slowdown in CVD mortality improvement was attributed to a possible reversal in the earlier decline of some major risk factors, including smoking, blood pressure, and diabetes mellitus (O'Flaherty et al., 2012).

Recent evidence shows that reversal of CVD mortality poses a major challenge for the public health policy for countries such as the U.S. and Australia (Lopez and Adair, 2019; Adair and Lopez, 2020). To be better prepared for a potential increase in CVD mortality in the future, we need to better understand and model the most recent historical data on premature CVD mortality.

1.2 OBESITY AND CVD MORTALITY

Global obesity prevalence has increased substantially over the last few decades (Ortega et al., 2016). In the U.S. alone, obesity prevalence has increased significantly among all age, sex, and racial/ethnic groups. In 2017-2020, the National Health and Nutrition Examination Survey (NHANES) reported that 42% of U.S. adults aged 20+ years were obese, compared with 31% in 1999-2000, while 20% of children aged 2-19 years in 2017-2020 were obese (CDC 2023, Stierman et al., 2021). The increase in obesity has numerous negative health consequences, including an elevated risk of CVD and related mortality. Numerous studies have identified a higher level of mortality for the obese population, in particular from CVD (Di Angelantonio et al., 2016; Prospective Studies Collaboration et al., 2009; Xu et al., 2018). The amount and quality of adipose tissue in the human body determines the CVD risks associated with obesity (Bastien et al., 2014). Obesity is directly linked with coronary heart disease, atrial fibrillation, and heart failure. Obesity is a major risk factor for diabetes, and its prevalence results in increased rates of CVD mortality. Childhood obesity, like adult obesity, is associated with the risk of CVD disease and mortality in later life because it predisposes individuals to these conditions as adults (Ayer et al., 2015).

According to a Global Burden of Disease (GBD) study, over two thirds of deaths attributed to obesity result from CVD mortality (GBD, 2017b). Hence, reducing obesity prevalence is recognized as a key factor for reducing global CVD risk and ultimately improving the survival rate and quality of life (Lopez-Jimenez et al., 2022). Recently, there has been a noticeable increase in obesity-associated CVD mortality in many high-income countries including U.S. and Australia, which have contributed to the reversal in the decline of CVD mortality in both countries (Adair and Lopez, 2020).

Given the significant rise in adult obesity prevalence across many high-income countries over the last few decades, future CVD mortality will undoubtedly be influenced by the prevalence of obesity (Ezzati et al., 2015). In this project, we identify obesity-related CVD deaths as deaths with CVD being reported as the underlying or an associated cause of death, along with one or more of obesity, diabetes, chronic kidney disease, lipidemias or hypertensive heart disease. These are conditions for which obesity status heightens the risk of mortality from CVD (see Adair and Lopez, 2020, and references therein). As such, they are a strong proxy for CVD mortality due to obesity. For ages 35–74, we compute obesity-related CVD mortality rates, and compare them with total CVD mortality rates, as well as non-obesity-related CVD mortality rates.

1.3 EDUCATION AND CVD MORTALITY

It is well acknowledged that mortality is higher among lower socioeconomic groups. These segments of the population may have experienced stagnation or even an increase in premature CVD mortality over recent years (Case and Deaton, 2021).

Lower educational attainment has been found independently associated with increased risk of all-cause and CVD mortality among both U.S. general population and the individuals with atherosclerotic CVD (Khan et al., 2023). Specifically, CVD mortality risk was found to be highest among individuals with an education level below high school (Khan et al., 2023; Beauchamp et al., 2010). For example, in Australia, people with lower education had almost double the mortality rates than the people with higher education status (Korda et al., 2020). A cohort study in Japan found higher mortality from all causes and CVD among the Japanese population with less than 10 years of education compared to more than 12 years of education (Ito et al., 2008).

Hence, it is important to consider socioeconomic factors while modeling CVD mortality. Education attainment has been frequently used as a proxy for socioeconomic level in mortality modeling (e.g., Albano et al., 2007; Montez and Zajacova, 2013; Lour´es and Cairns, 2020). More importantly, individual-level information on education attainment has better availability than other socioeconomic indexes. In this report, we define and consider three general education levels, namely low education, medium education, and high education. Education attainment data are collected and consolidated across several different data sources for the U.S. population. We then assess the inequality in CVD mortality.

1.4 EDUCATION AND OBESITY PREVALENCE

Research has found variations in the obesity prevalence by education and socioeconomic status (Ogden et al., 2017). In general, there is a positive correlation between obesity and education level.

A U.S. study revealed variations in obesity prevalence based on sex, race/non-Hispanic origin, and educational attainment; high prevalence was observed among people with less education from specific race/ethnic groups and sexes, including "non-Hispanic white" women and men, "non-Hispanic black" women, and "Hispanic" women (Ogden et al., 2017)[2]. Obesity prevalence levels were also found to be higher among adults with lower socioeconomic status and lower education levels in Colombia (Jimenez-Mora et al., 2020). Likewise, in Sweden, there was a dramatic increase in obesity and overweight prevalence from 1995-2017, particularly among individuals with lower education levels and those living in rural areas (Hemmingsson et al., 2021). Overall, consistent and substantial social gaps in obesity based on education have been found in OECD countries, with much larger gaps for women when compared to men in those countries (Devaux and Sassi, 2011).

Given that both obesity status and education level affect CVD mortality, in this report we aim to better understand the "twin" problem of how obesity and education jointly determine age-sex-specific premature CVD mortality. We contribute to existing literature by computing the conditional probability of cardiovascular deaths given obesity status as well as education attainment level, which will enable us to identify the extent to which obesity-related CVD mortality is affecting the lowest education group in society.

[2] The terms for race and ethnicity are from Ogden et al. 2017. Prevalence of obesity among adults, by household income and education—United States, 2011–2014 and may not reflect SOA preferred language.

Section 2: Data

In this project, we collect and combine the following sources for mortality, population exposure, health, and socioeconomic data, to compute the CVD mortality conditional on obesity status and education level.

2.1 THE NATIONAL CENTER FOR HEALTH STATISTICS (NCHS)

The NCHS records information regarding all individual deaths in the U.S. since 1959, including age, sex, month of death, causes of death, and education. This dataset has considerable advantages for modeling CVD mortality as it provides all conditions reported on the death certificate. We collect individual-level death data from the NCHS "Multiple Cause of Death Data" vital statistics database for the period 2003–2019. For education attainment level, there are two types of classifications, namely the 1989 version and the 2003 revision. We present the two types in Tables 1 and 2 below and illustrate how they fit with our categorization rule for "low", "middle", and "high" levels of education.

Table 1
NCHS 1989 VERSION OF EDUCATION ATTAINMENT

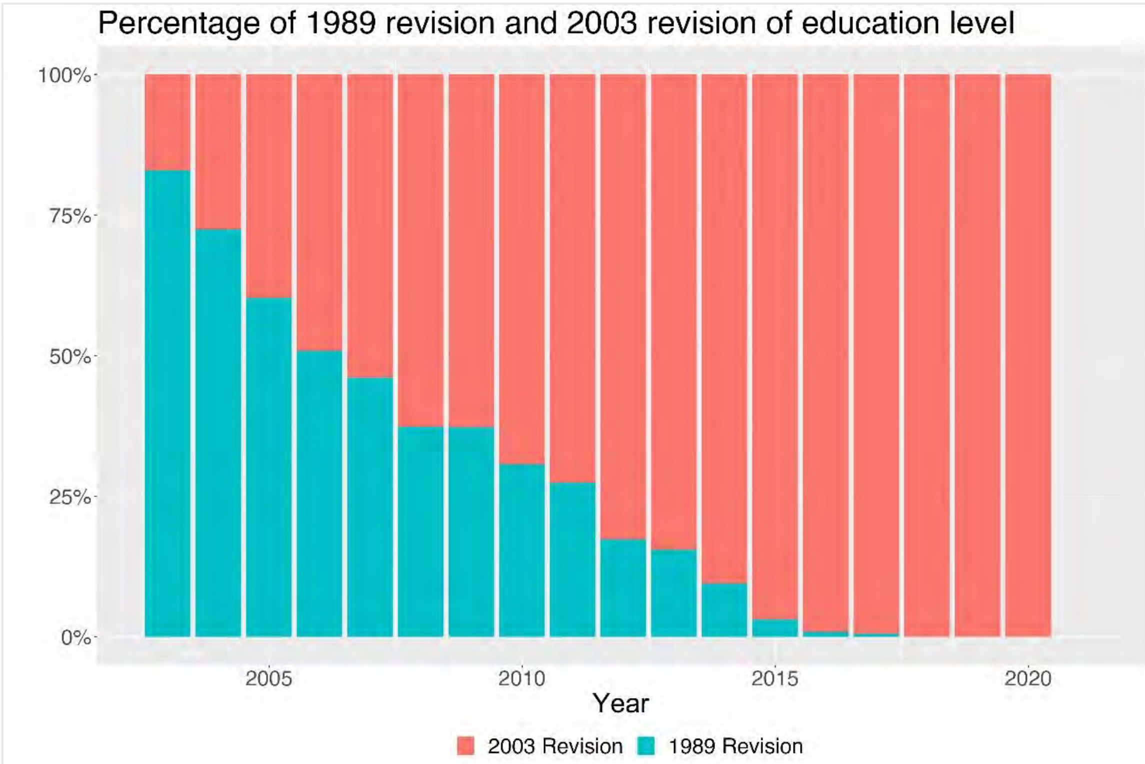
NCHS code	Description	Level
0	No formal education	low
1-8	Years of elementary school	low
9	1 year of high school	low
10	2 years of high school	low
11	3 years of high school	low
12	4 years of high school	middle
13	1 year of college	middle
14	2 years of college	middle
15	3 years of college	middle
16	4 years of college	high
17	5 years of college or above	high

Table 2
NCHS 2003 VERSION OF EDUCATION ATTAINMENT

NCHS code	Description	Level
1	8th grade or less	low
2	9-11th grade (includes 12th grade with no diploma)	low
3	High school graduate/GED or equivalent	middle
4	Some college credit but no degree	middle
5	Associate's degree	middle
6	Bachelor's degree	high
7	Master's degree	high
8	Doctorate or professional degree	high

In Figure 1, we illustrate the transition from the 1989 definition to the 2003 definition of education attainment level. We can see that from 2018 onwards, the NCHS dataset is fully following the 2003 definition. We believe that our grouping is consistent throughout the investigation period.

Figure 1
TRANSITION FROM THE 1989 DEFINITION TO THE 2003 DEFINITION OF EDUCATION ATTAINMENT LEVEL



Since we aim to model premature cardiovascular mortality rates, ages 35–74 will be our focus. In this project, we identify obesity-related CVD deaths as deaths with CVD being reported as the underlying or an associated cause of death, along with one or more of obesity, diabetes, chronic kidney disease, lipidemia or hypertensive heart disease being reported anywhere on the death certificate. Obesity is a major risk factor for mortality from these conditions (see Adair and Lopez, 2020, and references therein). As such, they are a strong proxy for CVD mortality due to obesity. See Table 3 for the causes of death considered with their corresponding ICD-10 codes.

Table 3
CODIFICATION OF CAUSES OF DEATH CONSIDERED

Cause of death	ICD-10 code
Cardiovascular	I00-I99
Diabetes	E10-E14
Hypertensive heart disease	I10-I13
Lipidemias	E78-E79
Chronic kidney disease	N18-N19
Obesity	E65-E68

2.2 SURVEY OF EPIDEMIOLOGY AND END RESULTS (SEER)

The Survey of Epidemiology and End Results (SEER) provides an excellent resource of U.S. population data since 1969 on U.S. population by age, race, sex, and more recently Hispanic origin (since 1990). We collected annual population data with both the 19 age groups (< 1, 1-4, . . ., 80-84, 85+) and 86 single-year age groups (< 1, 1, 2, . . ., 84, 85+), for the period 2003–2019.

2.3 CDC NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY (NHANES)

NHANES is a cross-sectional survey that has run every two years by the U.S. CDC beginning in 1999. It is designed to monitor the health and nutritional status of the U.S. population. The survey provides information on standardized measurements of weight and height. Body mass index (BMI) is calculated as weight in kilograms divided by height in squared meters. Overweight is defined as a BMI greater than or equal to 25 kg/m2, and obesity is defined as a BMI greater than or equal to 30 kg/m2. The survey also provides socioeconomic data on individual education attainment level. We collect individual-level data from the NHANES for the period 2003–2019 which includes waves 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2014, 2015–2016, 2017–2018, and 2017–March 2020 Pre-Pandemic Data[3]. Table 4 below shows the education codes reported in NHANES and their corresponding descriptions. Like Tables 1 and 2, we illustrate how they fit with our categorization rule for "low", "middle", and "high" levels of education.

Table 4
NHANES EDUCATION ATTAINMENT CODES

NHANES code	Description	Level
1	Less than 9th grade	low
2	9-11th grade (includes 12th grade with no diploma)	low
3	High school graduate/GED or equivalent	middle
4	Some college or AA degree	middle
5	College graduate or above	high

2.4 AMERICAN COMMUNITY SURVEY (ACS)

The U.S. Census Bureau (Census) is an agency of the U.S. Federal Statistical System and is responsible for the collection and publication of data about the American people and economy. We collected data of the education attainment of the population 18 years and over from the American Community Survey (ACS) which is a demographics survey program conducted by the Census. Educational attainment data is available from the survey on a 1-year, 3-year, and 5-year basis. We collected this information for the period 2003–2019. In Table 5, we show the education attainment levels reported in the ACS and their corresponding categorizations.

[3] Please note that field operations for the NHANES program were suspended in March 2020 due to the COVID-19 pandemic. Consequently, data collection for the NHANES 2019-2020 cycle was left incomplete, rendering the collected data non-nationally representative. To address this, data collected from 2019 to March 2020 were amalgamated with data from the NHANES 2017-2018 cycle to create a nationally representative sample of NHANES data spanning from 2017 to March 2020.

Table 5

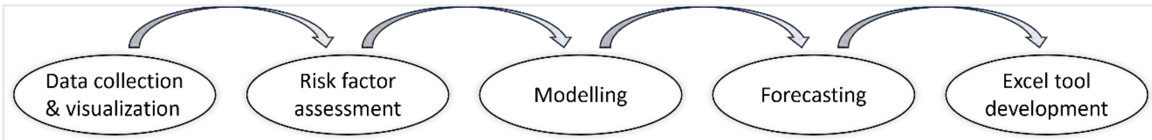
ACS EDUCATION ATTAINMENT CODES

USCB description	Level
1st - 4th grade	low
5th - 6th grade	low
7th - 8th grade	low
9th grade	low
10th grade	low
11th grade	low
High school graduate	middle
Some college no degree	middle
Associate's degree – occupational	middle
Associate's degree – academic	middle
Bachelor's degree	high
Master's degree	high
Professional degree	high
Doctorate degree	high

Section 3: Modeling Framework

The proposed project consists of five main stages illustrated in Figure 2 below.

Figure 2
PROJECT FLOWCHART



3.1 DATA COLLECTION AND VISUALIZATION

The first stage of the project involves collecting, processing, and consolidating data from different sources to ensure consistency. Upon data collection, we visualized obesity-related cardiovascular mortality data across the three major education groups, to identify any inequalities in mortality experience over the investigation period. Mortality data visualizations were separated by males and females.

3.2 INPUTS

To assess the key risk factors affecting CVD mortality rates, we compute the conditional probability of cardiovascular death given obesity status and education attainment level. Based on Bayes' theorem, for a certain age and sex, this conditional probability is calculated as

$$\Pr(CVD|O,E) = \frac{\Pr(O,E|CVD)\Pr(CVD)}{\Pr(O,E)}$$

where CVD denotes cardiovascular death, O denotes obesity status that can take the value of 0 (No obesity) or 1 (Obesity), and E denotes education attainment level that can take the value of 1 (Low education level), 2 (Medium education level), or 3 (High education level). For the three quantities on the right side of the equation above, we calculate them as follows. Pr(O,E|CVD) can be computed by the number of CVD deaths for a given obesity status and education level, divided by the total number of CVD deaths. Pr(CVD) is calculated as the number of CVD deaths divided by the total population exposure. The joint probability function Pr(O,E) can be computed as Pr(O|E)×Pr(E) which is the product of conditional probability and the proportion of a certain education level in the total population.

3.3 STOCHASTIC MORTALITY MODELING

Once conditional probabilities Pr(CVD|O,E) are computed for age groups 35–74, for both males and females, and for different obesity statuses and education levels, we fit these mortality time series using the well-known Lee-Carter model (1992). Lee-Carter model is one of the earliest stochastic mortality models, and arguably the most influential mortality model since the 1990s. The model is specified as follows:

$$\log\left(m_{x,t}\right) = a_x + b_x\kappa_t + \mathcal{E}_{x,t},$$

where $m_{x,t}$ is the mortality rate at age *x* and time *t*, calculated by the ratio of death counts to population exposure. a_x and b_x are age-related effects, and κ_t represents time-related effect. $\mathcal{E}_{x,t}$ is the residual term with mean equal to 0. The Lee-Carter model incorporates both age and time factors in a single model. To estimate the model, the following constraints are necessary for identification purposes:

$$\sum_x b_x = 1, \sum_t \kappa_t = 0.$$

These constraints imply that a_x is estimated by the average of $\log(m_{x,t})$over time:

$$a_x = \frac{1}{T}\sum_{t=1}^{T} \log(m_{x,t}).$$

For each combination of obesity status and education level, we fit a separate Lee-Carter model, which is done separately for both males and females.

3.4 MEAN-LEVEL AND INTERVAL PROJECTION

Based on the fitted Lee-Carter models developed in Section 3.3, we project future CVD mortality for different age groups, sexes, and more importantly for different obesity status and education attainment levels. Besides mean forecasts, we also compute prediction intervals at the 95% level.

In order to project future mortality rates, a time series model is generally fitted to κ_t and it is suggested by Lee and Carter (1992) that a random walk with drift process fits very well for mortality forecasting. A random walk with drift process is specified as follows:

$$\kappa_t = \kappa_{t-1} + d + e_t,$$

where d is the drift term, and e_t is the error term with mean equal to 0 and standard deviation equal to σ. The random walk with drift model is also known as the ARIMA (0,1,0) model. The mortality projection is implemented via the R package 'demography'.

3.5 OUTPUT AND EXCEL TOOL

After producing the forecast results, we integrate them into an interactive Excel tool for easy access to data results. This tool is designed for stakeholders of this project, particularly actuarial researchers and practitioners. The Excel tool includes instructions on how to navigate and use it and can be accessed from the same web page as this report.

Section 4: Empirical Results

4.1 TREND IN CVD MORTALITY RATE

Figure 3 and Table 6 show that the trend in CVD mortality rates in the U.S. from 2003–2019 differed by age groups. Overall, mortality rate trends are worse in more recent years and at younger ages. As expected, the level of CVD mortality rates were higher at older ages. At the oldest ages, there was a clear decline in the death rate from 2003–2009 for both males and females, reaching almost 3% per annum for ages 70–74. This decline continued until around 2015 for the 65–69 and 70–74 age groups after which it stabilized or increased slightly. The decline for the 55–59 and 60–64 age groups stopped around 2009 and thereafter increased. For all age groups in the 35–54 age range, there was no decline in mortality rates in the first few years of the period, but thereafter there was a rise, especially for ages 35–39 (1.5% male, 2.2% female) and 40–44 (1.5% male, 1.2% female). In most age groups up to 55–59 years, the CVD mortality rate was higher in 2019 compared with 2003, most notably in the 35–39 year-old age group (female: annualized rate change of 1.2% or 20% higher; male: annualized rate change of 0.8% or 13% higher).

In Figure 4, we plot the CVD mortality rate as a proportion of total mortality rate, by age and sex. We can see that proportionally, cardiovascular disease (CVD) constitutes a larger percentage of total mortality for males compared to females. Also, CVD mortality contributes a higher percentage of total deaths for older age groups compared to younger age group.

Figure 3
U.S. MORTALITY RATE (LOG SCALE) DUE TO CVD, BY SEX, AGES 35-74, AND YEARS 2003–2019

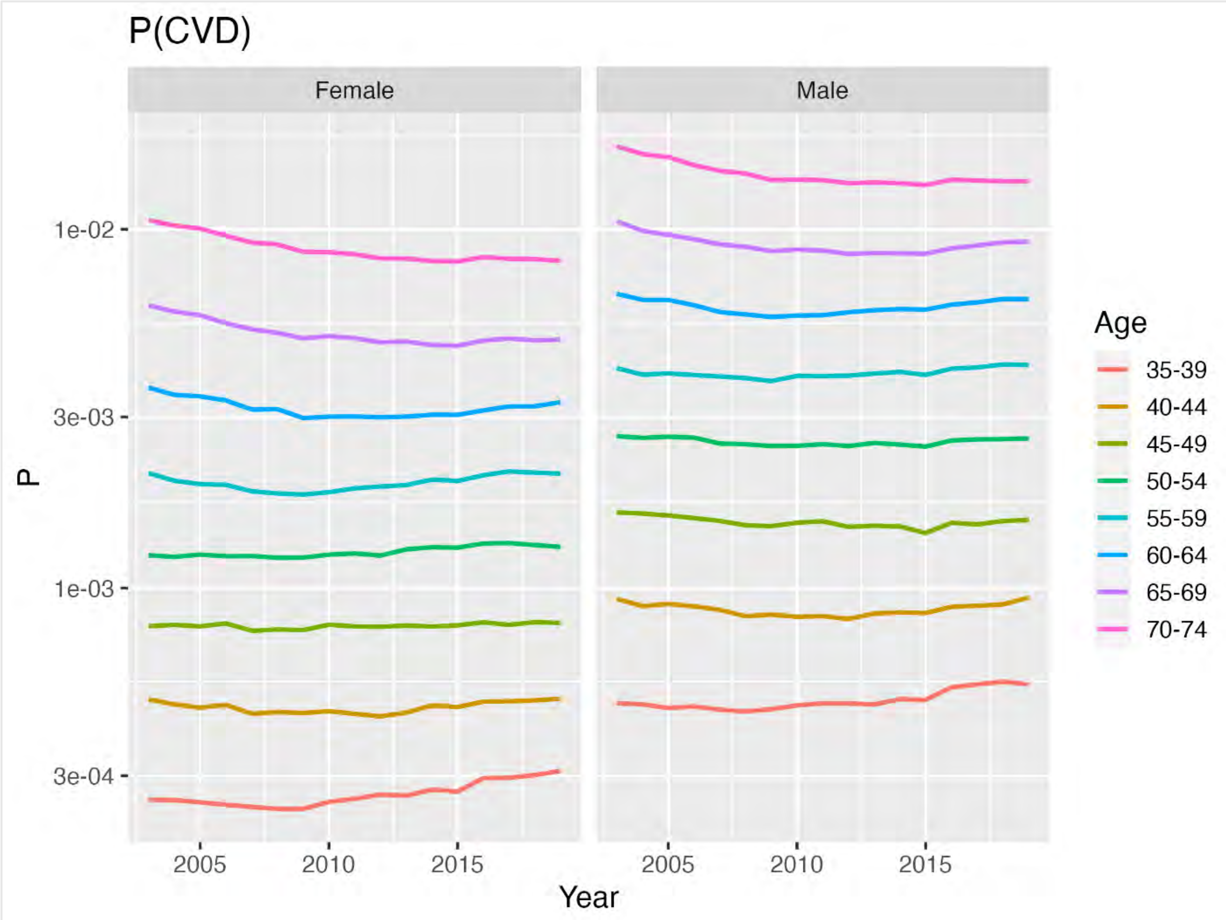


Figure 4
U.S. CVD MORTALITY AS A PROPORTION OF ALL-CAUSE MORTALITY, BY SEX, AGES 35-74, AND YEARS 2003–2019

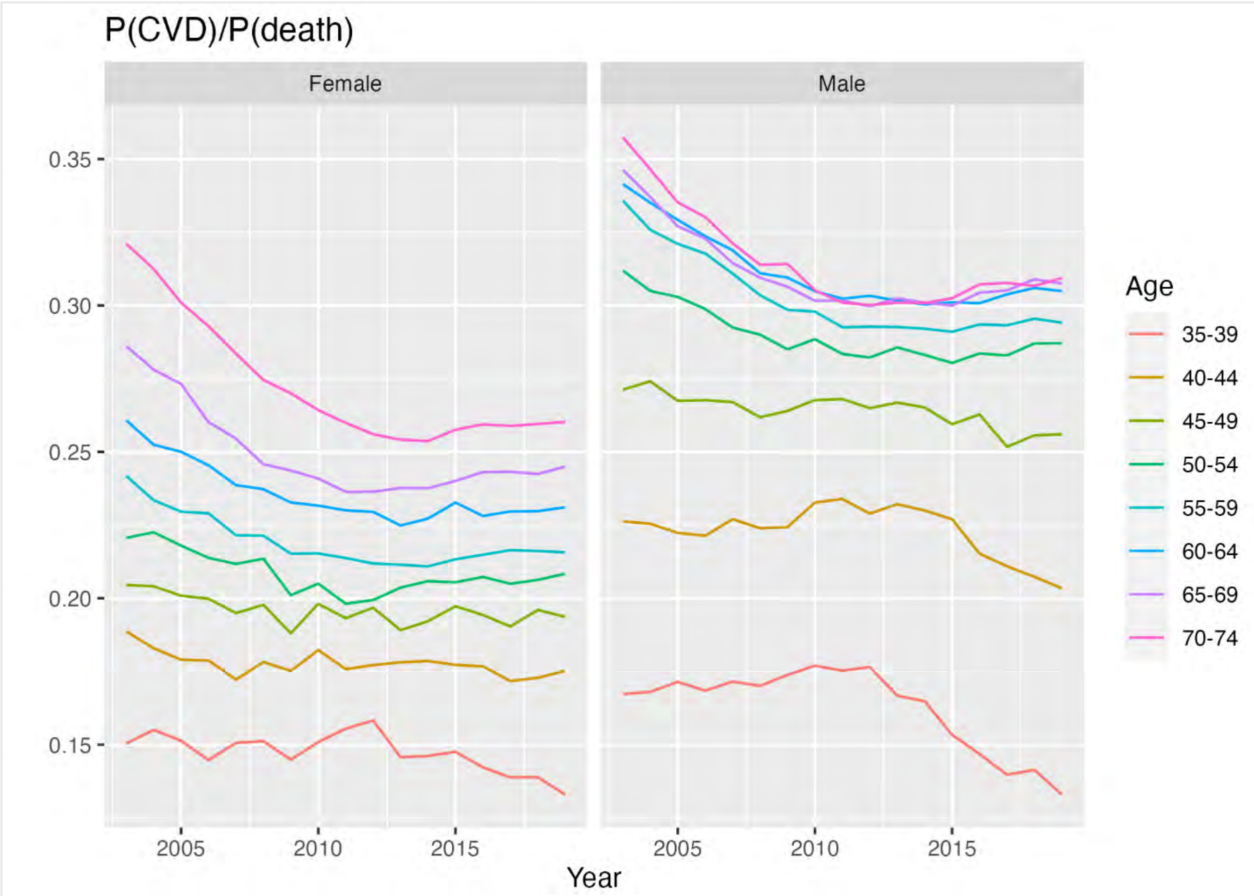


Table 6
ANNUALIZED RATE OF CHANGE (%) IN U.S. CVD MORTALITY RATE, BY SEX, AND AGES 35–74, FOR PERIODS 2003–2011, 2011–2019, 2003–2019

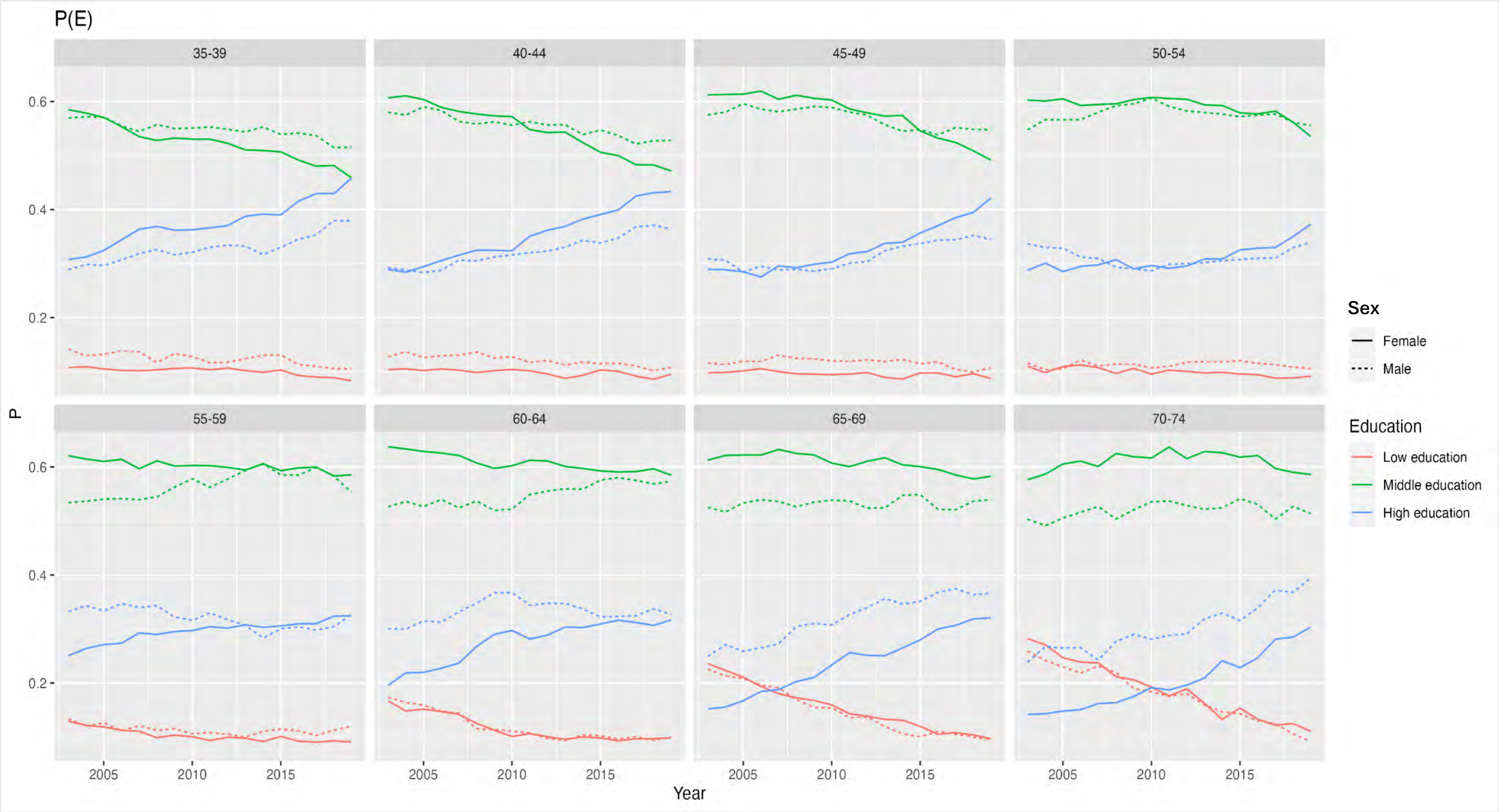
Female	Age Group							
	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74
2003–2011	0.1	-1.2	0.0	0.2	-1.2	-2.3	-2.6	-2.7
2011–2019	2.2	1.2	0.3	0.5	1.2	1.1	-0.1	-0.5
2003–2019	1.2	0.0	0.1	0.3	0.0	-0.6	-1.4	-1.6
Male	**35–39**	**40–44**	**45–49**	**50–54**	**55–59**	**60–64**	**65–69**	**70–74**
2003–2011	0.0	-1.4	-0.7	-0.6	-0.6	-1.7	-2.4	-2.7
2011–2019	1.5	1.5	0.1	0.5	0.9	1.3	0.7	-0.1
2003–2019	0.8	0.1	-0.3	-0.1	0.1	-0.2	-0.8	-1.4

4.2 TREND IN EDUCATION ATTAINMENT LEVELS

The proportion of the population in each education category shows a distinctive trend over 2003–2019 across age groups (Figure 5). At younger ages, a decline in the population of middle educational attainment is offset by an increase in the proportion of high education, especially for females. A noticeably higher proportion of males than females at ages 65–69 and 70–74 have high education attainment. For females at ages 35–39, high and middle education had equal proportions by 2019. Low education was the highest education attainment of only about 10% of the population at younger ages. At older ages, middle education remained steady as the most common educational attainment. There has also been an increase in the population at high educational attainment, resulting in declines in low education.

Figure 5

PROPORTION OF THE U.S. POPULATION IN EACH EDUCATION CATEGORY, BY SEX, AGES 35-74 AND YEARS 2003–2019



4.3 TREND IN OBESITY PREVALENCE RATE

When estimating the obesity prevalence rate for different age groups, sexes, and education attainment levels, we combine NHANES Survey Cycles to increase the sample size for reliable results[4]. In our analysis, we combine the four waves 2003–2004, 2005–2006, 2007–2008, and 2009–2010 to form estimates of obesity prevalence for the period 2003–2010. We then combine the remaining five waves 2011–2012, 2013–2014, 2015–2016, 2017–2018, and 2017–March 2020 Pre-Pandemic Data to obtain estimates of obesity prevalence for the period 2011–2019. The prevalence of obesity increased within each of the two periods. Moreover, since there is no significant difference in the obesity prevalence obtained in the data between low and middle level education groups, we have combined these two categories when estimating the obesity prevalence for different age groups and sexes.

There was an increase from 2003–2010 to 2011–2019 in the percentage of the 35–74 age group's population that were obese (Table 7). This increase occurred across all age groups and was at a fairly consistent magnitude, ranging from 2% to 7%. The level of obesity was similar across age groups, being slightly higher in the middle ages of the 35–74 age range. By 2011–2019, between 40–45% of the population were obese, depending on the age group.

Table 7

PERCENTAGE OF THE U.S. POPULATION THAT ARE OBESE, BY SEX, AND AGE GROUP FOR PERIODS,2003–2010 AND 2011–2019

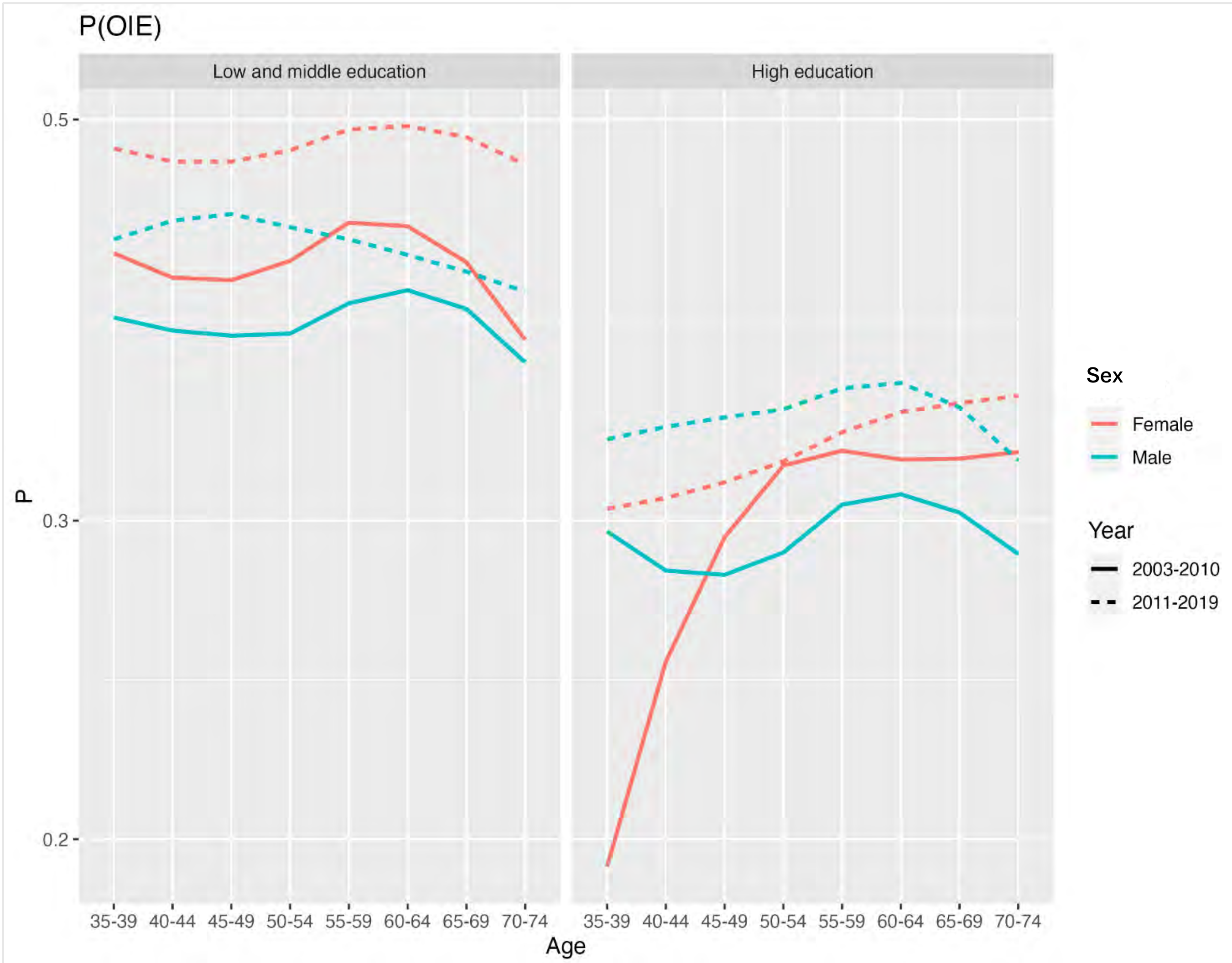
Year/Sex	Age Group							
Female	**35–39**	**40–44**	**45–49**	**50–54**	**55–59**	**60–64**	**65–69**	**70–74**
2003–2010	35.2	36.2	37.5	39.1	40.8	40.8	39.6	37.0
2011–2019	41.7	41.3	41.7	42.8	44.4	45.1	45.0	44.3
Male	**35–39**	**40–44**	**45–49**	**50–54**	**55–59**	**60–64**	**65–69**	**70–74**
2003–2010	36.2	35.5	35.3	35.5	36.9	37.4	36.6	34.6
2011–2019	39.9	40.7	41.1	40.7	40.5	40.0	38.9	37.1

A higher proportion of people who attained low or middle education were obese compared with those of higher education (Figure 6). At most age groups, the level of obesity in the low or middle education was around one-third higher than for high education. Again, the proportion of the population who were overweight/obese peaked at ages 55–59 or 60–64 years. However, for females of high education, obesity was far lower at ages 35–39 and 40–44 years than other ages, unlike for females of low-middle education and for males of both education categories. The increase in obesity from 2003–2010 to 2011–2019 was fairly consistent, with the exception of a large jump from a low base among younger high education females. We suspect that this phenomenon is partially attributed to low sample size. On the other hand, it is not unreasonable to assume an acceleration in obesity prevalence around age 45 for females, possibly due to menopause. According to a recent study, over 43% of menopausal women have obesity, and during menopause there is an increase in fat mass and a decrease in lean muscle mass (Knight et al., 2021).

[4] For more information on combing NHANES Survey Cycles, please refer to https://wwwn.cdc.gov/nchs/nhanes/tutorials/Weighting.aspx.

Figure 6

PROPORTION OF THE U.S. POPULATION WITHIN EACH SPECIFIC EDUCATION ATTAINMENT CATEGORY THAT ARE OBESE, BY SEX, AGES 35–74, AND YEARS 2003–10 AND 2011–19



4.4 TREND IN PROPORTION OF OBESITY-RELATED CVD MORTALITY

The proportion of CVD deaths that were obesity-related increased from 2003 to 2010 and again to 2019 (Figures 7–8). This increase occurred in each education category for both females and males. This proportion of CVD deaths that were obesity-related for each year was quite consistent for each combination of education level and sex, being less than 50% in 2003 and just over 50% in 2019 for all but females of high education.

Figure 7

PROPORTION OF U.S. CVD DEATHS THAT WERE OBESITY-RELATED BY EDUCATION CATEGORY, FEMALES, AGES 35–74, YEARS, 2003, 2010, AND 2019

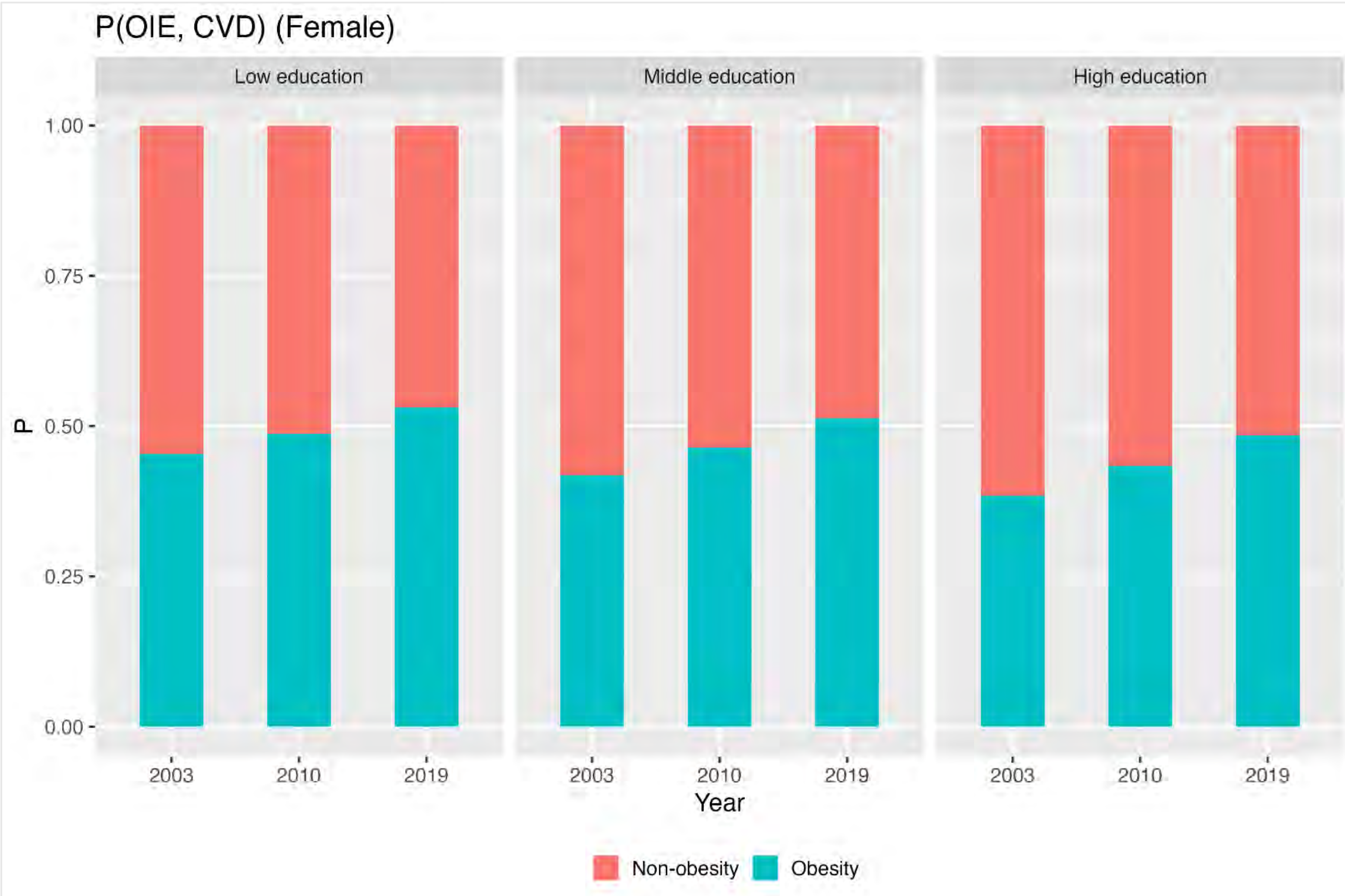
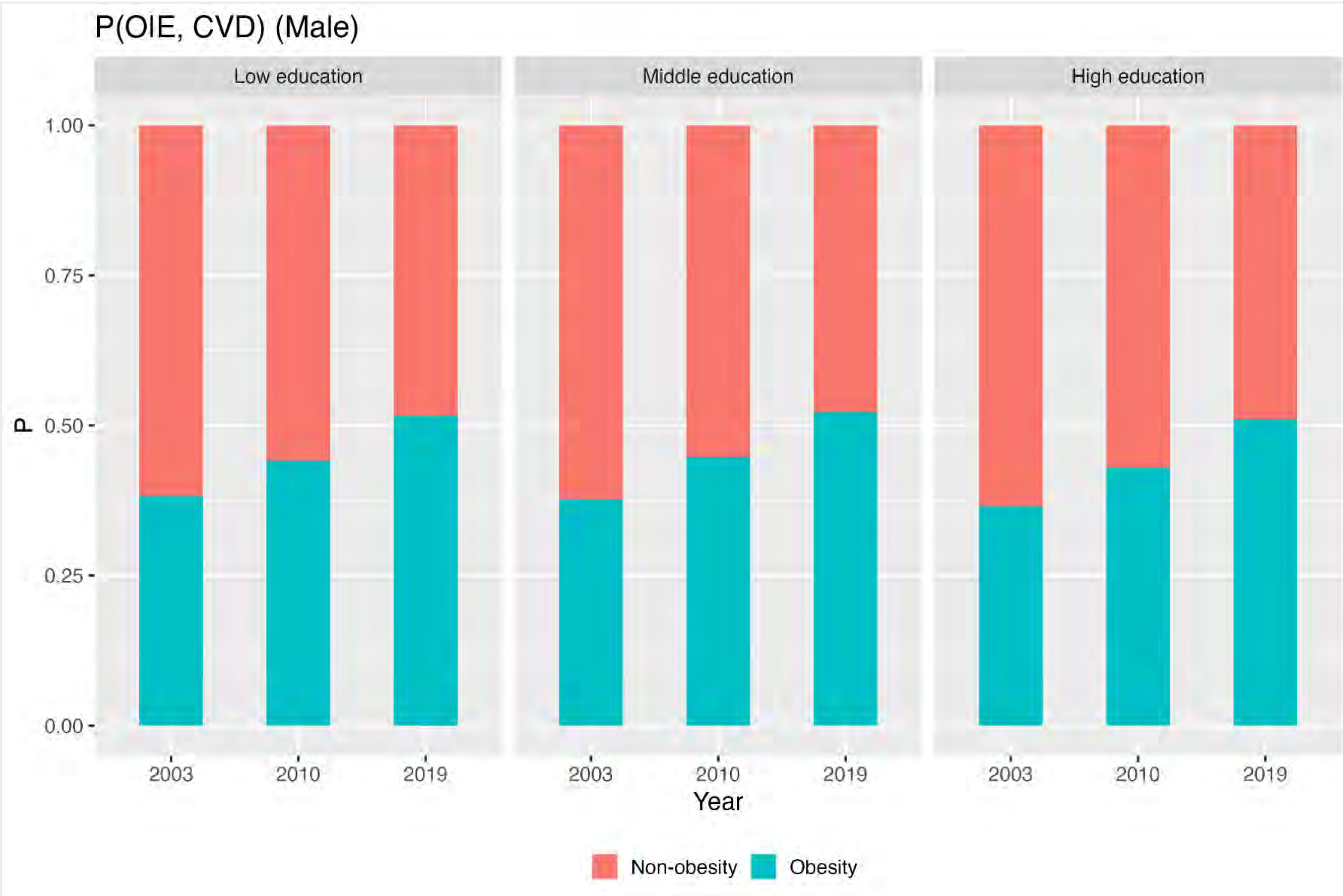


Figure 8
PROPORTION OF U.S. CVD DEATHS THAT WERE OBESITY-RELATED BY EDUCATION CATEGORY, MALES, AGES 35–74, YEARS 2003, 2010, AND 2019



Figures 9 and 10 show trends in the proportion of CVD deaths that are within each combination of obesity and education category. As such, they reflect both trends in education (shown in Figure 4) and also in the proportion of CVD deaths that were obesity-related (shown in Figure 6). For both sexes, there was a decline in the proportion of CVD deaths not attributable to obesity and in the low education category - this occurred in all age groups and is due to both non-obesity-related cardiovascular deaths and low education falling in these years. By contrast, there was an increase in the proportion of CVD deaths that were obesity-related and in the middle and high education categories, again in all age groups and for both sexes; each of these increase in isolation over the time period. This reflects the increase in both categories over the time period. The proportion of cardiovascular deaths not attributable to obesity and in middle education was steady. However, there were inconsistent trends by age group for the proportion of CVD deaths that were non-obesity-related and in the high education group, and obesity-related and in the low education group.

Figure 9

PROPORTION OF U.S. CVD DEATHS WITHIN A SPECIFIC OBESITY AND EDUCATION CATEGORY, FEMALES, AGES 35–74, YEARS 2003–2019

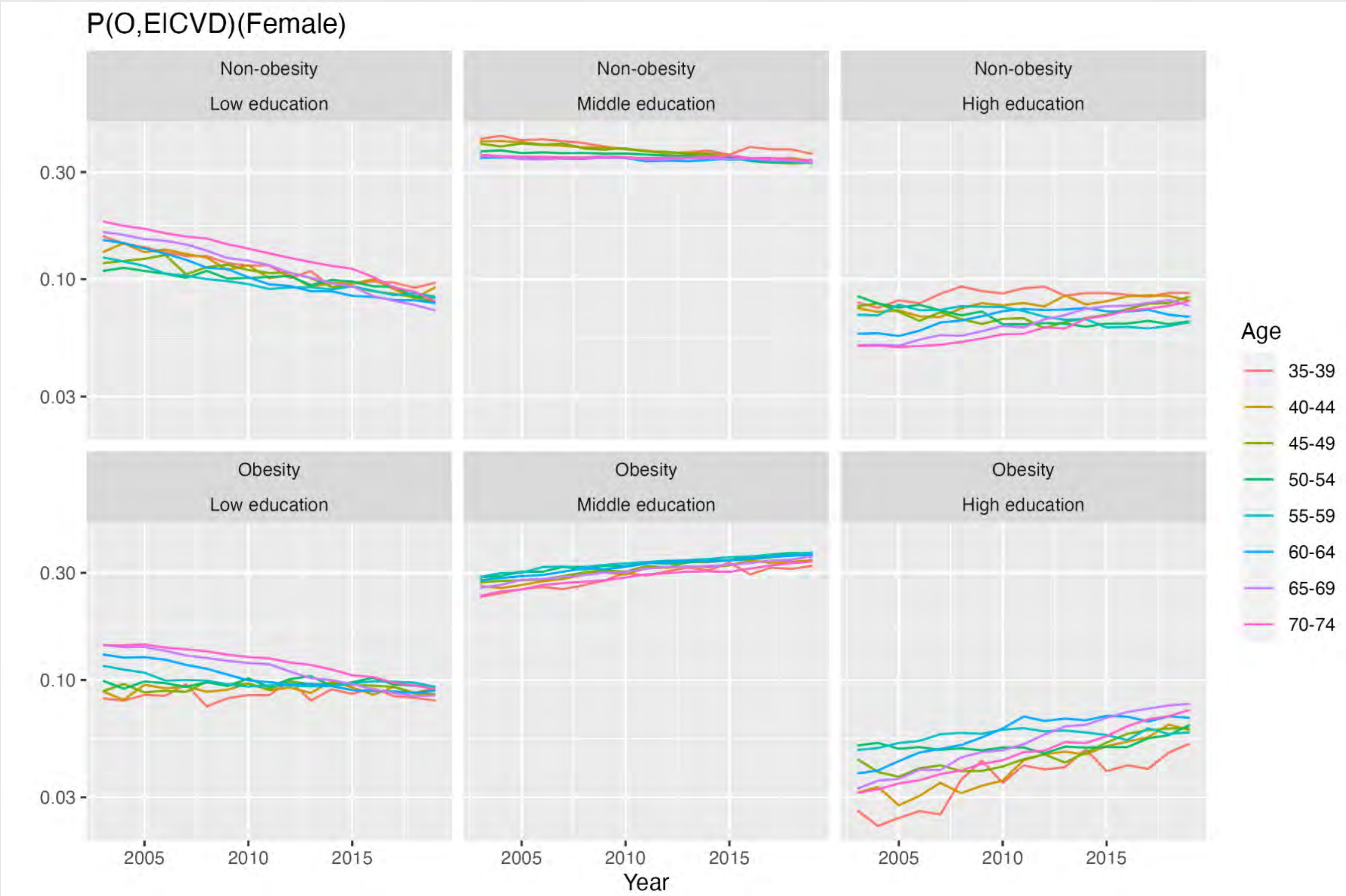
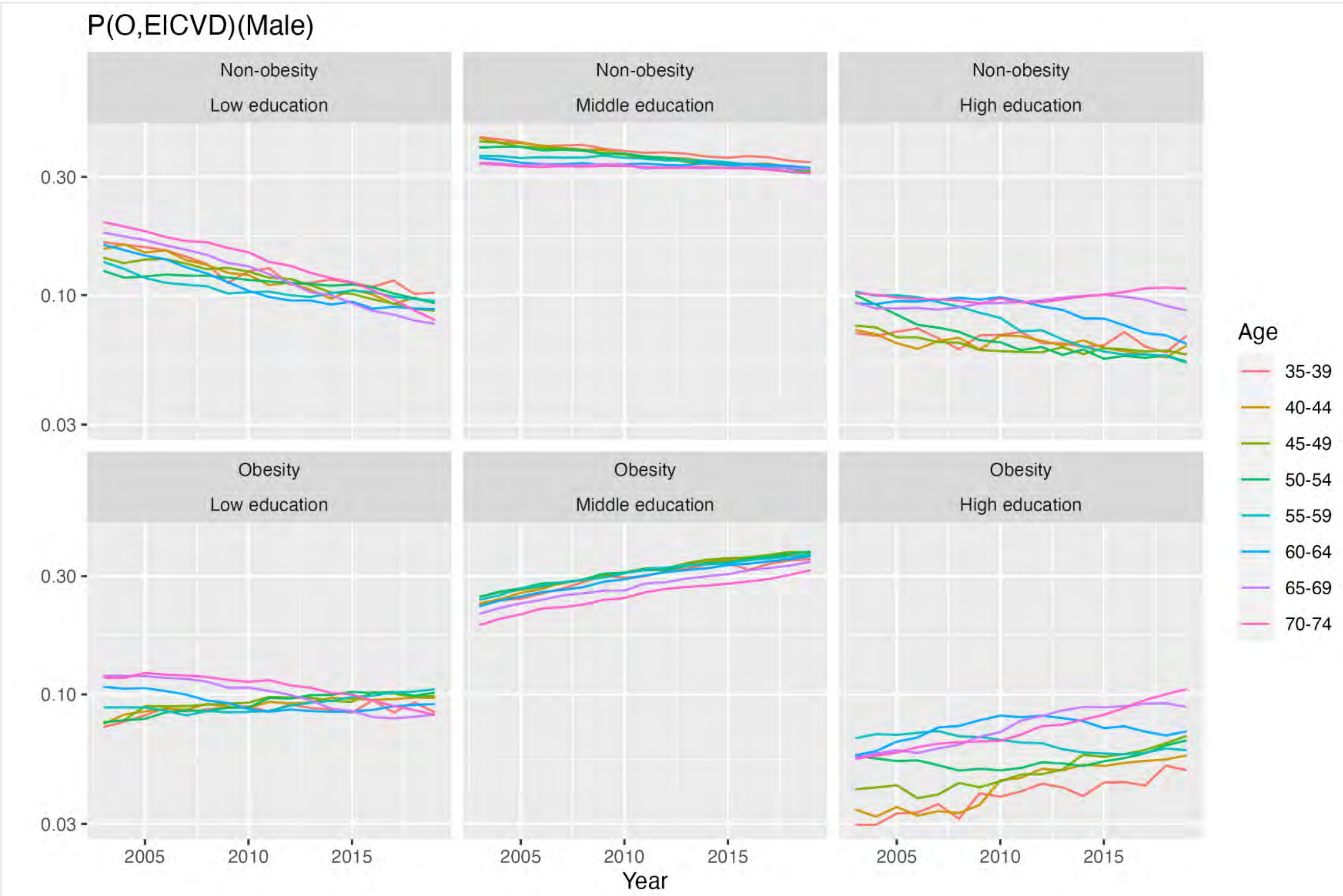


Figure 10

PROPORTION OF U.S. CVD DEATHS WITHIN A SPECIFIC OBESITY AND EDUCATION CATEGORY, MALES, AGES 35–74, YEARS 2003–2019



4.5 TREND IN CONDITIONAL CVD MORTALITY GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL

Over the period 2003–2019, the trend in the conditional probability of CVD deaths exhibited differences depending on obesity status and education level, as shown in Figures 11 and 12. The conditional probability was highest for those of low education and it increased for those who were obese at a quicker pace than others, leading to a widening of the gap in the probability of CVD death between the two groups. For those with middle education, the conditional probability was generally slightly lower than for low education, and there were also less favorable trends for those who were obese compared with others in this education group.

By 2019, in some age groups the conditional probability of CVD death for obese people in the middle education category was the same or even higher than the non-obese population in the low education category. In the high education category, the conditional probability of CVD death was much lower than for the other two education categories. For the non-obese population, the conditional probability of CVD death in this education group was lower than for the obese population and this gap widened over the time period due to declines for the former group and a stabilization or even increase in the latter group. These trends were mostly uniform across age groups, with a slightly stronger increase in the conditional probability for those of middle education in younger than older age groups, while a more pronounced decline for the non-obese population at high education.

Figure 11

CONDITIONAL PROBABILITY OF U.S. CVD DEATHS GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, FEMALES, AGES 35–74, YEARS 2003–2019

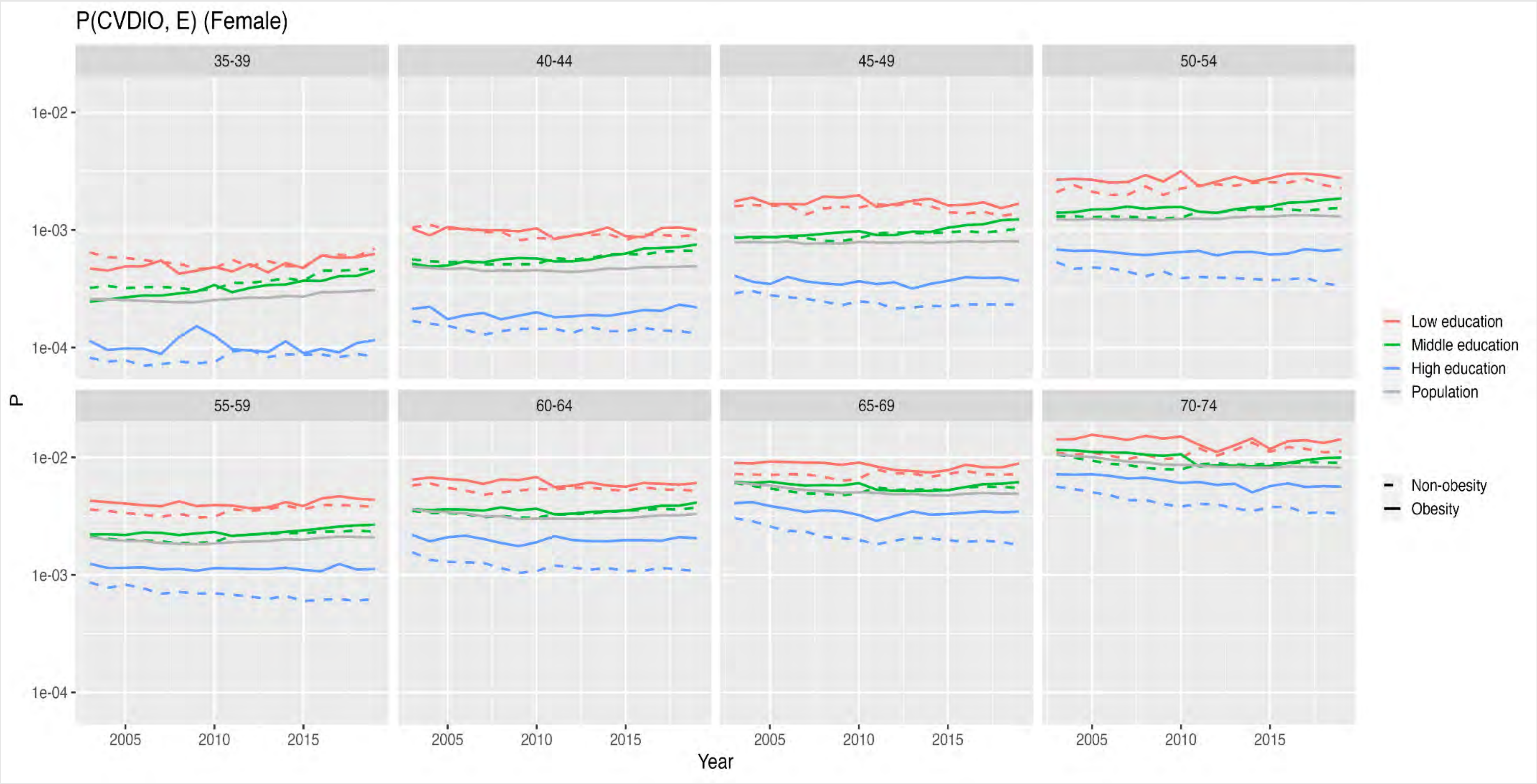
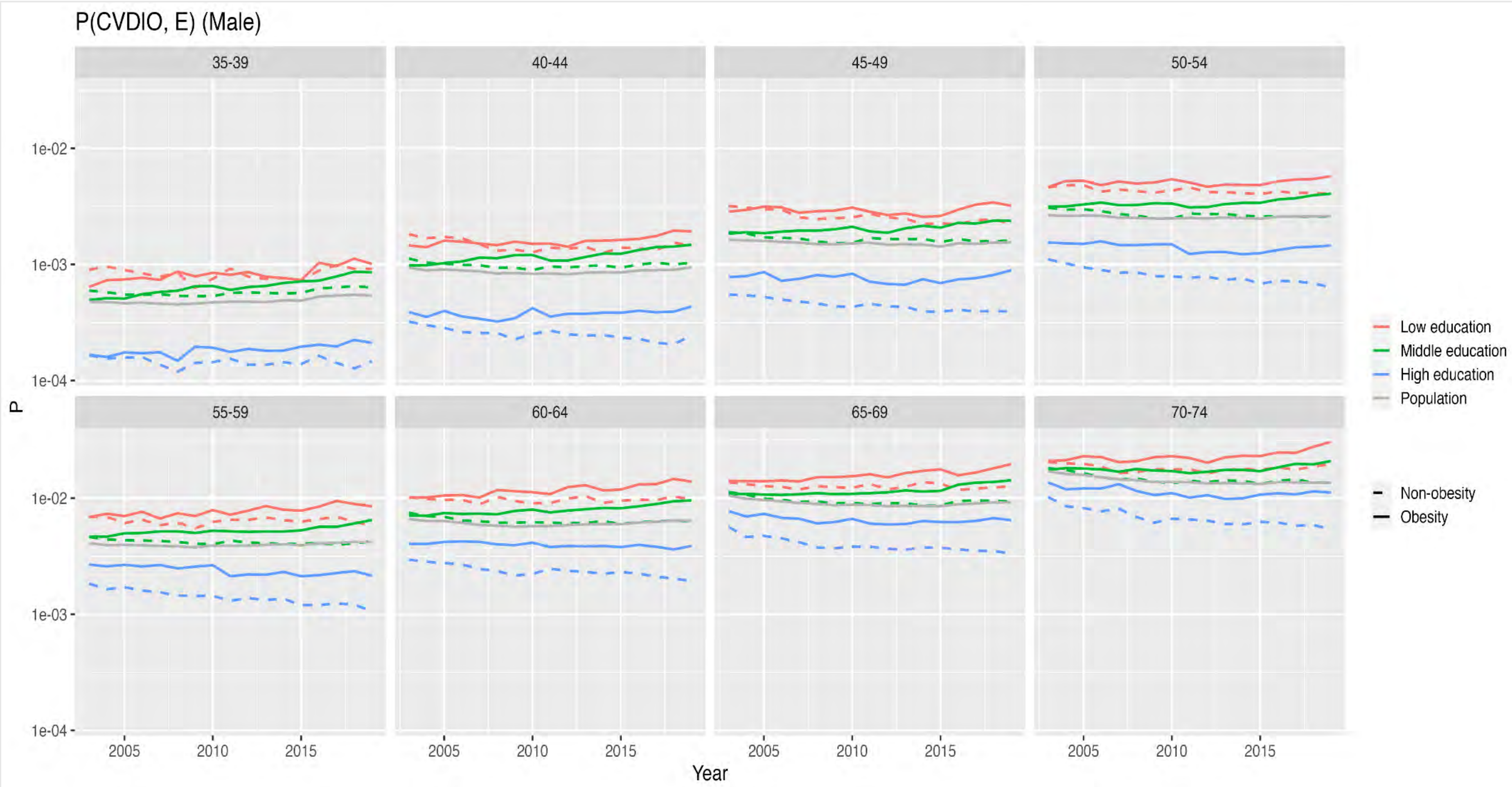


Figure 12

CONDITIONAL PROBABILITY OF U.S. CVD DEATHS GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, MALES, AGES 35–74, YEARS 2003–2019



In Figures 13 and 14, we present heatmaps illustrating historical improvements in CVD mortality from 2003 to 2019 across all obesity statuses and education levels for females and males, respectively. The color red indicates an improvement (decrease) in CVD mortality, while blue indicates a deterioration (increase). As depicted in these figures, overall, the improvement is higher for non-obese males and females compared to their obese counterparts. Additionally, individuals with low education levels show the smallest improvement over time, whereas those with high education levels demonstrate the most significant improvement. The middle education level appears to have stabilized CVD mortality over time, with the improvement rate being very close to 0.

We also plot CVD mortality change for the whole population including all education levels and obesity status, for females and males, respectively (Figures 15-16). These charts show that the improvement in CVD mortality is commonly observed in older age groups rather than younger age groups. Also, during the investigation period 2003–2019, the rate of CVD mortality decline slowed and, towards the end of the period, even reversed to become an increase.

Figure 13

HEATMAP OF HISTORICAL U.S. CVD MORTALITY CHANGE GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, FEMALES, AGES 35–74, YEARS 2003–2019

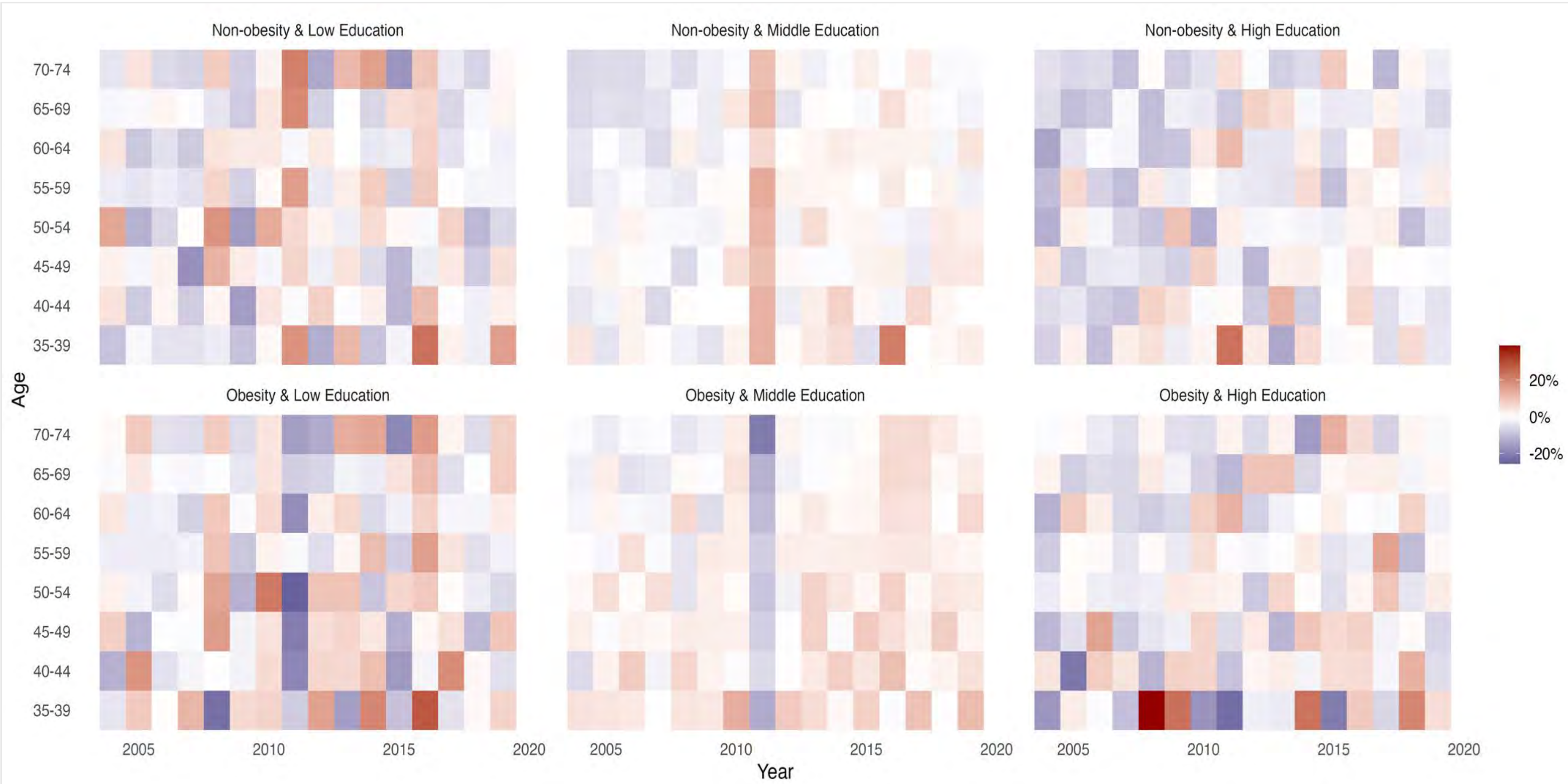


Figure 14

HEATMAP OF HISTORICAL U.S. CVD MORTALITY CHANGE GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, MALES, AGES 35–74, YEARS 2003–2019

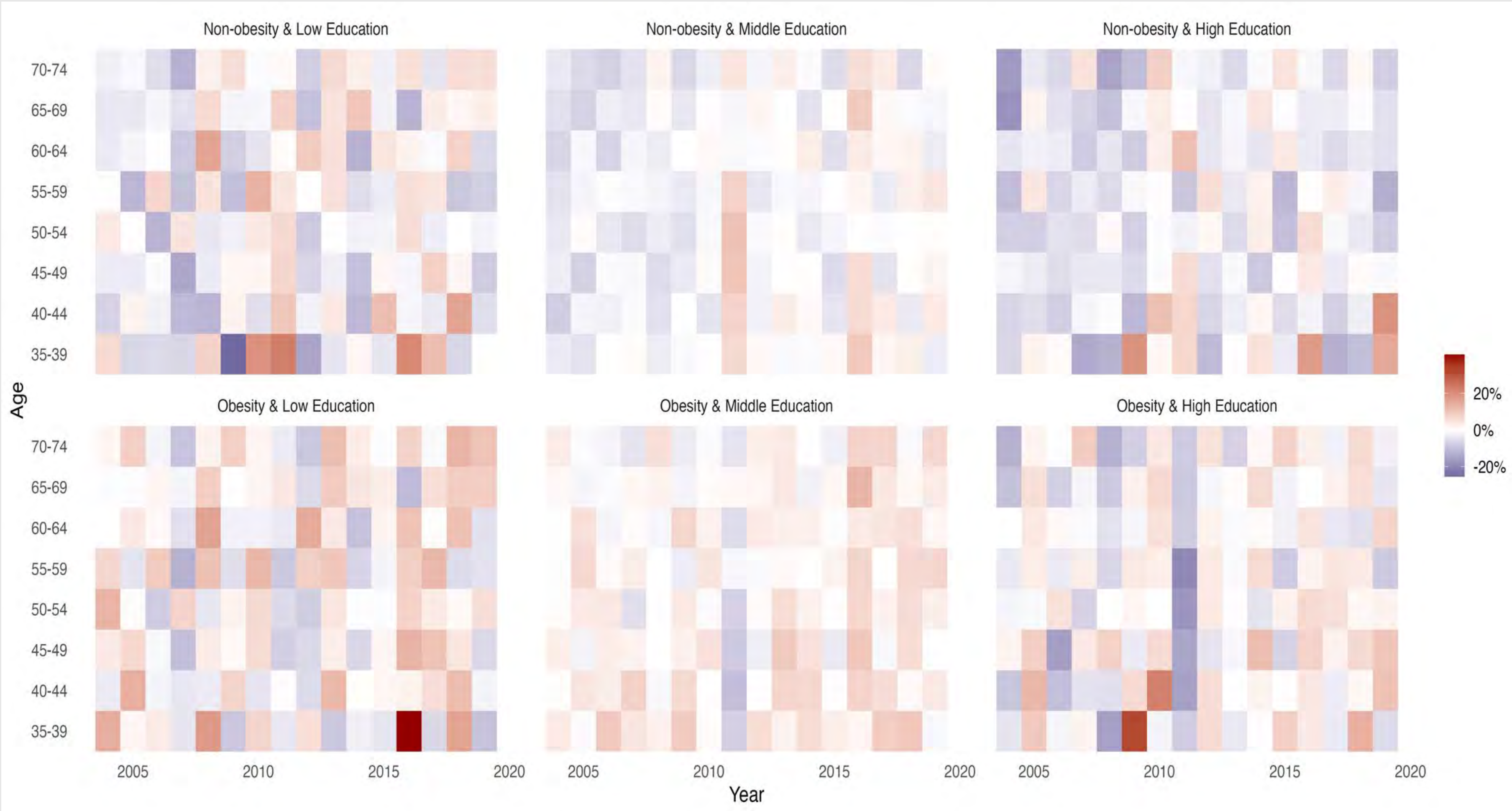


Figure 15

HEATMAP OF HISTORICAL U.S. CVD MORTALITY CHANGE, ALL OBESITY AND EDUCATION GROUPS COMBINED, FEMALES, AGES 35–74, YEARS 2003–2019

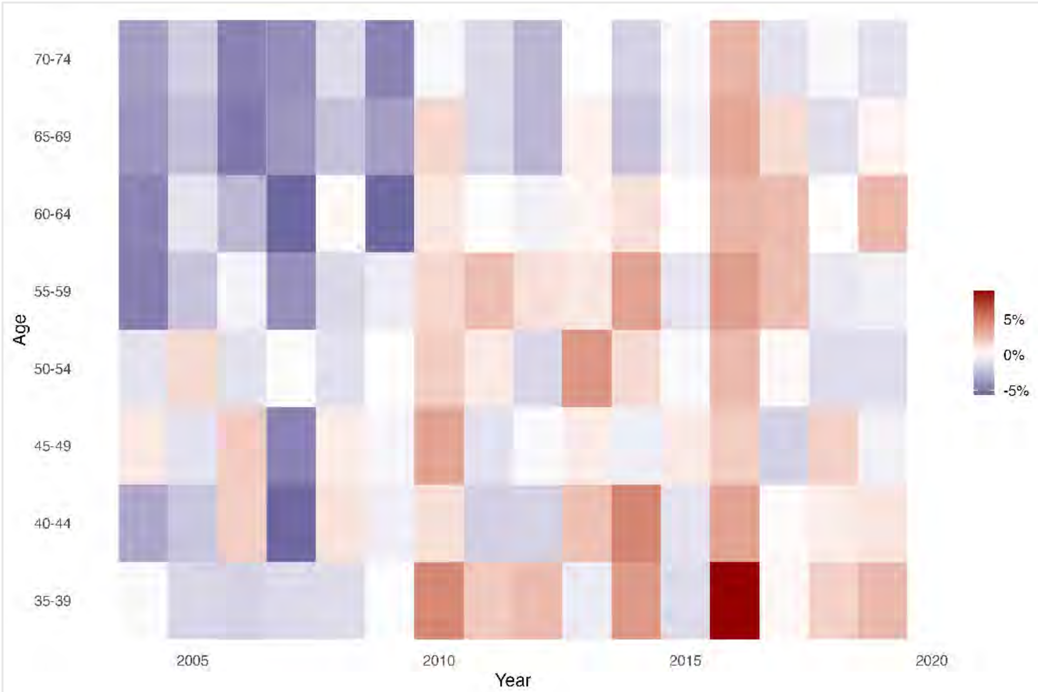
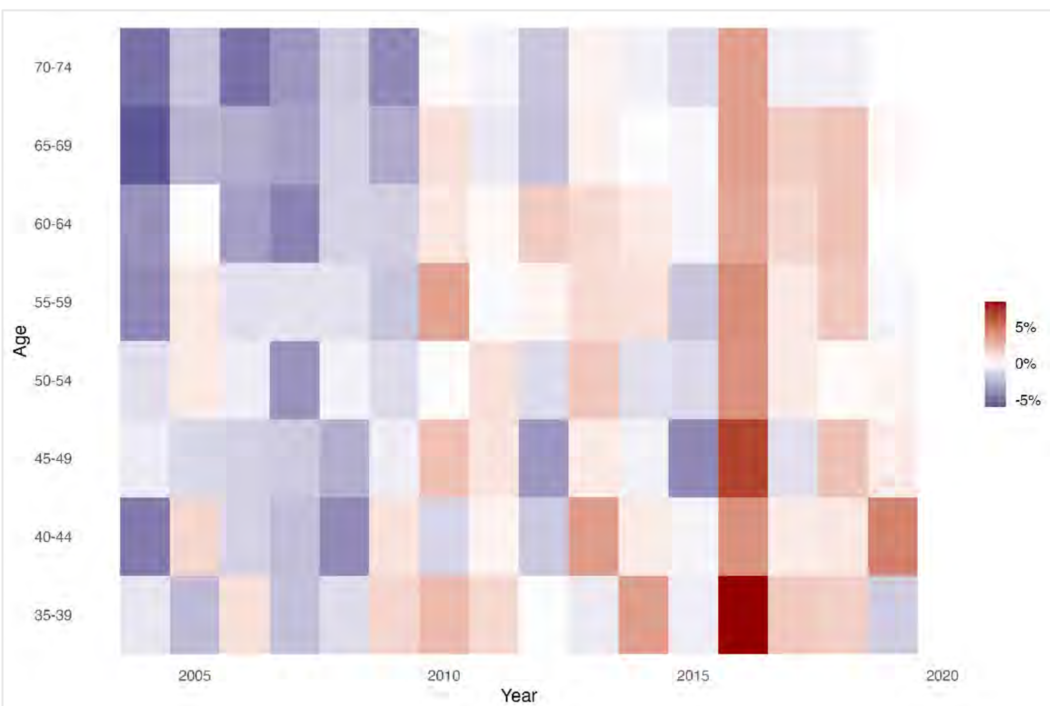


Figure 16

HEATMAP OF HISTORICAL U.S. CVD MORTALITY CHANGE, ALL OBESITY AND EDUCATION GROUPS COMBINED, MALES, AGES 35–74, YEARS 2003–2019



4.6 FORECAST OF CONDITIONAL CVD MORTALITY TO 2029

Over the forecast period to 2029, there is expected to be continued divergence of trends in the conditional probability of CVD deaths. We plot these results in Figures 17 and 18. For males, there is a forecast increase in the conditional probability for obesity in the low and middle education categories across all age groups. At each of these two levels of education, there is a forecast of continued widening of the gap in the conditional probability compared with the non-obese population, which either remains stable (younger ages) or declines slightly. For females, there is a forecast of a clear increase in the conditional probability of CVD deaths for obesity at middle education in ages 35–59 years while at low education it remains stable. The gap with the non-obese population at each of these education levels is not forecast to widen as much as for males. At the highest education level, the conditional probability of CVD deaths for the obese population is forecast to remain stable, while for the non-obese population is forecast to decline strongly in the older age groups while declining more slowly or remaining stable in the younger age groups. The more favorable trends in CVD mortality for those of higher education, whether obese or not, may reflect that their access to health care to treat CVDs, whether acute or non-acute, is improving more quickly than for those of lower education. It may also reflect the adverse impact of smoking on lower education groups, among whom rates are higher (Cao et al., 2023). The age group differences for those of high education may be due to the impact of lower lifetime smoking rates of successively younger cohorts who are entering older age groups, improved availability of medication to control CVD risk factors such as cholesterol and high blood pressure, and better acute and long-term treatment of acute cardiac events (Mensah et al., 2017). This leads to a substantial widening of the gap with the obese population of this education category, where the conditional probability either declines slightly (older ages) or is stable or increases slightly (younger ages).

Figure 17

CONDITIONAL PROBABILITY OF U.S. CVD DEATHS GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, BY AGE GROUP AND EDUCATION, FEMALES, AGES 35–74, YEARS 2003–2019 (ACTUAL) AND 2020–2029 (FORECAST)

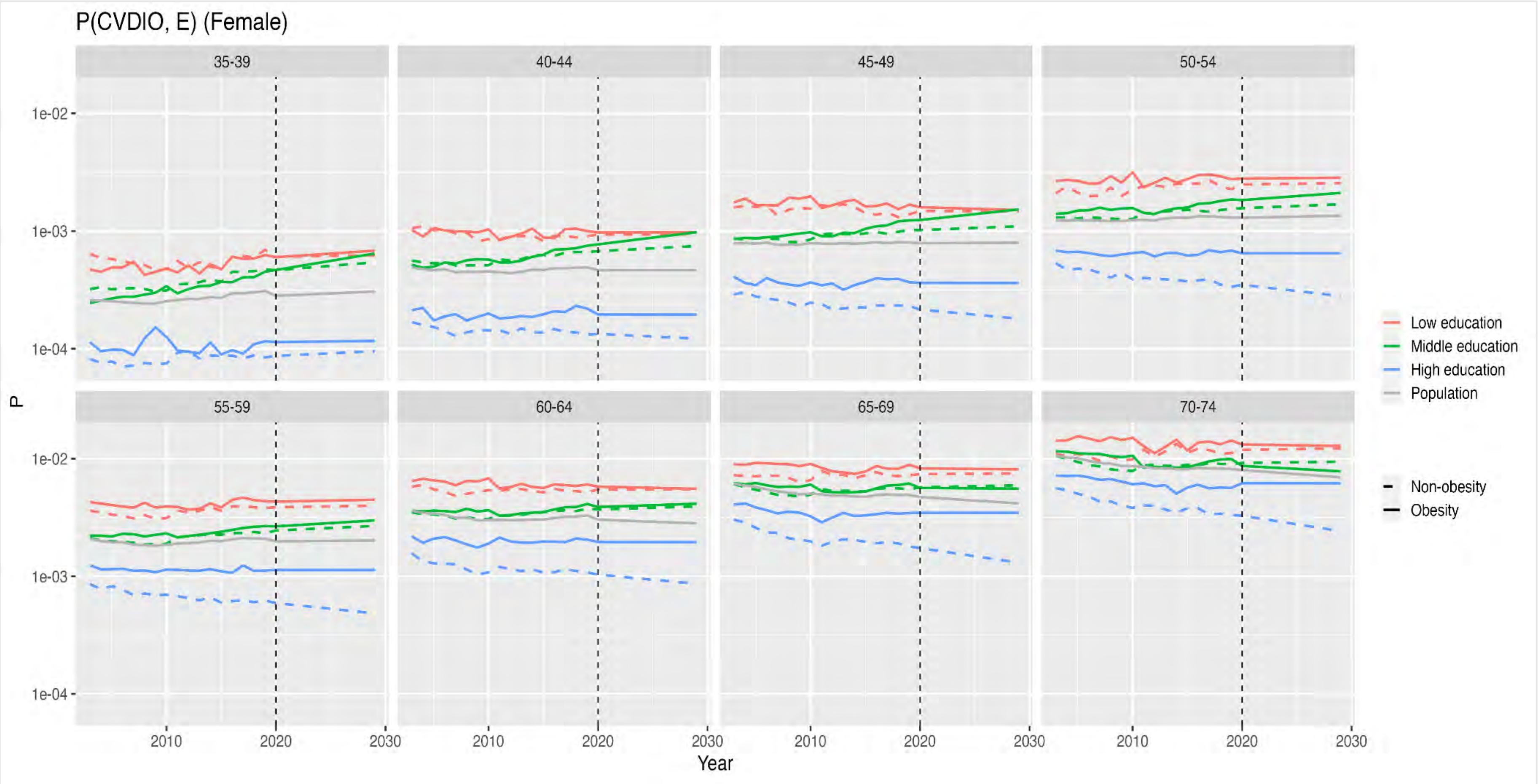
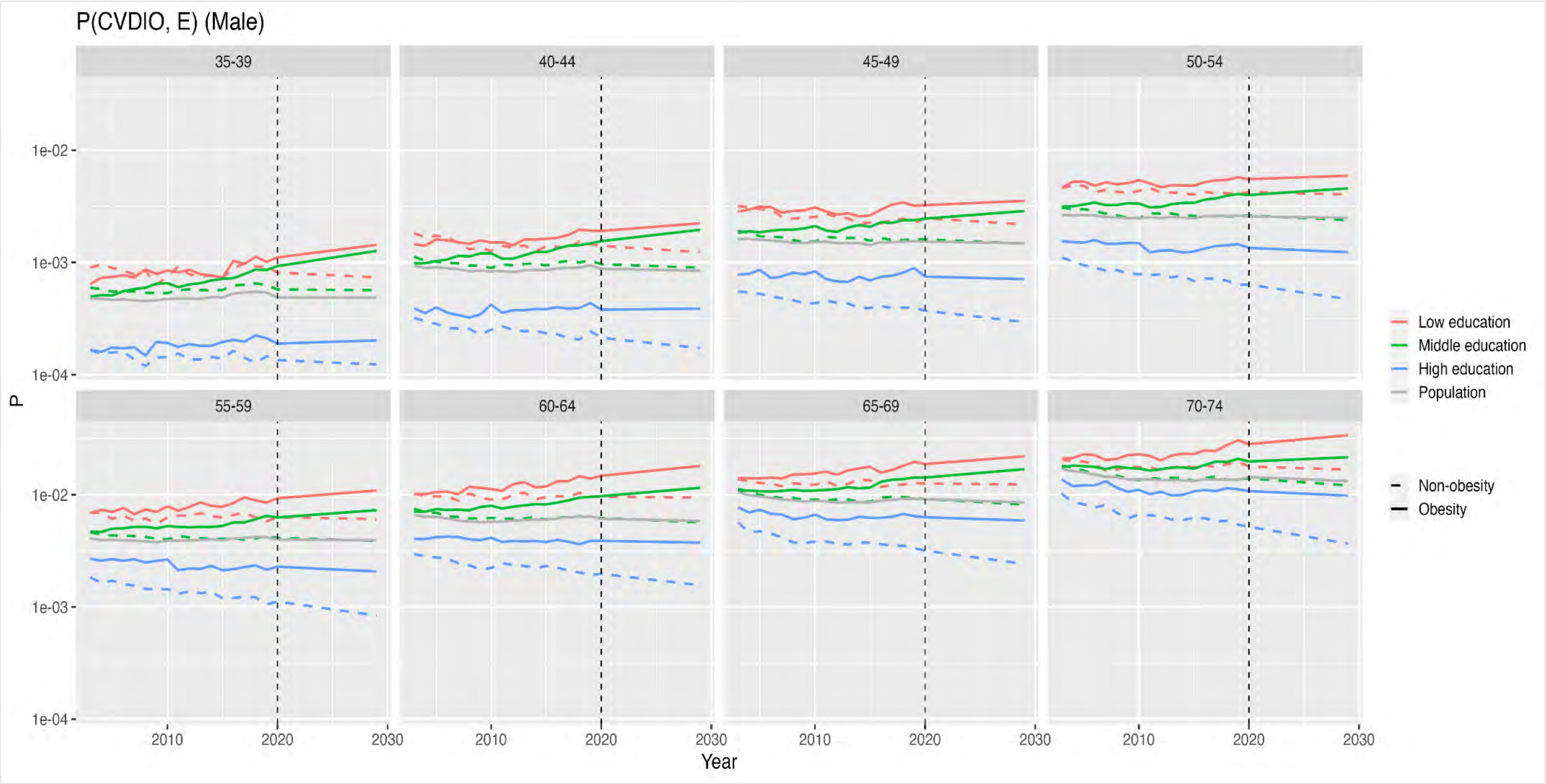


Figure 18

CONDITIONAL PROBABILITY OF U.S. CVD DEATHS GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, BY AGE GROUP AND EDUCATION, MALES, AGES 35–74, YEARS 2003–2019 (ACTUAL) AND 2020–2029 (FORECAST)



In Figures 19 and 20, we present heatmaps illustrating historical and projected improvements in CVD mortality from 2003 to 2029, across all obesity statuses and education levels, for females and males, respectively. Once again, red indicates an improvement (decrease) in CVD mortality, while blue indicates a deterioration (increase). Overall, the projection indicates improvement in CVD mortality for the non-obese population, particularly in the high education level group. Conversely, for the low-educated obese population, a continuation of deterioration in CVD mortality is anticipated into the future.

In Figures 21 and 22, we also plot the projected CVD mortality improvement for the whole population including all education levels and obesity status, for females and males, respectively. Again, further improvement in CVD mortality is expected in older age groups rather than younger age groups, for both males and females.

Figure 19

HEATMAP OF U.S. CVD MORTALITY CHANGE GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, BY AGE GROUP, FEMALES, AGES 35–74, YEARS 2003–2019 (ACTUAL) AND 2020–2029 (FORECAST)

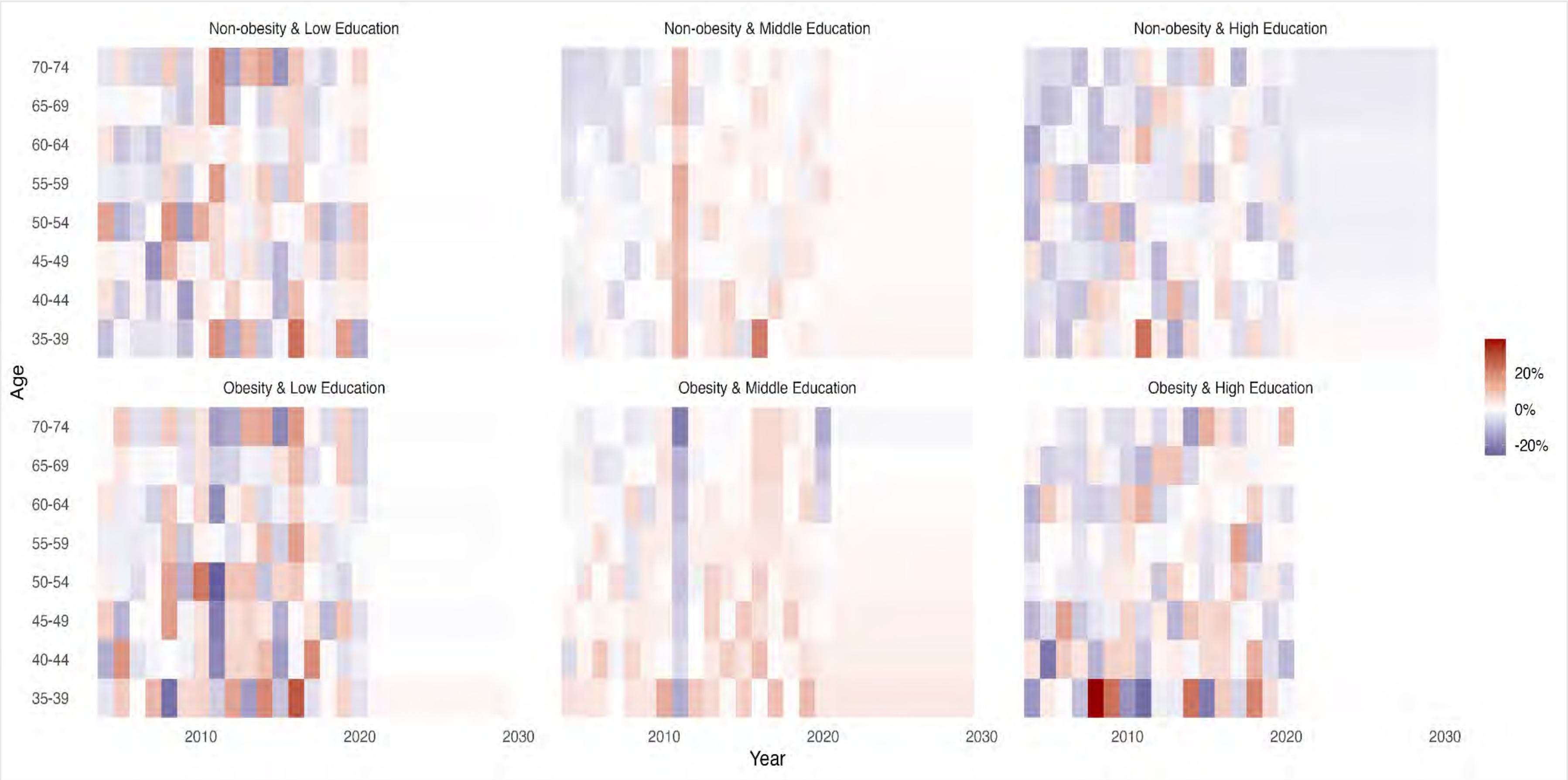


Figure 20

HEATMAP OF U.S. CVD MORTALITY CHANGE GIVEN OBESITY STATUS AND EDUCATION ATTAINMENT LEVEL, BY AGE GROUP, MALES, AGES 35–74, YEARS 2003–2019 (ACTUAL) AND 2020–2029 (FORECAST)

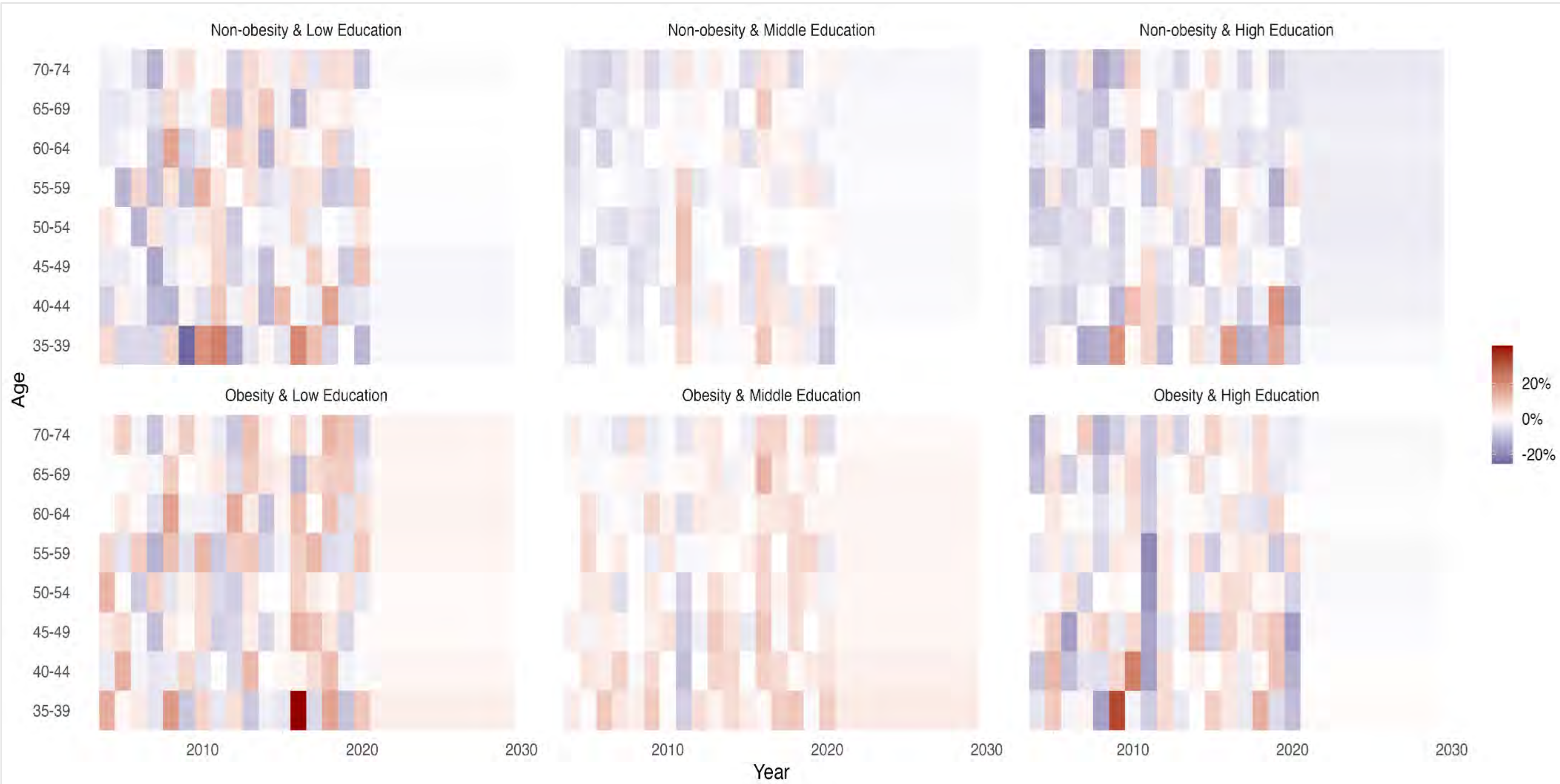


Figure 21

HEATMAP OF U.S. CVD MORTALITY CHANGE, WHOLE POPULATION, BY AGE GROUP, FEMALES, AGES 35–74, YEARS 2003–2019 (ACTUAL) AND 2020–2029 (FORECAST)

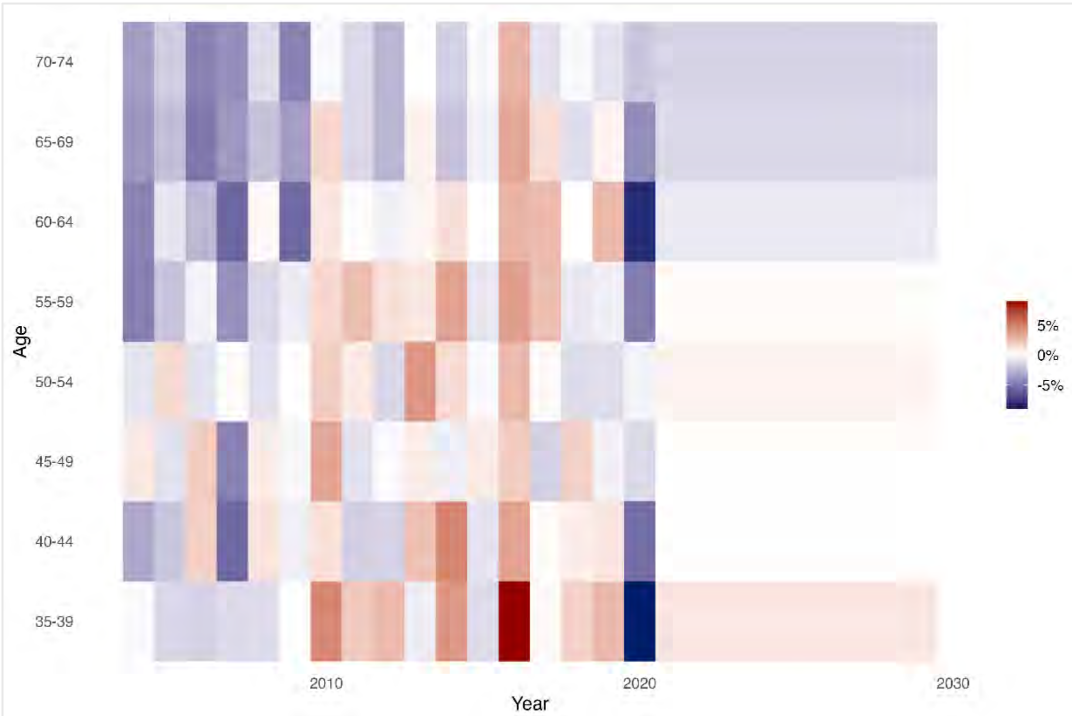
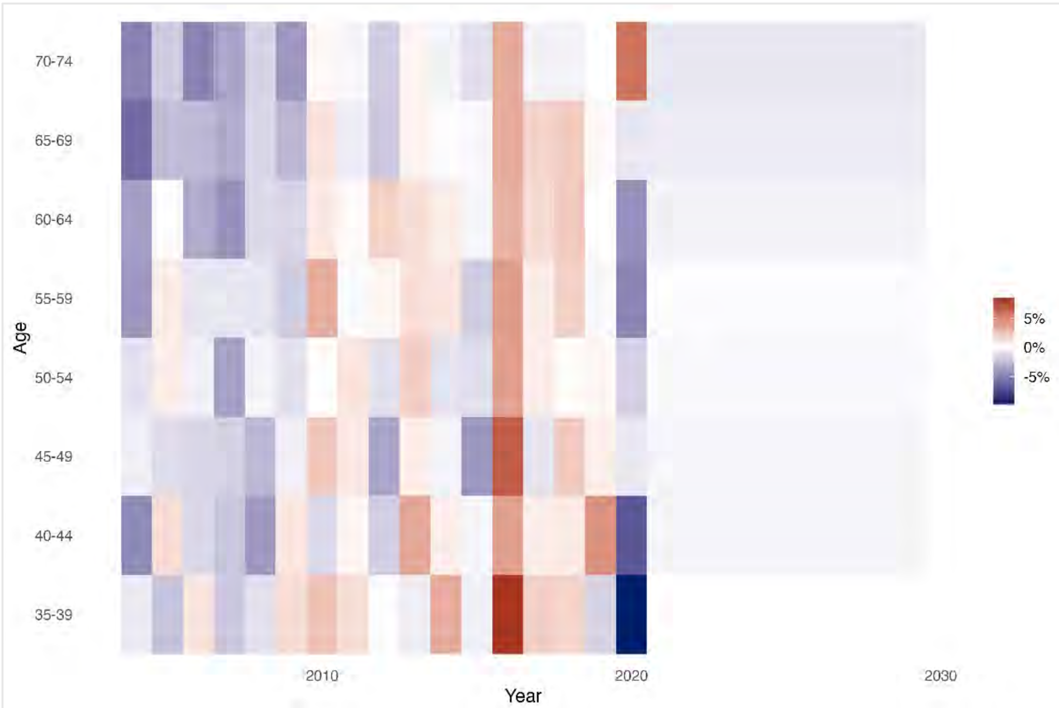


Figure 22

HEATMAP OF U.S. CVD MORTALITY CHANGE, WHOLE POPULATION, BY AGE GROUP, MALES, AGES 35–74, YEARS 2003–2019 (ACTUAL) AND 2020–2029 (FORECAST)



4.7 AN ACTUARIAL PERSPECTIVE

Our research findings on CVD mortality for different obesity statuses and education groups offer valuable insights for life and health insurance companies. Understanding the trends and patterns in premature CVD mortality can aid insurers in refining their risk assessment and management strategies.

The research reveals significant disparities in CVD mortality between obese and non-obese populations across different education levels. This information is crucial for insurance companies as it highlights how obesity, as a common risk factor, can affect CVD mortality differently depending on one's education level. Insurers may be able to tailor their underwriting processes to better account for these variations. This insight can also enhance risk assessment for the insurance company and improve portfolio monitoring.

Additionally, recognizing the behavioral risk factors associated with obesity emphasizes the potential impact of individuals' healthy choices. Insurance companies may play a role in supporting healthy choices, not only by offering insurance coverage (at a differentiated price), but also by incentivizing policyholders to adopt healthier lifestyles. This approach may lead to healthier policyholders and reduced CVD-related claims. For example, Meiji Yasuda Life Insurance partnered with the National Cerebral and Cardiovascular Center (NCVC) in joint research to advance non-medical approaches in preventing CVD[5]. Their three-year agreement involves talent sharing, developing public educational materials, and creating predictive disease tools. One outcome is the "Wellness for All Project", which was launched in April 2019 to enhance health

[5] For more information, please refer to https://www.nature.com/articles/d42473-022-00221-y

literacy and promote healthy habits[6]. This initiative offers customers health advice and disease risk predictions based on medical checkups and big data analytics. Those meeting certain health criteria receive cashback on insurance fees. With over 3 million participants, the project has resulted in improved health markers such as obesity and blood glucose levels.

Pension actuaries and actuaries specializing in U.S. individual life and annuities may find it valuable to note that improvements in CVD mortality for individuals in white-collar jobs and preferred underwriting classes are likely to be higher than those observed in the general population. This statement can be drawn from the likelihood that individuals with higher educational levels and better health are more inclined to work in white-collar professions. Moreover, they are more likely to purchase substantial individual annuity contracts and achieve favorable underwriting in life insurance purchases.

In summary, our report provides a foundation for life and health insurance companies to refine their assessment in CVD mortality risk, develop targeted products, and actively promote health and disease prevention among their policyholders. By recognizing the impact of education and obesity on premature CVD mortality, insurers can better serve their clients and contribute to a healthier, more resilient customer base.

[6] For more information, please refer to https://www.meijiyasuda.co.jp/english/disclosure/annual-reports/backnumber/annual_2020_06.pdf

Section 5: Conclusions

In this report, we investigate how obesity status and education attainment level jointly influence CVD mortality in the U.S. We first collect data on CVD mortality, obesity prevalence rate, and population education attainment information. Based on this information, we then compute conditional CVD mortality given obesity status and education attainment level. We model and forecast the conditional CVD mortality for each age group, sex, and combination of obesity status and education level.

In the following, we first summarize the key results from the project and then address the potential limitations of the research.

5.1 SUMMARY OF KEY RESULTS

- CVD mortality has been either increasing, especially in younger age groups, or remaining stable in more recent years.
- The prevalence of obesity has been increasing across all age groups and education levels.
- The proportion of highly educated individuals has been increasing over time.
- The proportion of CVD deaths that are obesity-related has been increasing over all education levels.
- There has been, and is forecast to be, a divergence in CVD mortality trends for obese vs non-obese populations across all education levels.
- The obese population has been experiencing, and is forecast to experience, either an increase or stabilization in CVD mortality, depending on the sex, age and education attainment, with worse outcomes for males in particular.
- The non-obese highly educated population has been experiencing, and is forecast to experience, a decrease in CVD mortality, while for those of low and middle education attainment it has been, and is projected to, remain stable in most age groups while is projected to decline slightly in other age groups.
- In the most recent years and projected into the future, the conditional CVD mortality for the obese population of middle education attainment exceed those of the non-obese population with low education, demonstrating that obesity more than offsets lower CVD mortality due to higher education.

5.2 LIMITATIONS

For readers, particularly those interested in applying the results of this research, it's important to understand the potential limitations of the study. First, it should be noted that we used an indirect measure of obesity in this project, by defining obesity-related CVD mortality via conditions reported on the death certificate (i.e., multiple cause of death data). Second, our mortality projections do not account for potential benefits from semaglutide drugs such as Ozempic and Wegovy that have been found to lead to weight loss. Third, we acknowledge that education may have a delayed impact on mortality, whereas we only measure education at the time of death in this project. Fourth, we did not consider the effect of the COVID-19 pandemic on CVD mortality, either in the initial years of the pandemic or its longer-term effects (e.g., Long COVID). While obesity-related premature CVD mortality rose substantially in 2020-2021 in the U.S., the aim of this report is to project obesity-related CVD mortality based on longer-term historical data, which are more likely to provide a dataset on which to base future projections (Adair, 2023). Lastly, our analysis also did not include additional variables that may have added further granularity to the results. The absence of geographic identifiers in the data prevented us from measuring regional variations in the results. We also did not include smoking status, which is a risk factor for CVD mortality. The analysis also did not include ethnicity, for which cut-off values of BMI to measure obesity can vary (Caleyachetty et al., 2021).

Section 6: Acknowledgment

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