Projecting Mortality for the Older Population in the United States: 2014 to 2060

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ABSTRACT

Mortality will become an increasingly important component of U.S. population projections as the nation grows older and a larger share of the population enters the older ages, which have the highest rates of mortality. We evaluate different methods for projecting mortality from 2014 to 2060, including time series, targeting, and Bayesian approaches. Results from each model will be evaluated through comparisons of projected life expectancy at birth, shifts in the age pattern of the projected mortality rates, and changes in the projected number of deaths. Results from this work will be used to provide a recommendation on the methodology for projecting mortality to be used in the Census Bureau's next series of national projections, to be released in 2014.

INTRODUCTION

As the U.S. population grows older over the coming decades, which is reflected by the projected growth in the share of the population in the oldest ages, we anticipate mortality projections will become an increasingly important component in the production of the U.S. Census Bureau's national population projections. In this paper, we provide an overview of the methods we have used in the past to project mortality and present options for approaches to consider as we begin work on the next series of national projections, to be released in 2014.

BACKGROUND

The Census Bureau produces population projections using the cohort-component method that is based on assumptions about demographic components of change – future births, deaths, and net international migration (Day, 1996; Hollmann et al., 2000; U.S. Census Bureau, 2008; U.S. Census Bureau, 2012). To project future deaths, assumptions must be developed regarding how much future death rates will change from what we currently observe and how quickly that change will occur. The Census Bureau has employed methods of extrapolation, time series forecasting, and interpolation to an ultimate level to generate mortality projections used in the production of national population projections. Changes in the methods used to project mortality reflect our ongoing efforts to improve our projections methodology, which we continue with this work.

In the series released in 1996, mortality was projected to the year 2050 through extrapolation of annual rates of change in the time series, based on death rates for 1969-1971, 1979-1981, and 1989-1991. These mortality projections were produced separately by age, sex, race, and Hispanic origin (Day, 1996).

Four years later, the Census Bureau shifted to a method by which mortality was projected through interpolation to a target life table created for the year 2150 (Hollmann et al., 2000). An intermediate life table for the year 2065 was created first, using projections of life expectancy at

birth for males and females based on work produced by Lee and Tuljapurkar (1998; 2001). The rate at which mortality was projected to decline for the intermediate life table was based on a survey of experts in the field (Rosenberg and Luckner, 1998). The target life table for the year 2150 was produced by assuming that the declines in mortality rates for males and females projected for the intermediate life table, in 2065, would continue until 2150. Age-specific death rates (ASDRs) were then projected by sex, race, and Hispanic origin through interpolation between the 1990 base ASDRs for each sex-race-Hispanic origin grouping and the year 2150 ASDRs by sex, which were obtained from the target life table. Projections through the year 2100 were used to produce the population projections released in 2000.

For the series released in 2008, the Census Bureau's approach to projecting mortality changed again. For that series, mortality was projected for the non-Black/non-Hispanic population using time series analysis (U.S. Census Bureau, 2008). Mortality was projected for this group by sex with a one-parameter relational logit, to which autoregressive integrated moving average (ARIMA) models were fit. Mortality was projected for the all other race and Hispanic origin groups, collapsed into two categories representing non-Hispanic Black and Hispanic (of any race), by assuming these groups would converge on the mortality schedules for the non-Black/non-Hispanic group in 2075. The age-sex specific mortality rates for the other two groups were derived via logistic interpolation between the observed schedules for these groups in 2003 and the forecast 2075 schedules for the non-Black/non-Hispanic population. Projections through the year 2050 were used to produce the population projections released in 2008.

In 2012, the Census Bureau offered another approach to projecting mortality by projecting life expectancy at birth (hereafter referred to as life expectancy) by sex, race, and Hispanic origin (U.S. Census Bureau, 2012). To begin, an ultimate life expectancy was estimated separately for males and females. Life expectancy for each race and Hispanic origin, by sex, was then projected by assuming that life expectancy will improve over time and approach the ultimate level predicted by

our model. The pace of that improvement was modeled as an exponential decline in how far apart the current estimates of life expectancy were for each group and the ultimate level they were assumed to move toward.[1]

Age-specific death rates were created from the projections of life expectancy using the Coale-Demeny West model life table, which was obtained from the United Nations (United Nations Population Division, 2012 and 2010). While this model does not explicitly assume convergence among groups, males and females within each race and Hispanic origin group are projected to approach the ultimate life expectancy for their sex. If the projection were extended far enough into the future, all groups would achieve a projected life expectancy near the ultimate level and, as a result, life expectancy values would be very similar across groups by that point.

As we begin development of the 2014 National Projections, we are once again evaluating methods for projecting mortality and considering whether improvements can be made by adopting a new model for our next series. Here, we consider further use of time series and targeting approaches to projecting mortality.

DATA AND METHODS

Death rates are calculated from death registration data compiled by the National Center for Health Statistics (NCHS) for the period from 1989 to 2010. The death data are used in conjunction with the Census Bureau's Population Estimates to produce a series of death rates by age and sex for three race and Hispanic origin groupings (U.S. Census Bureau, 2011).

Death data include four categories of race – White, Black, American Indian or Alaska Native (AIAN), and Asian or Pacific Islander (API) – and two categories for Hispanic origin – Hispanic and Not Hispanic. For the period from 2000 to 2011, the population estimates were produced for a total

[1] Estimates of Hispanic life expectancy are higher than any other group, which is something largely questioned by the research community (Abraido-Lanza et al., 1999; Elo et al., 2011; Hummer et al., 1999; Li et al., 1998; Ruiz et al., 2013). Because we do not find these patterns plausible, Hispanic life expectancy was projected to converge on the rate projected for the non-Hispanic White and API populations in 2035.

of 31 race groups consistent with the revised Office of Management and Budget (OMB) standards for data on race and ethnicity (Office of Management and Budget, 1997). To maintain continuity of the estimates across the time series, we use bridged race intercensal estimates for 2000 to 2010.[2] Deaths to non-residents are excluded from the series.[3]

Due to concerns about the quality of race reporting in the death data over the time period, we collapse the non-Hispanic race groups into two categories. Groups with similar mortality patterns are combined. As a result, death rates are produced for three race and Hispanic origin groups: (1) non-Hispanic White and non-Hispanic API; (2) non-Hispanic Black and non-Hispanic AIAN; and (3) Hispanic (of any race).

In this paper, we test several approaches to projecting mortality, with a focus on targeting and time series methods. First, we update the Census Bureau's targeting method (described above) from the 2012 series, to provide results for a model that assumes convergence on an ultimate life expectancy for all race and Hispanic origin groups. The targeting approach was updated to include mortality data for 2010, extending the time series used in the projection for 1989 to 2010 (in the 2012 series we based the mortality projections on death data for 1989 to 2009). Next, we explore time series approaches, considering the Lee-Carter model for projecting mortality and subsequent variants of that model (Lee and Carter, 1992; Lee and Miller, 2001; Booth et al., 2002; Renshaw and Haberman, 2003).

The original Lee-Carter model is a two-step procedure, which includes fitting the mortality data with a base model that contains an age and time component using singular value decomposition (Lee and Carter, 1992). The base model is forecasted by keeping the age component fixed, then fitting and forecasting a time series model for the time component. The time component

[2] Bridged race estimates are those where multiple-race responses are converted back to the single-race categories consistent with the 1977 Office of Management and Budget standards for data on race and ethnicity.
[3] Non-residents are defined as persons whose reported state of residence is *not* one of the 50 states or the District of Columbia.

is referred to as $k(t)$, the overall level of mortality across all ages at time *t*. The age component, referred to as $b(x)$, is the rate and direction of change at age *x* from the overall level of mortality. In many cases, $k(t)$ can be easily modeled with a random walk with drift, but this particular specification for $k(t)$ is not required in the approach. In the Lee-Carter specification, the log of the mortality rate *m* at age *x* in year *t* is given by:

$$log\big(m(x,t)\big) = a(x) + b(x) \cdot k(t), \qquad [1]$$

where $a(x)$ is the average of the log mortality rates at age *x* and $b(x)$ and $k(t)$ are as described above.

Since it is assumed that the rate of change in mortality at age *x* remains constant throughout the forecast, it is reasonable to estimate $b(x)$ from a historical time series of comparable length. The mortality schedules we use are available from 1989 to 2010, a 22-year fitting period. Our intent is to forecast mortality 50 years into the future for these groups. However, using the estimated rate of change from the shorter fitting period can result in implausible age distributions of mortality, particularly in the later years of the forecast (as can be seen in the results section below).

To overcome this limitation, we have devised our own variant of the Lee-Carter model to borrow information from a longer time series of mortality data (1961 to 2010) by sex to inform the forecast for a reference group: non-Hispanic White and API. The forecast for each sex of the reference group is obtained by first applying a Lee-Carter fit to each mortality time series by sex from 1961 to 2010 to estimate the rate of change in mortality by age over the 50-year fitting period. The forecast for each remaining group is obtained by modeling and forecasting differences from the reference group with Lee-Carter parameters and then summing these forecasted differences with the forecast of the reference group.

If $log\big(m(x,t,s,g)\big)$ is the log mortality rate at age *x* and time *t* for sex *s* in group *g*, where *g*=1 for non-Hispanic White and non-Hispanic API, *g*=2 for non-Hispanic Black and non-Hispanic AIAN, and *g*=3 Hispanic of any race, then let $a(x,s,g)$ and $k(t,s,g)$ represent the Lee-Carter

parameters in the s^{th} sex and the g^{th} origin group, where $a(x,s,g)$ is the average level of mortality at age x in sex s in group g, and $k(t,s,g)$ is the overall level of mortality across all ages at time t in sex s in group g.

The forecast for the reference group, non-Hispanic White and API, is constructed by imposing the rate of change in mortality rates by age observed in the longer time series from 1961 to 2010. For example, the rate of change in mortality by age for all females observed in the 50-year time series is applied to the non-Hispanic White and API female group. We refer to the parameter that describes the rate of change in mortality by age x over the longer (50-year fitting period) time series as $b_{long}(x,s)$, with s=1 for males and s=2 for females.

The other two Lee-Carter parameters for a reference group – $a(x,s,g)$, the average level of mortality at age x in sex s and in group g, and $k(t,s,g)$, the overall level of mortality across all ages at time t in sex s and in group g – are estimated using the shorter (22-year fitting period), sex and origin-specific time series of historical mortality rates.

The reference groups have the following base model:

$$log\big(m(x,t,s,g)\big) = a(x,s,g) + \ b_{long}(x,s)\cdot k(t,s,g), \qquad [2]$$

for g=1 (non-Hispanic White and non-Hispanic API), where $a(x,s,g)$, $b_{long}(x,s)$, and $k(t,s,g)$ are described as above.

Let $\tilde{a}(x,s,g)$ denote the average log differences between the g^{th} group and the reference group for the s^{th} sex, and let the parameter $\tilde{b}(x,s,g)$ denote the rate of change for age x in the differences for the g^{th} origin group in sex s for g=2,3. And finally, let $\tilde{k}(t,s,g)$ represent the overall level of differences between the gth group and the reference group for sex s, also for g=2,3.

The mortality schedules for all non-reference groups can be recovered by adding the differences from the reference group to the mortality schedules of the corresponding reference group, as follows:

$$log\big(m(x,t,s,g)\big) = log\big(m(x,t,1,1)\big) + \tilde{a}(x,1,g) + \tilde{b}(x,1,1) \cdot \tilde{k}(t,1,g) \quad \text{for males} \qquad [4]$$

and

$$log\big(m(x,t,s,g)\big) = \underbrace{log\big(m(x,t,2,1)\big)}_{\text{Reference group}} + \underbrace{\tilde{a}(x,2,g) + \tilde{b}(x,2,1) \cdot \tilde{k}(t,2,g)}_{\text{Differences from the reference group}} \quad \text{for females,} \qquad [5]$$

for g=2 for non-Hispanic Black and non-Hispanic AIAN and g=3 for Hispanic of any race.

In summary, the forecast for the non-Hispanic White and API reference group for each sex, which was informed by the longer time series, is obtained and then the modeled differences between each group and reference group are forecasted. The forecasts for the non-reference groups are obtained by summing the forecasted reference group mortality schedule with the schedule of forecasted differences.

RESULTS

Targeting Approach

Results for the targeting approach are presented in Figures 1 and 2. Projections of the mortality rates by age are displayed in Figure 1. Results for males are shown on the left and females are displayed on the right. The first graph shows results for the non-Hispanic White and API group, followed by non-Hispanic Black and AIAN in the middle, and Hispanics shown at the bottom of the figure. The darker shades of blue (for males) and red (for females) represent the earliest years of the forecast and lighter shades represent the latest years in the forecast. In the targeting approach, mortality rates are projected to decrease for all ages over the projection period, with the largest improvements projected in the young to middle adult ages.

The projected life expectancies at birth for 2011 to 2060 are provided in Figure 2. Life expectancy at birth is projected to increase for all groups. In 2011, non-Hispanic Black and AIAN males had the lowest life expectancy at birth at 71.9 years. While this group is projected to continue to have the lowest life expectancy at birth, it is projected to increase to 81.7 by 2060. This is an increase of nearly 10 years. Life expectancy for all other groups falls between 75 and 85 years in 2011 and by 2060 these groups are projected to have life expectancies at birth between 85 and 90 years. The differences in the life expectancy at birth of males and females within each race and Hispanic origin group are projected to grow smaller for all groups. In 2011, the differences between males and females was 4.6 years for non-Hispanic White and API, 6.2 years for non-Hispanic Black and AIAN, and 4.8 years for Hispanics. By 2060, the differences are projected to decrease by about 2 years for each group, with the sex differential falling to 2.9 years for non-Hispanic White and API, 4.0 years for non-Hispanic Black and AIAN, and 3.1 years for Hispanics.

Time Series Approach

We first present results for mortality projections produced using the original Lee-Carter method in Figure 3. Because the mortality rates in our time series decline more rapidly for some

ages than at others, resulting in larger values of the parameter $b(x)$ for some ages, faster change is projected at some ages leading to implausible age distributions of the mortality rates in the projected years. We address these issues by implementing our own variant of the Lee-Carter model, which takes into consideration information from a longer time series of mortality data for the total population by sex to inform the forecast of our largest group, the non-Hispanic White and API group. To address issues for the smaller groups, non-Hispanic Black and AIAN and Hispanics, we project their rates by forecasting the differences between those groups and the non-Hispanic and API groups, by sex. Our hope is that this will overcome issues with projecting smaller groups with shorter time series of data.

Results for our modified Lee-Carter approach are provided in Figures 4 and 5. Figure 4 shows the projected mortality rates by age for each of the three race and Hispanic origin groups by sex. The modified approach yields improvements in the age distribution of the mortality rates in the forecasted years for the non-Hispanic White and API group. The results for the non-Hispanic Black and AIAN and Hispanic groups show improvements in the age distributions of the mortality rates compared to what was observed from the original Lee-Carter model, but there are still some issues with the age distributions for these groups in the later years of the forecast. There is also a crossover of the mortality rates at the oldest ages for most groups.

The projected life expectancies at birth from our modified Lee-Carter model are provided in Figure 5. Life expectancy at birth is projected to increase for all six groups and the differences between groups, both by race and Hispanic origin and by sex, at the end of the projection period are much smaller than what was found in the targeting approach. Life expectancy at birth is projected to fall between 82 and 87 years for all groups in this model. The differences in life expectancy at birth by sex within each group are projected to drop below two years. By 2060, the sex differential is projected to drop to 1.4 years for non-Hispanic White and API, 1.7 years for non-Hispanic Black and AIAN, and 1.2 years for Hispanics.

Comparing the Targeting and Time Series Approaches

Projections of the mortality rates by age in 2060 from each of the three models are compared in Figure 6. The observed rates from 2010 are also included (dashed black line) to show how much the rates are projected to change over the 50 year period. For the non-Hispanic White and API group, the targeting approach projects slightly less improvement in the mortality rates under age 20 and greater improvements in the rates at ages 20 to 60, compared to the Lee-Carter models. For the non-Hispanic Black and AIAN and Hispanic groups, the Lee-Carter model results in a more pronounced bimodal distribution of the rates by age than does the targeting approach. The Lee-Carter model forecasts slightly greater improvement in the rates under 20 and also between the ages of 20 and 40. There are also some ages where the targeting approach projects greater improvement in the mortality rates for these groups, notable around age 30 for non-Hispanic Black and AIAN males and at age 20 for non-Hispanic Black and AIAN females as well as Hispanic males and females.

The projections of life expectancy at birth from the targeting, original Lee-Carter, and modified Lee-Carter approaches are compared in Figures 7 and Table 1. In general, the time series model forecasts a slightly smaller increase in life expectancy at birth between 2011 and 2060 than does the targeting approach. The exception to this trend is non-Hispanic Black and AIAN males. This group is projected to experience an increase of 11 years in life expectancy at birth in the modified Lee-Carter model compared to 9.8 years in the targeting approach. Males are projected to experience increases in all three models, with the range of differences between models in 2060 at 0.7 years for Hispanic males, 1.0 years for non-Hispanic White and API males, and 1.7 years for non-Hispanic Black and AIAN males. Differences for females are more pronounced in 2060, ranging from 1.3 for non-Hispanic Black and AIAN females and 2.6 for both non-Hispanic White and API females and Hispanic females.

One area of concern with both Lee-Carter methods is that they result in much lower sex differentials in life expectancy than the targeting method. By 2060, they project the sex differentials will be less than 2 years for all three groups (see Figure 8 and Table 2) compared to values of about 3 to 4 years for the targeting method. The United Nations Population Division (2014a) projects female life expectancy and models the sex differentials to get the male life expectancy. Their estimates show a sex differential of about 3.8 years for the United States in 2060 (United Nations Population Division, 2014b).

DISCUSSION

Thus far, we have generated two series of mortality projections derived from models based on targeting an ultimate level and time series analysis. While both models project a general overall improvement in life expectancy for all race and Hispanic origin groups, we question the shift in the differences in life expectancy at birth by sex within each group, particularly for the time series approach. The narrow range of difference in life expectancy at birth for both the race and Hispanic origin groups as well as by sex displayed in the results for the modified Lee-Carter approach may represent too rapid an improvement for some groups and not enough for others. One method of addressing this may be to adopt an approach similar to one used by the United Nations, to project sex differentials to use to derive measures from the projection of one sex (e.g., females) for the other sex (e.g., males). This approach was recently implemented by the United Nations in their long-term projections (United Nations Population Division, 2014a).

As we continue with this research, we also plan to explore methods not previously used by the Census Bureau to project mortality. The first is a hybrid of the time series and targeting approaches, which imposes bounds on the projection derived from the time series analysis (e.g., Bravo, 2010). The Lee-Carter model in its original form has proven unsatisfactory due to results that display implausible age patterns and divergence of life expectancy for males and females. Our

modification to the Lee-Carter model yields improvements, but there are still some questionable age patterns for the non-reference groups.

Use of a Lee-Carter type time series approach, with a lower bound on death rates (or upper bound to life expectancy), may provide a middle of the road, hybrid approach. This approach benefits from statistical modeling and incorporates demographic judgment to keep forecasts within the realm of what currently seems demographically 'plausible.' This hybrid approach, a compromise between historical data and demographic plausibility, lends itself to a Bayesian analysis, since the extent of demographic plausibility (i.e., expected age distributions and sex differentials in life expectancy) may be incorporated into the model in the form of a prior distribution.

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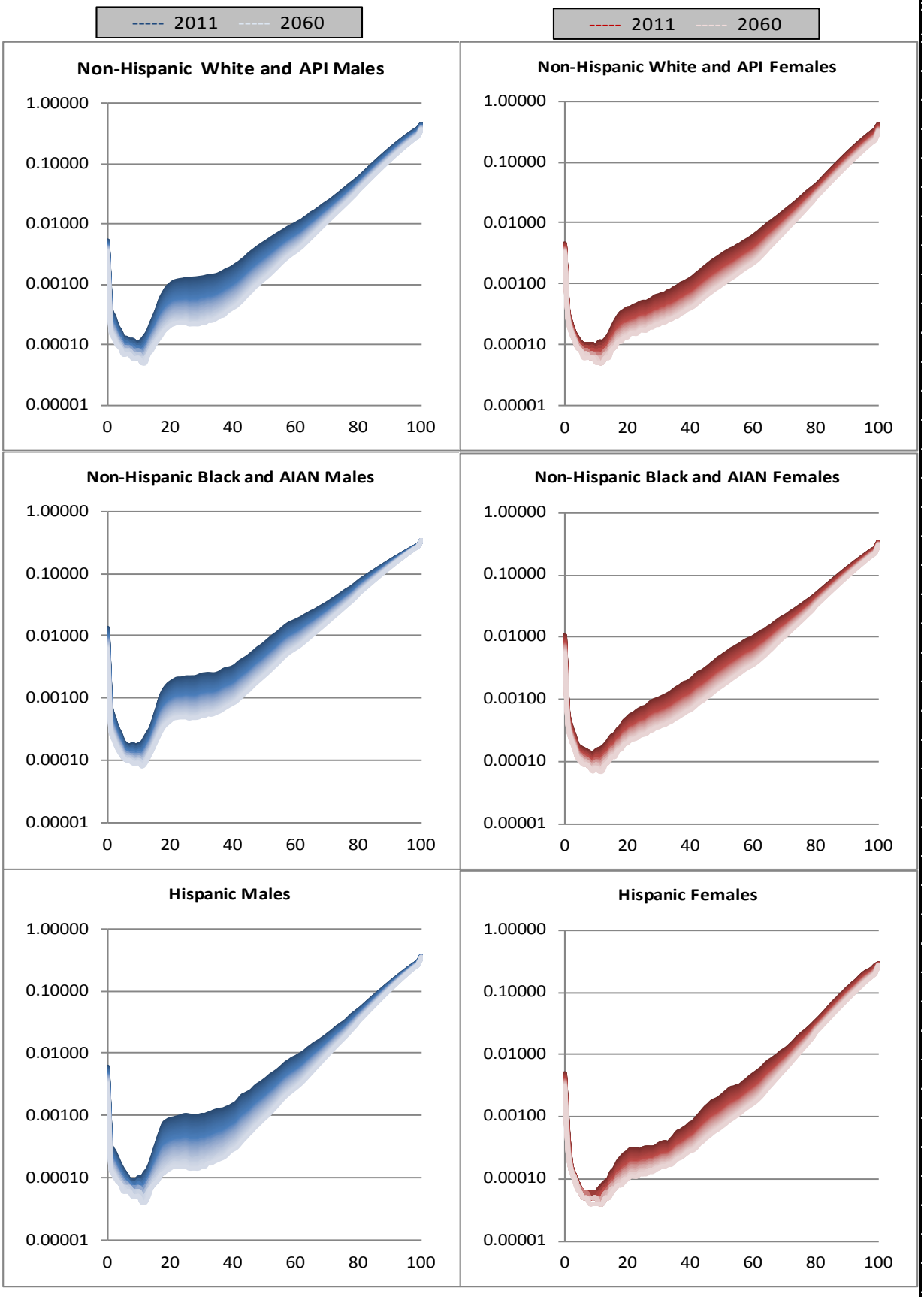
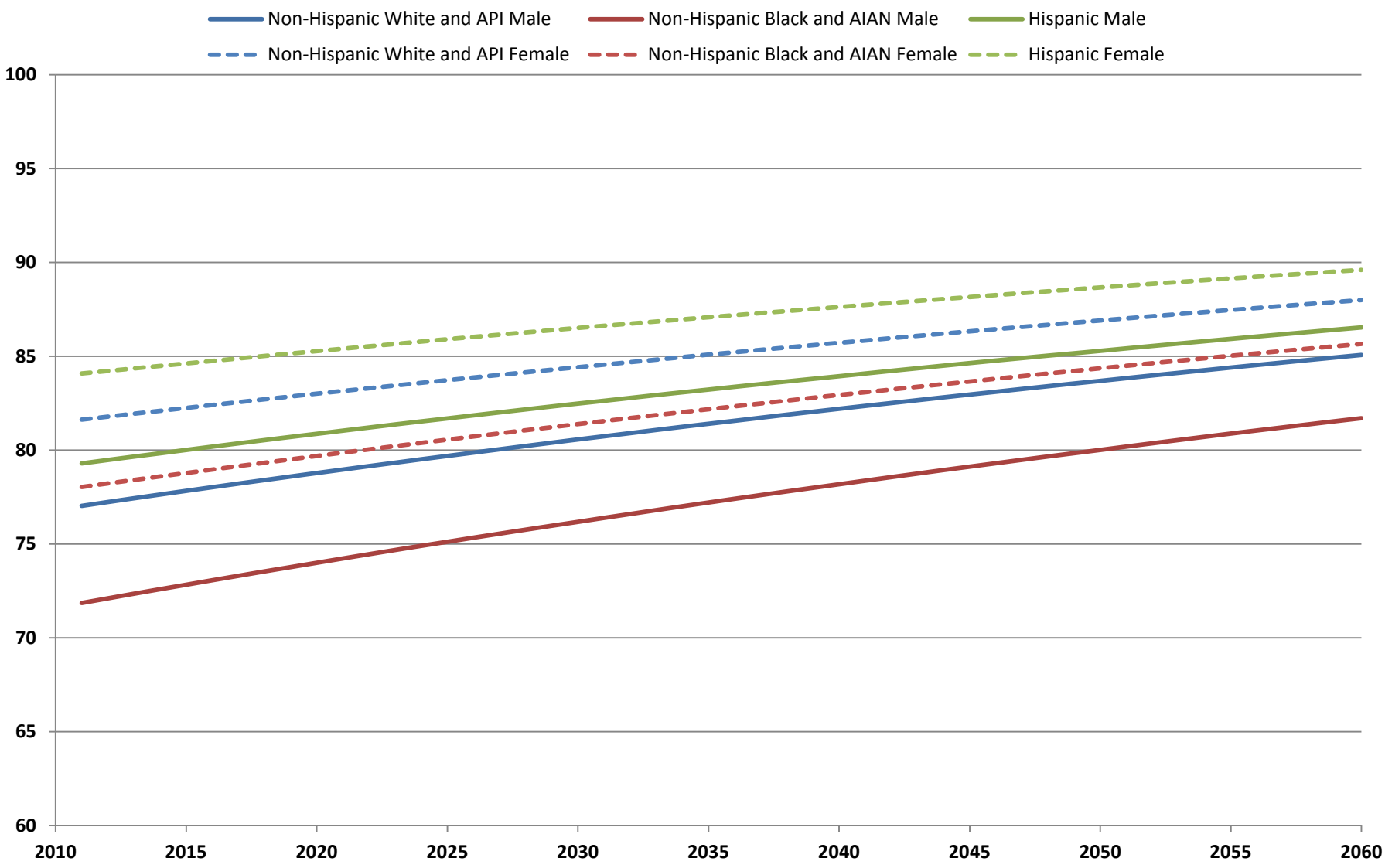
Figure 1. Projected Mortality Rates by Group, Sex, and Age from the Targeting Approach: 2011 and 2060



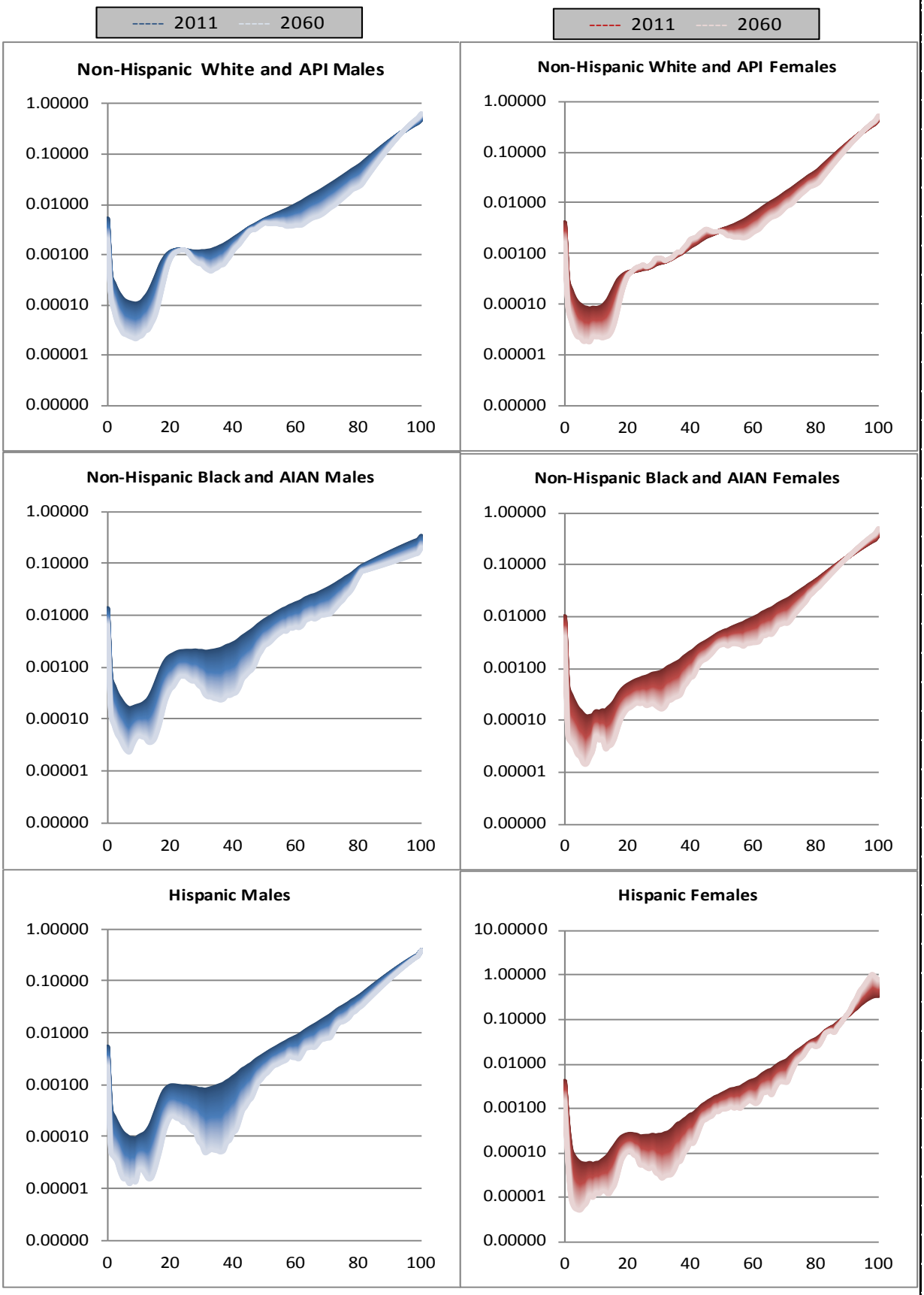
Source: U.S. Census Bureau, Population Division.

Figure 2. Projected Life Expectancy at Birth by Group and Sex from the Targeting Approach: 2011 to 2060



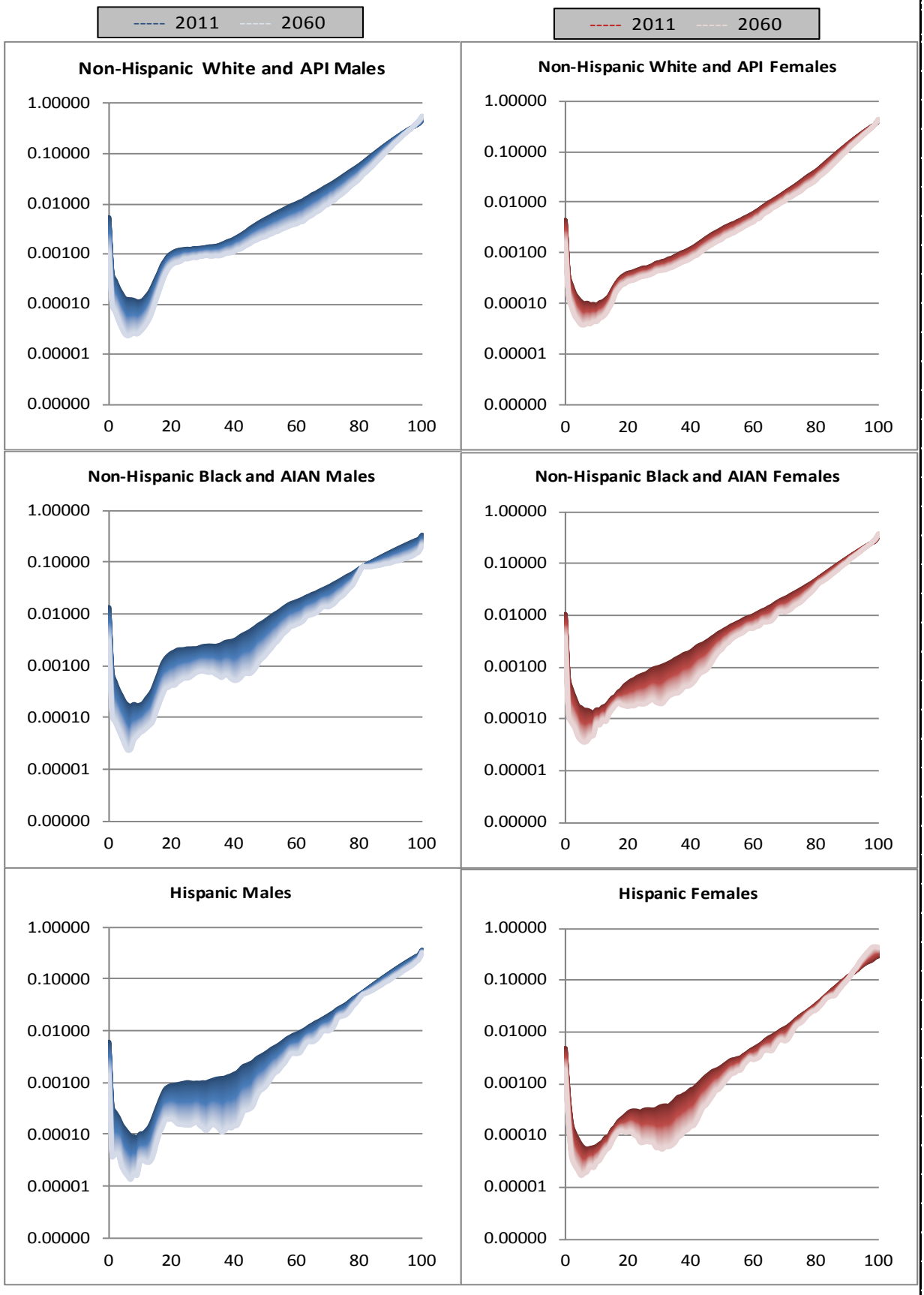
Source: U.S. Census Bureau, Population Division.

Figure 3. Projected Mortality Rates by Group, Sex, and Age from the Original Lee-Carter Model: 2011 and 2060



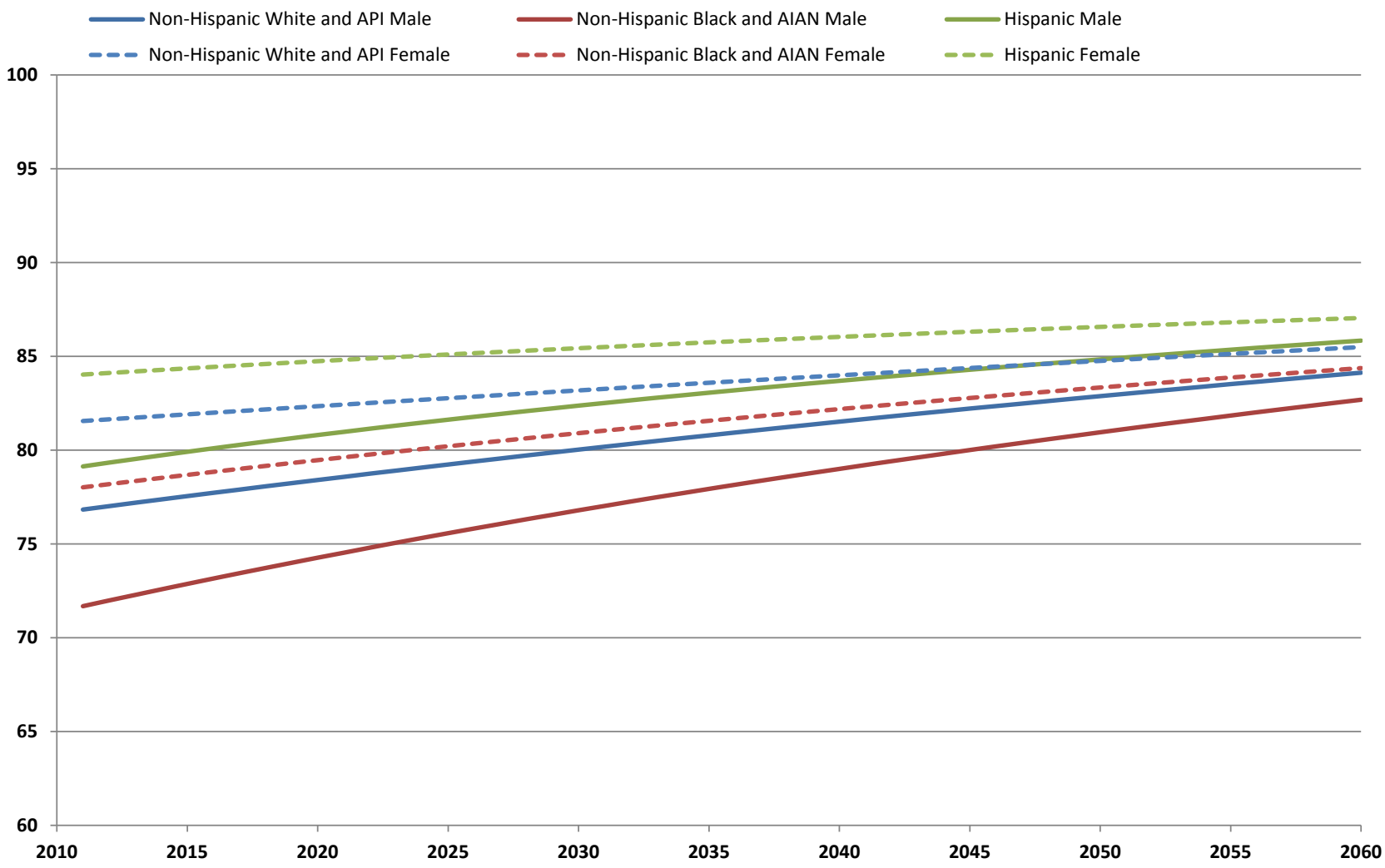
Source: U.S. Census Bureau, Population Division.

Figure 4. Projected Mortality Rates by Group, Sex, and Age from the Modified Lee-Carter Model: 2011 and 2060



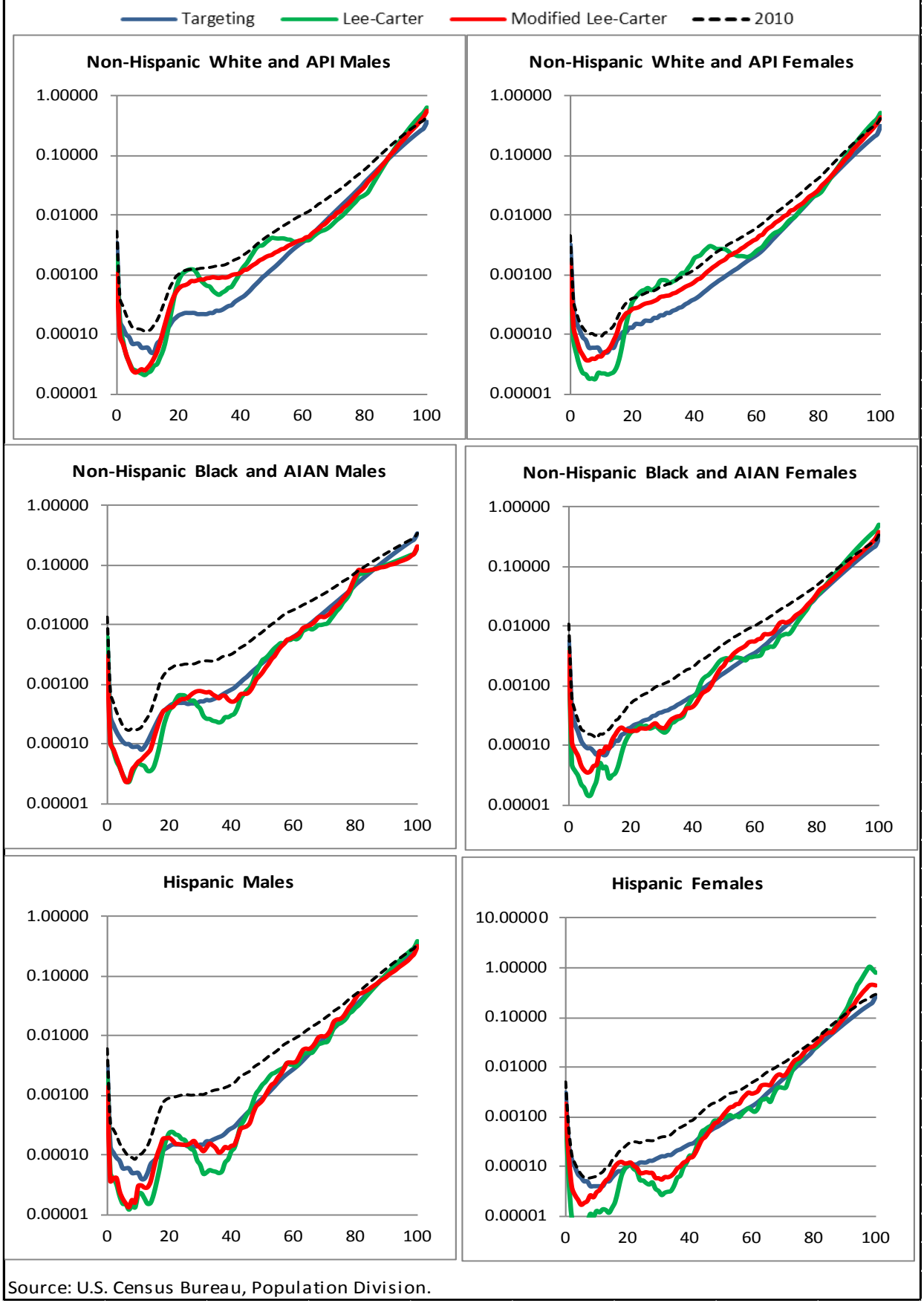
Source: U.S. Census Bureau, Population Division.

Figure 5. Projected Life Expectancy at Birth by Group and Sex from the Modified Lee-Carter Model: 2011 to 2060



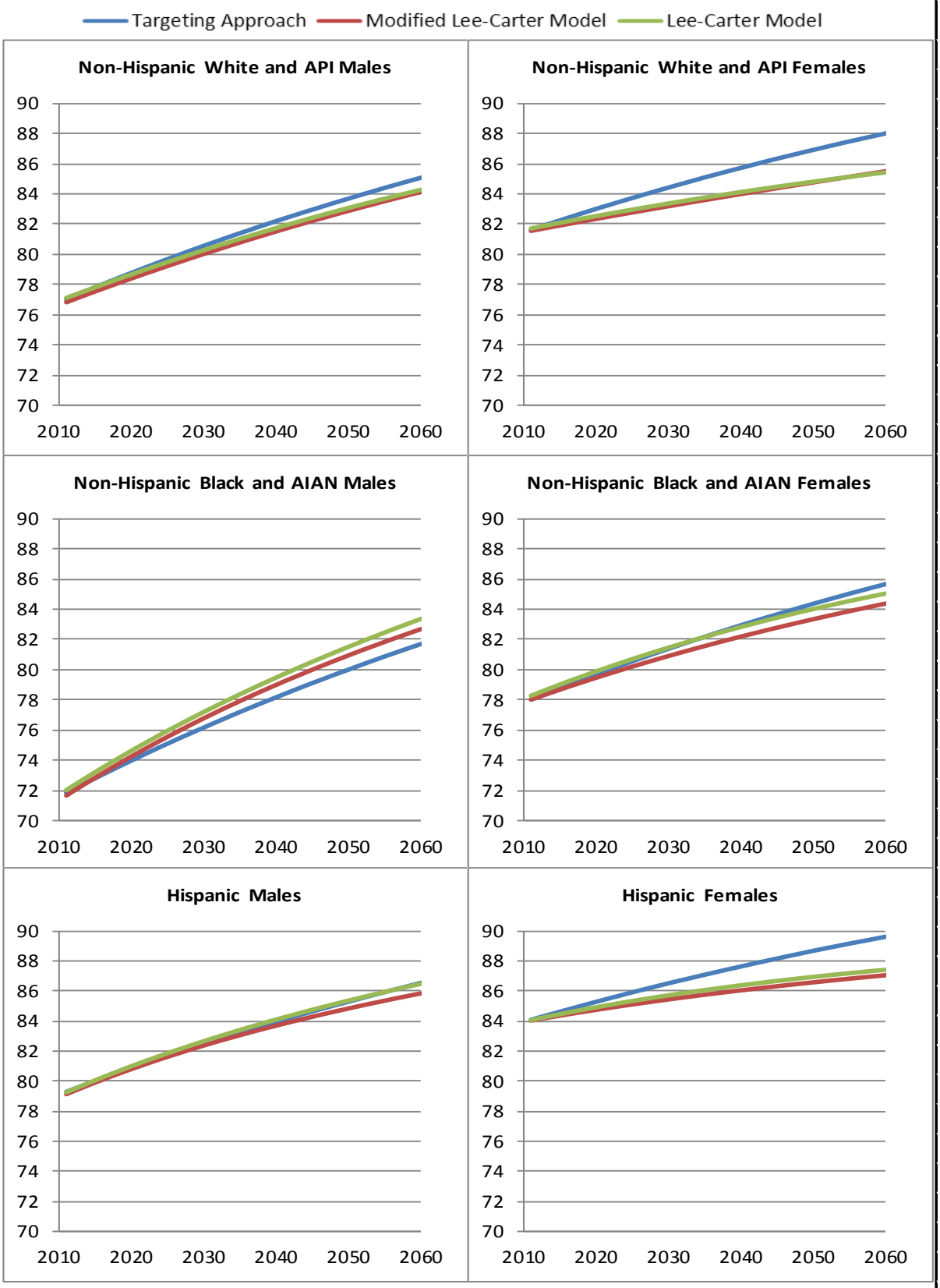
Source: U.S. Census Bureau, Population Division.

Figure 6. Projected Mortality Rates by Group, Sex, Age, and Method: 2010 and 2060



Source: U.S. Census Bureau, Population Division.

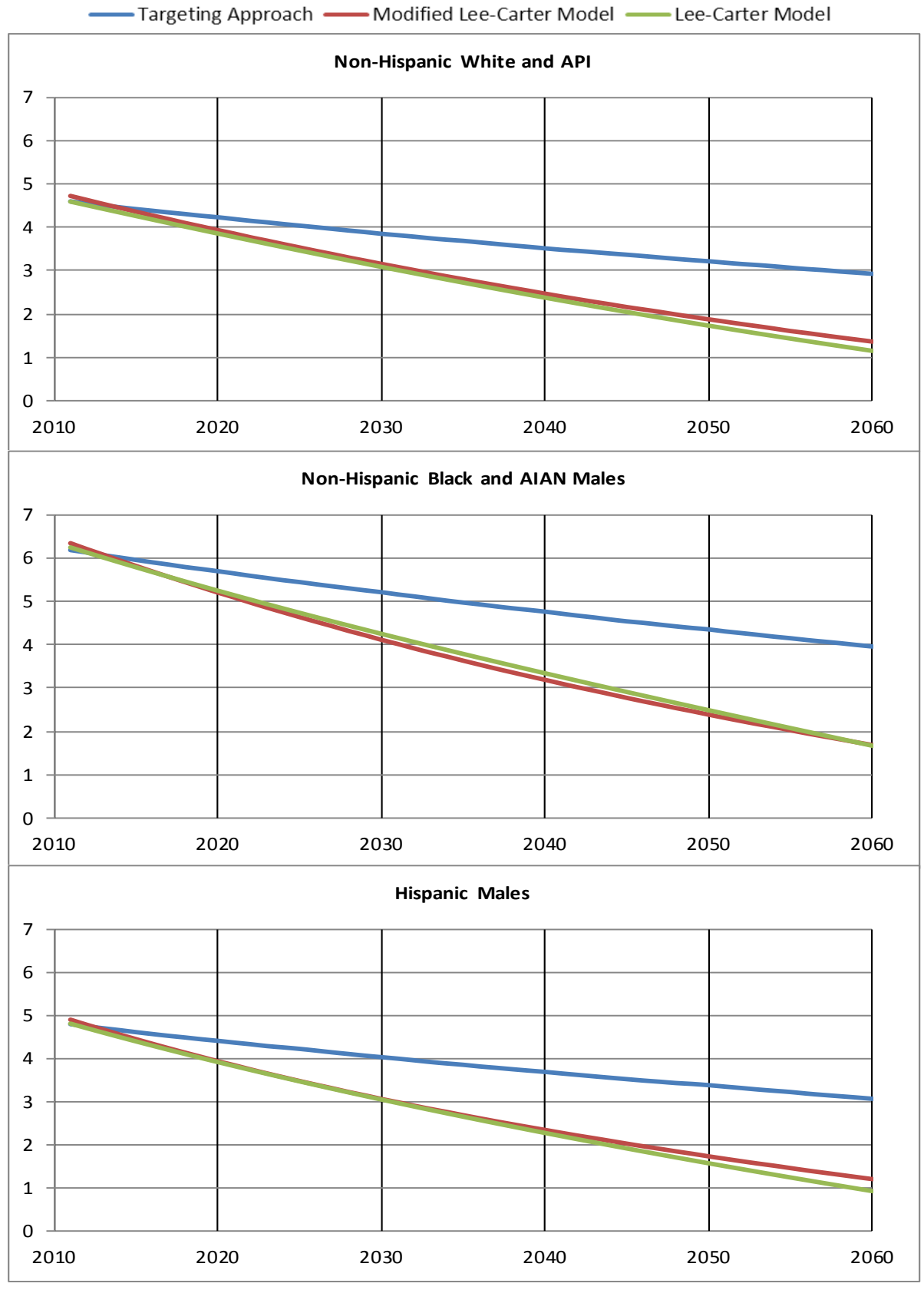
Figure 7. Projected Life Expectancy at Birth by Group, Sex, and Method: 2011 to 2060



Source: U.S. Census Bureau, Population Division.

Table 1. Projected Life Expectancy at Birth by Race, Hispanic Origin, and Sex: 2011 to 2060																		
Year	Targeting Approach						Lee-Carter Model						Modified Lee-Carter Model					
	Non-Hispanic White and API		Non-Hispanic Black and AIAN		Hispanic		Non-Hispanic White and API		Non-Hispanic Black and AIAN		Hispanic		Non-Hispanic White and API		Non-Hispanic Black and AIAN		Hispanic	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
2011	77.0	81.6	71.9	78.0	79.3	84.1	77.1	81.7	72.0	78.3	79.3	84.1	76.8	81.6	71.7	78.0	79.1	84.0
2020	78.8	83.0	74.0	79.7	80.9	85.3	78.7	82.5	74.6	79.9	81.0	84.9	78.4	82.3	74.3	79.5	80.8	84.7
2030	80.6	84.4	76.2	81.4	82.5	86.5	80.3	83.4	77.2	81.5	82.7	85.7	80.0	83.2	76.8	80.9	82.4	85.4
2040	82.2	85.7	78.2	82.9	83.9	87.6	81.7	84.1	79.5	82.8	84.1	86.4	81.5	84.0	79.0	82.2	83.7	86.0
2050	83.7	86.9	80.0	84.4	85.3	88.7	83.1	84.8	81.5	84.0	85.4	86.9	82.9	84.8	81.0	83.3	84.8	86.6
2060	85.1	88.0	81.7	85.7	86.5	89.6	84.3	85.4	83.4	85.0	86.5	87.4	84.1	85.5	82.7	84.4	85.8	87.0
Projected Change from 2011 to 2060	*8.0*	*6.4*	*9.8*	*7.6*	*7.2*	*5.5*	*7.1*	*3.7*	*11.3*	*6.8*	*7.2*	*3.3*	*7.3*	*3.9*	*11.0*	*6.4*	*6.7*	*3.0*
Source: U.S. Census Bureau, Population Division.																		

Figure 8. Projected Sex Differentials in Life Expectancy at Birth by Group and Method: 2011 to 2060



Source: U.S. Census Bureau, Population Division.

Table 2. Projected Female Advantage in Life Expectancy at Birth by Race and Hispanic Origin: 2011 to 2060									
Year	Targeting Approach			Lee-Carter Model			Modified Lee-Carter Model		
	Non-Hispanic White and API	Non-Hispanic Black and AIAN	Hispanic	Non-Hispanic White and API	Non-Hispanic Black and AIAN	Hispanic	Non-Hispanic White and API	Non-Hispanic Black and AIAN	Hispanic
2011	4.6	6.2	4.8	4.6	6.2	4.8	4.7	6.3	4.9
2020	4.2	5.7	4.4	3.9	5.2	3.9	3.9	5.2	3.9
2030	3.8	5.2	4.0	3.1	4.2	3.0	3.2	4.1	3.1
2040	3.5	4.8	3.7	2.4	3.3	2.3	2.5	3.2	2.3
2050	3.2	4.4	3.4	1.7	2.5	1.6	1.9	2.4	1.7
2060	2.9	4.0	3.1	1.2	1.7	0.9	1.4	1.7	1.2
Source: U.S. Census Bureau, Population Division.									