# Analyzing the impact of mortality assumptions on projection outcome with the Probabilistic Population Projection Model

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**Abstract**

Mortality is one of the three core demographic parameters that drive population growth. In recent years, populations of many highly developed countries age due to increasing life expectancy and decreasing fertility. A growing proportion of elderly people is a key characteristic of aging populations. As elderly people are mostly affected by mortality, generating mortality assumptions will gain more importance in population projections. To analyze the impact of mortality assumptions on the projection outcome, we conduct a population projection with real-world data for Germany with the Probabilistic Population Projection Model (PPPM) that has several methodological advantages (in generating mortality assumptions and analyzing projected outcome) compared to typical projection models. An unique feature of the PPPM is the association of the projection outcome and its generating assumptions for each projection trial. This feature allows us to combine selected result paths to a distribution that have one or more certain assumptions in common. Therefore, we conduct one projection with multiple mortality assumptions, and compare thereafter result distributions that are a combination of result paths with different mortality assumptions. Our results indicate, that mortality assumptions indeed have a major impact on projected total population size in older populations, and that common probabilistic projection approaches can underestimate future uncertainty due to their restriction to only one assumption with stochastic variation for each model parameter.

## 1 Extended abstract

Mortality is (next to fertility and migration) one of the three core demographic parameters that drive population growth. In recent years, populations of many highly developed countries age due to increasing life expectancy and decreasing fertility. A growing proportion of elderly people is a key characteristic of aging populations. As elderly people are mostly affected by mortality, less by migration, and not at all by fertility, generating mortality assumptions will gain more importance in population projections. For this reasons, we want to analyze the impact of mortality assumptions on the projection outcome. Therefore, we use the Probabilistic Population Projection Model (PPPM) [1] that has several methodological advantages (in generating mortality assumptions and analyzing projected outcome) compared to typical projection models.

The unknown future development of mortality, fertility, and migration mainly trigger inherent uncertainty of population projections; especially when errors in data and computation can be excluded, and the projection model is appropriate. In the past, life expectancy at birth increased almost linearly in highly developed countries [2, 3, 4, 5, 6, 7]. However, when estimating future mortality, a forecaster can use multiple sources of information that may reveal different potential directions. There are various quantitative and qualitative methods that are more or less suitable to transform these potential directions into real estimates with concrete assumption values for future mortality. Data driven methods are objective, but they are limited to extrapolate the past development without any major changes into the future. A forecaster's expertise is then limited to the choice of a base period with a certain underlying mortality trend that coincides with his or her expectation. New mortality trends, that can be triggered by innovative biomedical technologies, or changing individual health-related behaviour, can only be captured by qualitative methods that include expert judgment. A compromise that combines quantitative and qualitative methods is, for instance, the correction of an extrapolated mortality estimate with expert judgement according to the insights of different sources of information. If various sources of information reveal different potential future developments for mortality, all of these trajectories should be included in a population projection to capture future uncertainty comprehensively.

Potential future developments for mortality differ in their level, trajectory, and expected likelihood. Such a diversity can not be captured by common probabilistic projection approaches [8, 9, 10, 11] due to relatively strong model-based restrictions; for instance, common approaches typically determine a method to generate one point forecast for each projection year, and a theoretical distribution for random errors around these point forecasts to capture future uncertainty. In contrast, the PPPM can capture the diversity of future mortality more comprehensively by including *multiple* potential future developments with stochastic variation. Neither certain methods for generating potential directions, nor theoretical distributions for random errors are determined to build the joint distribution of mortality assumptions.

In general, the PPPM is a probabilistic model that projects natives, immigrants, emigrants and their descendant generations by single age and sex simulatively. The *association* between randomly chosen assumptions and generated results for each projection trial provides various alternatives to analyze the impact of mortality assumptions on projection outcome: The impact of one ore more mortality assumptions for one or more subpopulations can be analyzed on output quantities (like population counts or Old Age Dependency Ratio) for one subpopulation or an aggregate of subpopulations.

To illustrate the power of result analysis with the PPPM, we show how the result distribution of the total population changes when a multitude of mortality assumptions is systematically reduced. To do this, we only have to conduct one population projection that includes all potential mortality assumptions. Thereafter, we only have to select those result paths that have been generated with certain mortality assumptions.

As we want to show this mortality effect on the total population in a rather realistic setting, we project the German population from 2007 to 2050 with the PPPM. The initial joint distribution for German native male mortality consists of six representative assumption paths with stochastic variation (see Figure 1). The blue assumptions presume a steady increase in life expectancy at birth on three different levels: $85.32$ (blue), $87.17$ (turquoise), and $88.26$ (darkblue) in 2050, whereas the red and green assumptions presume a moderate increase in life expectancy at birth:

81.68 (darkred), 80.32 (red), and 76.86 (green) in 2050.[1] Each of these potential directions is weigthed with an occurrence probability that represents its expected likelihood.

To analyze the impact of mortality on total population, we compare corresponding result distributions that are generated (1) with all six mortality assumptions, and that are only generated (2) with the blue mortality assumptions, (3) with the red mortality assumptions, and (4) with the green mortality assumptions. As the three latter result distributions are only a part of the original result distribution, they are called *mini* projections.

Figure 2 depicts the result distribution for the total population of the overall projection as well as of the three mini projections over the projection horizon from 2007 to 2050. Given the underlying assumptions, the German total population probably shrinks. Apparently, the mini projections cover only a part of the overall result distribution, whereby the green/red/blue mini projection covers the lower/mid/upper part of the overall result distribution due to its lower/medium/higher life expectancy assumptions.

Figure 3 shows respective cumulative distribution functions and probability density functions for the total population in 2050. In the projection with all six mortality assumptions, the total population ranges between 60.94 and 76.38 million, whereas the total population ranges between 67.81 and 76.38 million in the blue mini projection, between 63.63 and 70.59 million in the red mini projection, and between 60.94 and 66.79 million in the green mini projection. Obviously, the blue mortality assumptions cause higher total population counts than the red and the green mortality assumptions due to its higher life expectancy assumptions.

These results reveal at least two interesting insights:

(1) Mortality assumptions have a major impact on total population size in these projections: Lower mortality assumptions cause higher total population counts than higher mortality assumptions. If mortality impact was less strong, lower mortality assumptions would also cause lower total population counts. Mortality's impact is so strong in these projections due to the increasing share of elderly people (see Figure 4) that are foremost affected by mortality.

(2) The less mortality assumptions are considered, the smaller is the variance of the result distributions for the total population. This effect indicates that common probabilistic projection approaches can *underestimate* future uncertainty due to their restriction to only one assumption with stochastic variation (for each model parameter). This is especially true when future development is highly uncertain and different sources of information reveal potential directions that substantially vary in their level, trajectory, and expected likelihood.

[1] We have *multiple* fertility and mortality assumptions for each subpopulation. If the reader is interested in additional information at this point, he or she can obtain them on authors' request.

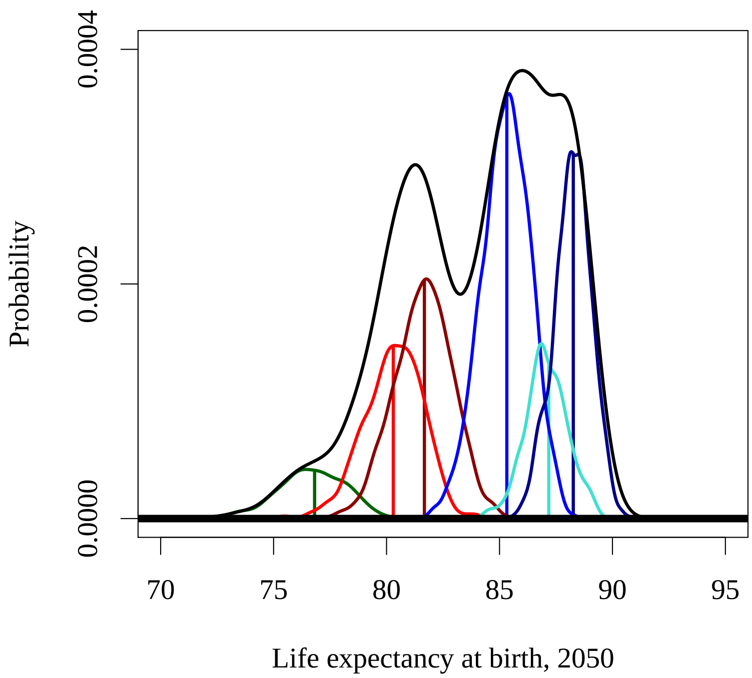


Figure 1: Overall joint distribution (black curve) consists of the green, red, darkred, blue, turquoise, and darkblue representative assumption path (green, red, darkred, blue, turquoise, and darkblue vertical line) with stochastic variation (green, red, darkred, blue, turquoise, and darkblue curve).

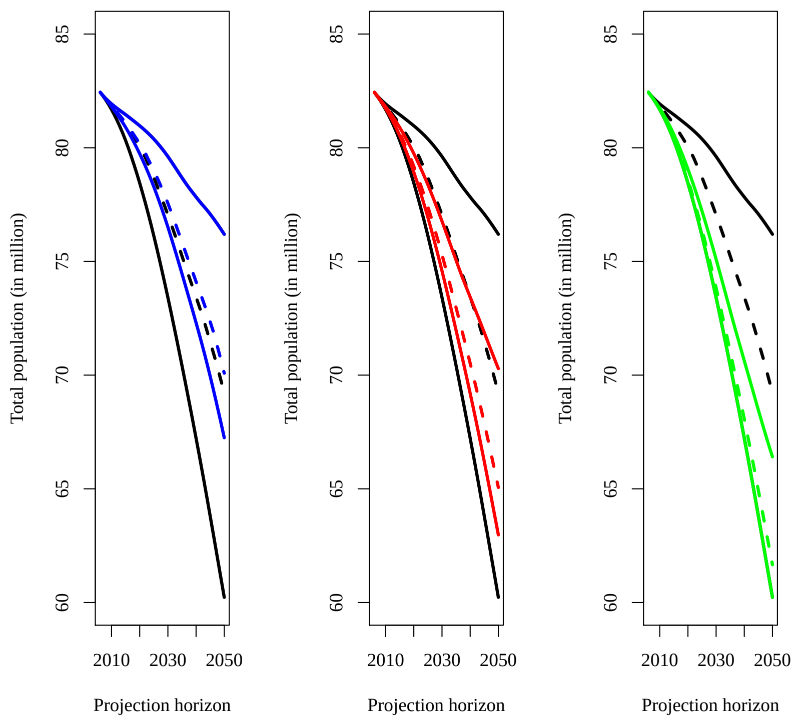


Figure 2: Result distribution for the German total population from 2007 to 2050 of the projection with all six mortality assumptions (black) and from the three mini projections with only blue, only red, and only green mortality assumptions (see Figure 1). Depicted are the quantiles $0$ (solid line), $0.5$ (dashed line), and $1$ (solid line) for each result distribution.

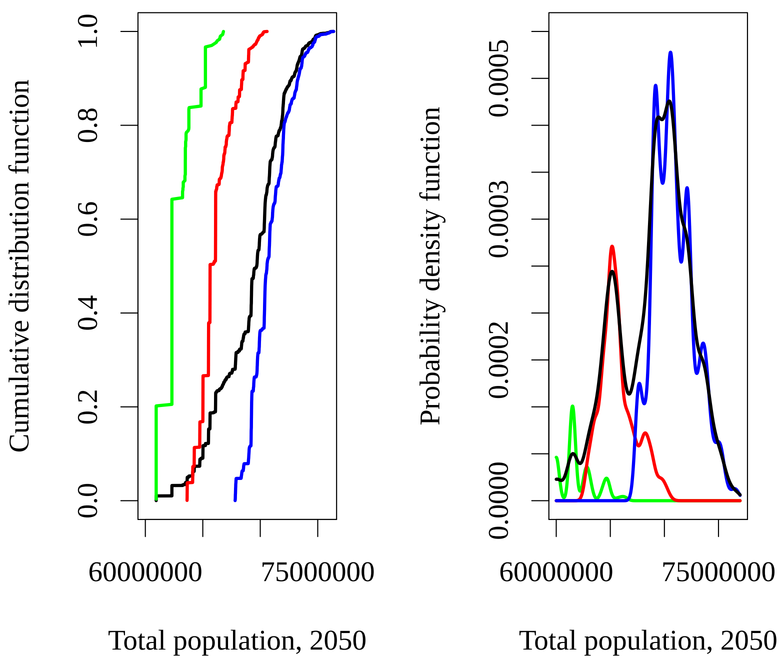


Figure 3: Cumulative distribution function (left) and probability density function (right) for the German total population in 2050. Depicted are result distributions from the projection with all six mortality assumptions (black) and from the three mini projections with only blue, only red, and only green mortality assumptions (see Figure 1). Obviously, high life expectancy assumptions induce higher total population counts in the blue mini projection than less life expectancy assumptions in the red and green mini projections.

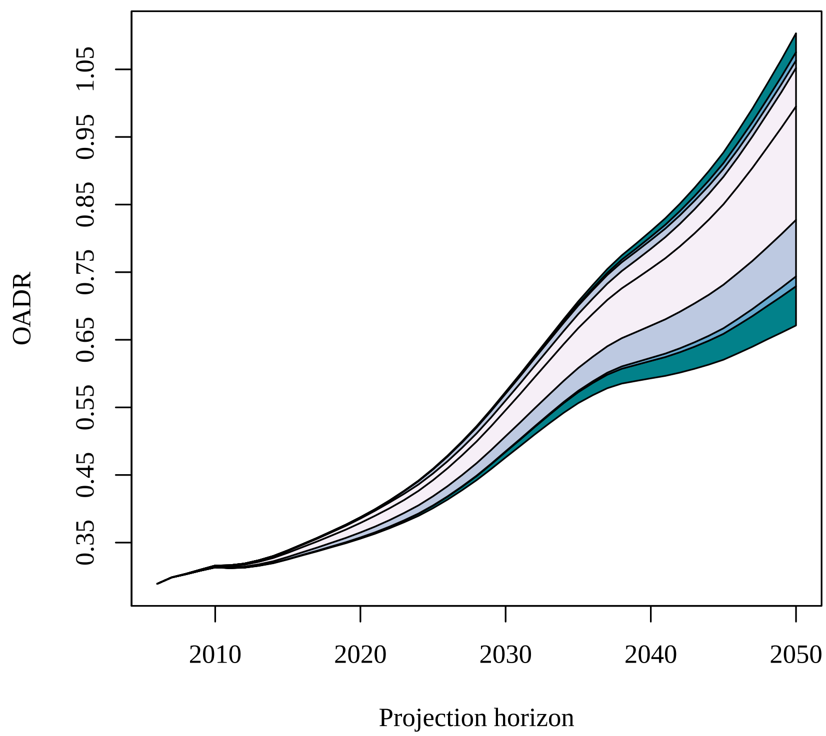


Figure 4: Old Age Dependency Ratio (OADR) of the total population for the quantiles $0$, $0.025$, $0.05$, $0.1$, $0.5$, $0.9$, $0.95$, $0.975$, $1$ over the projection horizon in the projection with all six mortality assumptions. Given the underlying assumptions, the ratio of persons aged $65+$ to persons between age $15$ and $64$ will probably increase in the total population.

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