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Risk sharing rules for longevity risk: impact and wealth transfers

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DESIGN 66

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and Thijs Markwat

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DESIGN PAPER 66

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1 Introduction

In this paper, we consider pension plans in which actuarial gains or losses at the fund level are covered by adjustments of the accrued rights of the surviving participants. At the level of the pension fund, an actuarial loss (gain) arises if the number of participants that survived during the year is higher (lower) than expected at the beginning of the year, and/or if “best-estimate” projections of future mortality rates are adjusted downwards (upwards). It is common practice that institutes such as the Dutch Actuarial Society (AG) or Statistics Netherlands (CBS) frequently revise best-estimate projections of future mortality rates. Such updates can lead to non-negligible changes in the best-estimate value of pension liabilities.

We examine mechanisms by which actuarial gains and losses that arise due to longevity risk are neutralized via adjustment of the accrued rights of the participants. If more participants survived than expected, or if best-estimates of their future survival rates are adjusted upwards, the accrued rights of the participants are adjusted downwards so as to keep the best-estimate value of the liabilities at fund level equal. When the value of accrued rights is expressed in real terms, such adjustments can (at least in part) be implemented via conditional indexation schemes. If the adjustment is immediate and complete, the mechanism implies that the funding ratio is unaffected by longevity risk. If instead the effect of a mortality shock on the value of the liabilities can be spread out over a period of, say, ten years, the adjustment mechanism mitigates, but does not fully eliminate, the effect of longevity risk on the funding ratio.

The current practice regarding adjustment rules (for example, conditional indexation rules) is that the adjustment factor is the same for every participant. The impact of updates in best-estimate future mortality rates on the value of pension annuities, however, can be very different depending on the age of the participant. This implies that an age-independent adjustment mechanism can lead to (unintended) wealth transfers between generations. The benefits and drawbacks of collective systems with risk sharing between generations have been discussed intensively in the past few years (see, for example, Bonenkamp et al., 2013; Chen et al., 2014; Beetsma and Bucciol, 2015). Some suggest moving to a system with individual pension accounts, while still allowing for sharing of longevity risk, or so-called "biometric risk" (see, e.g., Bergamin et al., 2014; Boelaars et al., 2014; Bovenberg and Gradus, 2014). We consider a number of rules for sharing longevity risk that differ in the extent to which longevity risk is shared within or over cohorts, and investigate the impact of each adjustment rule on the accrued rights of participants, and on wealth transfers between generations.

The remainder of the paper is organized as follows. In Section 2, we discuss the setup of the analysis. In Section 3, we qyuantify the effect of micro- and macro-longevity risk on the aggregate value of the liabilities of all participants belonging to a certain cohort. We then use these results in Section 4 to determine the required adjustment to accrued rights to neutralize the effect of micro- and macro-longevity risk for a number of adjustment rules that differ in the extent to which micro- and macro-longevity risk is shared within or over cohorts. In Section 5 we show the effect of the adjustment rules on transfers of wealth between generations, and between survivors and non-survivors within generations. Section 6 concludes.

2 Setup of the analysis and main conclusions

2.1 Quantifying the impact of longevity risk

We consider several mechanisms that a pension fund or life insurer can use to adjust accrued rights to compensate for actuarial gains/losses that arise at the portfolio level, due to longevity risk.

Longevity risk is the uncertainty regarding realized survival rates of the participants in the portfolio, and can be decomposed in two components. First, even if the pension fund or insurer would be able to estimate/forecast without error the future survival probabilities of its participants, the actual number of survivors would typically deviate from the expected number of survivors, purely due to random variation. This risk is referred to as *micro-longevity risk*. Second, pension funds or insurers can typically not perfectly forecast future survival rates. This implies that "true" survival probabilities can deviate from *ex ante* "best-estimate" survival probabilities. This risk is referred to as *macro-longevity risk*. For a more extensive discussion of longevity risk and its potential impact, see, for example, De Waegenaere et al. (2010).

We consider the impact of longevity risk on a one-year horizon. Then, the pension fund or insurer is affected by micro- and macro-longevity risk due to:

- *one-year survival uncertainty*: uncertainty regarding the number of participants that will survive the year; this uncertainty occurs due to the combined effect of both micro- and macro-longevity risk;

- *mortality trend uncertainty*: because future mortality rates are uncertain and hard to predict, "best-estimate" predictions are revised frequently. We will refer to a change in best-estimate future mortality rates due to such a revision as a "*longevity shock*". When best-estimate mortality rates will be revised at the end of the year, the pension fund or insurer faces uncertainty regarding the "best-estimate" death probabilities that will be used at the beginning of the next year to value the liabilities of those participants who survived.

In this paper, we first illustrate the impact of these two sources of longevity risk on the best-estimate value of pension liabilities. We then propose several mechanisms that can be used to share this risk between and within cohorts, and we investigate the extent to which these mechanisms give rise to systematic or non-systematic wealth transfers between generations.

2.2 Adjustment mechanisms for longevity risk

Because micro-longevity risk is a non-systematic source of risk[1] while macro-longevity risk is a systematic source of

[1] Under the assumption that differences between the realized survival rates in the portfolio and the corresponding population survival probabilities decrease (and converge to zero) when portfolio size increases.

risk, we allow for the case where the pension fund uses separate adjustment factors for these two sources of longevity risk. For each of the two adjustment factors, we consider a number of mechanisms that differ in the extent to which participants share risk with each other.

Current practice regarding adjustment of accrued rights for both micro- and macro-longevity risk is to use the same adjustment factor for each participant, which effectively means that both micro- and macro-longevity risk is shared with all participants. However, because a longevity shock can have a different impact on different cohorts, using the same adjustment factor for macro-longevity risk for each cohort can lead to significant transfers of wealth. To avoid such transfers, one could consider instead adjustment mechanisms in which the extent to which macro-longevity risk is shared with participants of other cohorts is limited. We will consider adjustment mechanisms in which young cohorts only share risk with individuals of the same cohort, while old participants not only share risk with participants of their own cohort, but also with participants of other (old) cohorts. This way, large transfers of wealth between young and old can be avoided. Specifically, the elderly can be protected from large reductions in accrued rights that could occur if they share risk with the young, and a longevity shock occurs that increases annuity values of the young significantly more more than annuity values of the old. On the other hand, the old are better off ex post with risk sharing with the young if a longevity shock occurs that increases annuity values of the old more than the young. We therefore also consider a case in which macro-longevity risk is fully borne by the active generations, so that retirees do not face adjustments of their pension payments due to longevity shocks.

In contrast to macro-longevity risk, sharing micro-longevity risk with other generations does not create systematic transfers of wealth between generations. Moreover, sharing micro-longevity risk with all participants in the fund would allow them to maximally benefit from the risk reduction that arises from pooling risk. In our analyses, we will consider both cases in which micro- and macro-longevity risk are treated in the same way, and cases in which micro-longevity risk is shared with all participants, and macro-longevity risk is shared only with participants of certain cohorts.

For each combination of adjustment rules for micro-longevity risk and for macro-longevity risk, we determine the wealth transfers between generations. We also determine the "biometric return" for a participant that survived the year. This return is defined as the relative change in the value of his/her annuity due to the combination of the realization of longevity risk and any adjustment of his/her accrued rights.

2.3 Main conclusions

Our analyses yield the following conclusions:

- The effect of longevity risk on the value of pension liabilities is non-negligible, even on a one-year horizon.

The relative importance of micro- and macro-longevity risk on a the value of the liabilities of a cohort, however, depends strongly on the age and the size of the cohort:

  - The impact of *micro-longevity risk* is increasing in age and decreasing in size of the cohort. For cohorts aged 70 or younger, the relative impact of micro-longevity risk is negligible, unless the cohort would be very small. In contrast, for older cohorts, micro-longevity risk can have a substantial impact, especially for the oldest old for whom cohort size is typically also small.
  - The impact of *macro-longevity risk* can depend strongly on age. In our analysis, best-estimate future mortality rates are determined and updated with a Lee-Carter approach. We find that longevity risk has a bigger impact on younger individuals. It becomes negligible for the oldest old.

- These differential impacts of micro- and macro-longevity risk on different cohorts suggest that the current system of adjustment of pension rights (in which accrued rights of all participants are adjusted with the same factor in response to longevity risk) can induce significant transfers of wealth between generations.

- Because micro-longevity risk is a non-systematic source of risk which mainly impacts the oldest old, we suggest that this source of risk is continued to be shared over as many participants as possible, as is currently done. In our benchmark analysis, we find that sharing micro-longevity risk over all participants reduces the potential impact on the value of the liabilities substantially for the oldest old, while having a negligible impact on the younger.

- Because macro-longevity risk is a systematic source of risk, the current adjustment mechanism can create systematic transfers of wealth between generations. In our analyses, wealth is transferred from the old to the young if mortality rates are adjusted downwards (as has occurred frequently in the past), whereas wealth is transferred from the young to the old if mortality rates are adjusted upwards (as has occurred for some ages with the introduction of the 2014 AG table).

- Adjustment mechanisms in which retirees no longer share macro-longevity risk with active participants eliminate wealth transfers between these groups. Moreover, we find that such mechanisms substantially reduce the impact of macro-longevity risk on the payments of the retirees, and increase the impact on the accrued rights of the active participants. One way of achieving such reduced risk sharing would be to (fully) mitigate the impact on active cohorts by adjusting retirement age also for their already accrued rights.

3 How longevity risk affects different cohorts

Our primary goal is to investigate wealth transfers between generations, when the accrued rights of the participants are adjusted to compensate for changes in the best-estimate value of the liabilities due to micro- and/or macro-longevity risk. The extent to which such wealth transfers will occur depends on the adjustment rule, and on how longevity risk affects each individual cohort. Suppose, for example, that a reduction in best-estimate future mortality rates affects one cohort much more than another cohort. Then, using an adjustment rule in which the accrued rights of all participants are adjusted with the same factor would induce a wealth transfer from the cohort that is least affected by the update to a cohort that is more affected by the update. The same holds true if the impact of micro-longevity risk is significantly different for different cohorts. Therefore, in this section, we first quantify the effect of micro- and macro-longevity risk on each individual cohort.

In Section 3.1, we analyze the effect of macro-longevity risk on the best-estimate value of (deferred) annuities. In Section 3.2 we analyze the change in the aggregate best-estimate value of the liabilities of a cohort due to the combined effect of micro- and macro-longevity risk. In Section 3.3, we illustrate the effects for a benchmark fund.

3.1 Effect of macro-longevity risk on the best-estimate value of (deferred) annuities

In this section, we model the impact of macro-longevity risk on the best-estimate value of (deferred) annuities.

We consider a setting in which a pension fund or insurer has valued its liabilities at the beginning of a given year t using the best-estimates of future mortality rates available at that time. At the end of year t best-estimate future mortality rates are re-estimated, leading to changes in the best-estimate value of (deferred) annuities. We consider the effect of this change at the beginning of year $t+1$. We use the following notation:

- ${}_{\tau}\widehat{p}_{x,t+1}$: the best-estimate value of the probability that a participant aged x at the beginning of year $t+1$will survive at least τ years, based on best-estimate future mortality rates determined at the beginning of year t, i.e.,

  $$ {}_{\tau}\widehat{p}_{x,t+1} = \widehat{p}_{x,t+1} \cdot \widehat{p}_{x+1,t+2} \cdot \ldots \cdot \widehat{p}_{x+\tau-1,t+\tau}, $$

  where $\widehat{p}_{y,s}$ denotes the date-t best-estimate value of the probability that a participant aged y at the beginning of year s will survive at least one more year;

- $LE(x)$ and $PV(x)$: the best-estimate life expectancy and value of a (deferred) annuity, for an x-year old at the beginning of year $t+1$, using a flat term structure of interest rates r, and best-estimates of future survival probabilities determined at the beginning of year t, i.e.,

$$LE(x) = \sum_{\tau \geq 1} {}_{\tau}\widehat{p}_{x,t+1}, \quad (1)$$

$$PV(x) = c(x) \cdot \left(\sum_{\tau \geq \max\{67-x,0\}} \frac{{}_{\tau}\widehat{p}_{x,t+1}}{(1+r)^{\tau}} \right), \quad (2)$$

where $c(x)$ denotes the annual payment of the annuity.

Now suppose that at the end of year t, a new best-estimate table is determined, for example because additional mortality data is available. When best-estimate mortality rates are updated, the best-estimate value of (deferred) annuities changes. We use the following notation:

- $\Delta LE(x)$ and $\Delta PV(x)$: change in best-estimate life expectancy and in the best-estimate (deferred) annuity value, respectively, for an x-year old at the beginning of year $t+1$, due to re-estimation of best-estimate future survival rates.

The impact of a longevity shock of course depends on the extent to which the best-estimate mortality rates change. As mentioned before, institutes such as CBS and AG regularly issue new best-estimate mortality forecasts. In Figure 1, we illustrate the impact of changes in the best-estimate mortality projections issued by the Dutch Actuarial Society (AG) in 2010, in 2012, and in 2014. The left panel shows the *annualized* percentage change in the best-estimate value of remaining cohort life expectancy and the right panel shows the *annualized* percentage change in the best-estimate value of (deferred) annuities with interest rate $r = 2\%$.[2]

The figure shows that the annualized relative changes in life expectancy and in annuity values are rather sensitive to the transition of life tables considered, without a clear systematic pattern. This occurs in part because both in 2010 and in 2014, the AG changed its projection method. Hence, the changes in these two cases reflect the combined effect of new mortality data and a change of projection method. In 2012 no (substantial) changes were made to the projection method at that time.

Because future changes in projection method are unpredictable, we will in our analysis consider model-based longevity shocks. Specifically, we assume that at the beginning of each year t, mortality forecasts are made using the Lee and Carter (1992) approach. Once year t is over, the model is re-estimated using "observed" mortality rates during the year, and new best-estimate projections for future mortality rates are determined. Uncertainty in realized mortality rates during year t then creates uncertainty in the date-$(t + 1)$ best-estimate mortality projections, which in turn induces uncertainty in the valuation of liabilities at the beginning of year $t + 1$. To illustrate the potential impact of this uncer-

[2] The 2010 revision reflected mortality changes over a period of 5 years while both the 2012 and the 2014 revisions reflected changes over a period of two years. To make the results comparable, we annualize the changes by determining the equivalent yearly percentage change.

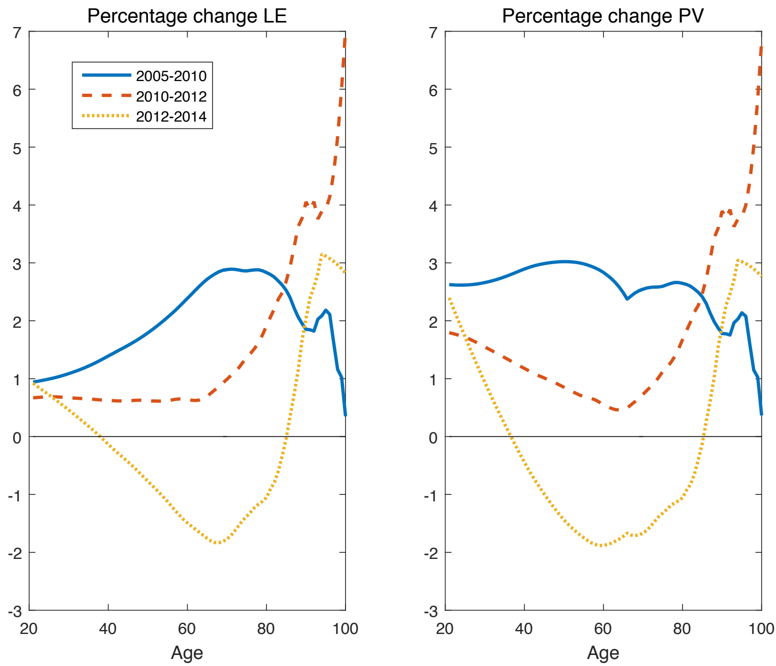

Figure 1: Annualized percentage change in the best-estimate value of cohort life expectancy (left panel) and in the best-estimate value of a (deferred) annuity with $r = 2\%$ (right panel), due to revisions of best-estimate future mortality rates by the Dutch Actuarial Society (AG) in 2010, 2012, and 2014.

tainty, we determine 95% forecast intervals of the effects of re-estimating best-estimate rates on the value of deferred annuities. The boundaries of these forecast intervals correspond to the 2.5% and the 97.5% quantiles of the drift term in the mortality improvement factor in the Lee and Carter (1992) model. We will refer to these boundaries as the "2.5% *scenario*" and the "97.5% *scenario*", respectively.

- The 2.5% *scenario* corresponds to decreases in mortality rates (as compared to previous best-estimates); the probability that a scenario occurs that results in bigger *decreases* in mortality rates is at most 2.5%.[3]

- The 97.5% *scenario* corresponds to increases in mortality rates (as compared to previous best-estimates); the probability that a scenario occurs that results in bigger *increases* in mortality rates is at most 2.5%.

The details of the approach that we use to generate updated best-estimate mortality rates are presented in the appendix.

In Figure 2, we illustrate the impact of re-estimating best-estimate future mortality rates on the best-estimate probability that a person aged $x = 25, 35, 45, 55$, or 65 will still be alive after n years (i.e., ${}_n\widehat{p}_{x,t+1}$), for $n = 0, ..., 80$. The solid curve represents the cumulative survival probability under the best-estimate mortality table as estimated at the beginning year t. The dashed curves represent the 95% forecast

[3] This statement is given the model assumptions and based on asymptotic approximations for the estimators used.

intervals for the cumulative survival probabilities under the re-estimated best-estimate mortality table at the beginning of year $t + 1$. The upperbounds of the forecast intervals correspond to mortality rates that are lower than the date-t best estimates (mortality improvements), and illustrate the well-known phenomenon of rectangularization. The lowerbounds of the forecast intervals correspond to mortality rates that are higher than the date-t best estimates. The latter occurred for certain ages under the 2014 update of AG tables.

Figure 2 shows that the confidence bands are larger for younger participants than for older participants. This means that the potential impact (positive or negative) of the longevity shock is larger for younger participants than for older participants. We illustrate this further in Figure 3.

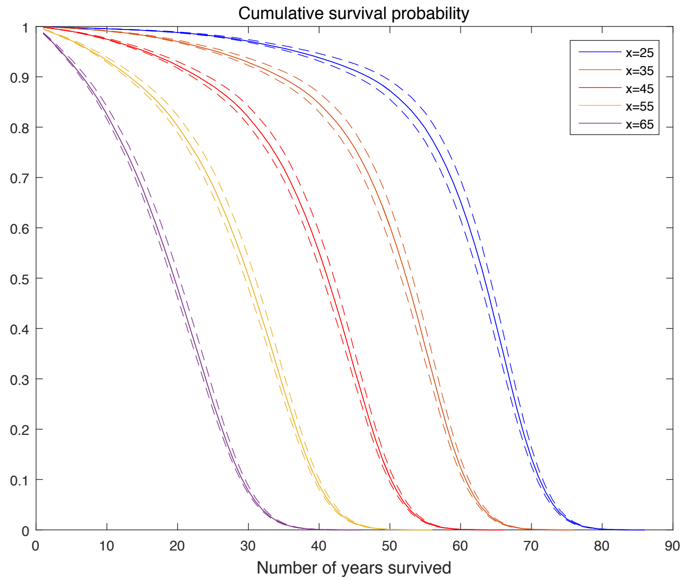

Figure 2: The 95% forecast interval for the date-$(t+1)$ best-estimate cumulative survival probabilities for individuals aged x at the beginning of year $t+1$, i.e., ${}_n\widehat{p}_{x,t+1}$, for different values of x. The solid curves display the cumulative survival probabilities under the date-t best-estimate mortality table. The dashed curves display the 95% forecast interval for the cumulative survival probabilities under the updated (date-$(t+1)$) best-estimate mortality table.

Figure 3 displays the 95% forecast interval of the percentage increase or decrease (due to the re-estimation of best-estimate future mortality rates) in the probability that an $x-$year old at the beginning of year $t+1$ is still alive at age y (i.e., it displays the percentage change in ${}_{y-x}\widehat{p}_{x,t+1}$). The left panel displays results for $y < 65$; the right panel displays

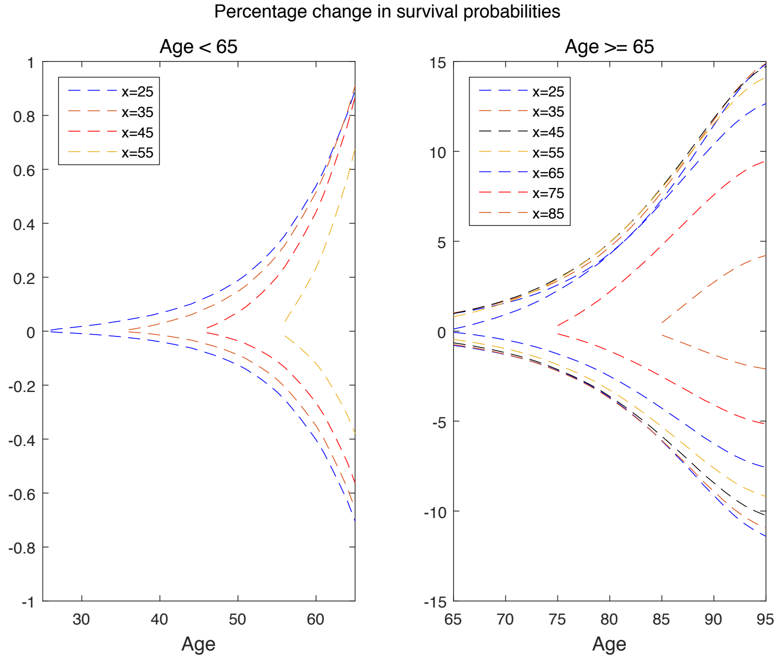

Figure 3: The 95% forecast interval for the percentage change in the date-$(t+1)$ best-estimate probability of being alive at age y, for individuals aged x at the beginning of year $t+1$. The left panel considers $y < 65$; the right panel considers $y \geq 65$.

results for $y \geq 65$. The figure shows two effects:

- **Current age (x) effects**:
  - For future ages $y \leq 65$ (left panel), the impact of longevity shocks is bigger for younger individuals (lower current ages x); both the potential relative increases (upper bounds of the forecast interval)

  and potential relative decreases (lowerbounds of the forecast interval) are bigger in magnitude.
- For future ages $y > 65$ (right panel), the impact of longevity shocks is not always bigger for younger individuals.

This occurs because there are two countervailing effects. First, the impact of a longevity shock is bigger for mortality rates in later years. Because younger individuals (lower x) reach a given age y at a later time than older individuals, the probability of being alive at age y increases (decreases) more due to the longevity shock for younger persons. On the other hand, the date-t best-estimate survival rates ${}_{y-x}\widehat{p}_{x,t+1}$ of younger individuals are already higher, so with a change of the same magnitude (say $+/-0.01$), the relative effect is smaller for a younger individual. The figure shows that the first effect dominates for ages up to $y = 65$, while the second effect can dominate for $y > 65$.

- **Future age (y) effects**: For any given current age x, the impact of the longevity shock on the probability of reaching age y (${}_{y-x}\widehat{p}_{x,t+1}$) is monotonically increasing in y. For example, the left panel shows that the forecast intervals for the probability of reaching future ages $y \leq 65$ are smaller than $[-1\%, 1\%]$ for all values of the current age x. In contrast, the forecast intervals for the probability of reaching future ages $y \geq 66$ can be as large as $[-13\%, +15\%]$. This occurs because the survival rates at younger ages are already high, which gives less room for improvement.

We now discuss the effect of longevity shocks on best-estimate cohort life expectancy and best-estimate (deferred) annuity values, as a function of the current age x. First, note that the relative effect of a longevity shock on cohort life expectancy can be seen as a weighted average of the relative effects of the shock on the multi-period survival probabilities ${}_{y-x}p_{x,t+1}$ for $y = x, x+1, ...$. Therefore, the above described **future age effect** suggests that the relative impact of a longevity shock on cohort life expectancy will be increasing in age for ages $x \leq 66$, because for younger individuals, relatively high weight is put on survival to future ages younger than 65, for which the relative impact of the longevity shock is small. For higher ages x, the **current age effect** suggests that the impact of the longevity shock will decrease as age x increases. Moreover, because the best-estimate value of a deferred annuity depends only on ${}_{y-x}\widehat{p}_{x,t+1}$ for $y \geq 67$, the **current age effect** suggests that the impact of the longevity shock will decrease as current age x increases. This intuition is confirmed in Figure 4. It displays the 95% forecast interval of the relative changes in the best-estimate value of the remaining cohort life expectancy ($\frac{\Delta LE(x)}{LE(x)}$, solid lines) and the best-estimate value of a (deferred) annuity ($\frac{\Delta PV(x)}{PV(x)}$, dashed lines) due to the longevity shock, as a function of the age x of the participant at the time the longevity shock occurs.

We consider four values for the discount rate r used to determine the best-estimate value of the (deferred) annuities. Table 1 complements Figure 4. In this table we display the 95% forecast intervals for selected ages x, and $r = 2\%$.

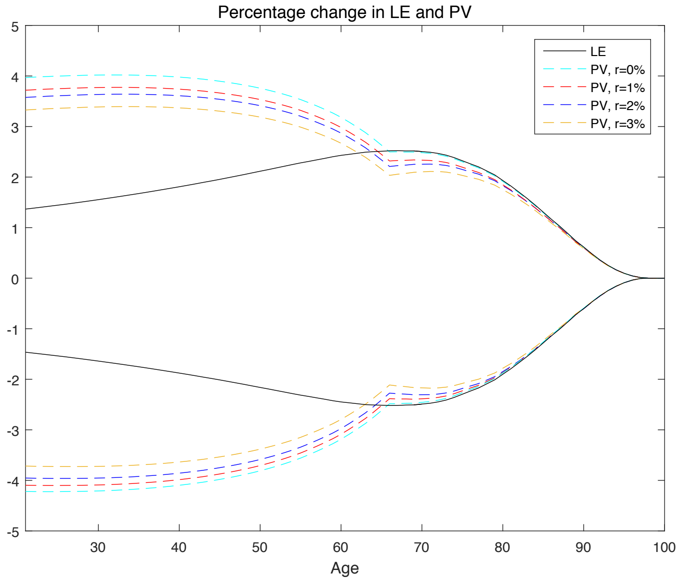

Figure 4: The 95% forecast interval for the percentage change in cohort life expectancy (solid lines) and for the percentage change in the best-estimate value of a deferred annuity annuity (dashed lines), as a function of current age x. For the annuity value, we display results for discount rates $r = 0\%, 1\%, 2\%$ and 3%.

The results in Figure 4 show that the effects of longevity shocks on the best-estimate value of a (deferred) annuity can be much larger (in absolute value) for younger participants than for older participants. Whereas the 95% forecast interval for a 85-year old is approximately $[-1\%, +1\%]$, it

	$\Delta LE(x)/LE(x)$		$\Delta PV(x)/PV(x)$	
Age	2.5%	97.5%	2.5%	97.5%
25	-1.56	1.46	-3.86	3.61
35	-1.78	1.70	-3.81	3.63
45	-2.04	1.99	-3.63	3.52
55	-2.34	2.31	-3.20	3.14
65	-2.52	2.52	-2.22	2.21
75	-2.23	2.26	-2.08	2.10
85	-1.14	1.17	-1.11	1.13
95	-0.04	0.04	-0.04	0.04

Table 1: The 2.5% quantile and the 97.5% quantile of the percentage change in date-($t+1$) best-estimate cohort life expectancy and the percentage change in the date-($t+1$) best-estimate best-estimate (deferred) annuity value with $r = 2\%$, for individuals aged x at the beginning of year $t+1$.

is approximately $[-3.8\%, +3.6\%]$ for a 25-year old. These differences suggest that using the same adjustment factor for all participants to compensate for the aggregate increase in the value of their liabilities, as is currently done, can lead to significant wealth transfers between generations cohorts. However, as mentioned before, the size of the wealth transfers depends on the aggregate effect on all participants in a cohort, taking into account that not all participants survive. Therefore, in the next section, we look at the combined effect of uncertainty in survival and uncertainty in best-estimate future mortality rates, on the aggregate value of the liabilities of all participants belonging to the same cohort.

3.2 Change in best-estimate value of the liabilities of a cohort

In this section, we show how the best-estimate value of the aggregate liabilities of all participants in a cohort changes due to the combined effect of micro-longevity risk (one-year survival uncertainty) and macro-longevity risk (the updating of mortality rates). Micro- and macro-longevity risk affect the aggregate value of the liabilities of a cohort in two ways. First, micro-longevity risk implies that the fraction of participants in the cohort that will still be alive at the end of the year (after the realization of mortality in that year) differs from the ex-ante best-estimate survival probability, even if this best estimate equals the "true" survival probability. Second, macro-longevity risk implies that the value of the liabilities of the surviving participants can change due to an update in the best-estimate future mortality rates.

Over the course of one year, the value of a pension annuity changes not only due to longevity risk, but also due to other factors such as changes in the duration of the annuity payments or changes in the term structure of interest rates used to discount future payments. Because our focus is on the effect of longevity risk on the value of the liabilities, we assume annuities are valued using a deterministic and flat term structure of interest rates. We also assume that longevity risk realizes at the end of the year. Specifically, to quantify longevity risk over a given year t, we make the following timing assumptions:

- End of year $t-1$:
  - for each participant, it becomes known whether he survived year $t-1$, so fund composition at the start of year t is known;
  - the Lee-Carter model is estimated and the corresponding best-estimate future survival probabilities are determined for years $t, t+1, t+2, \ldots$.
- Beginning of year t: the annuity pays off to each retiree.
- End of year t:
  - for each participant, it becomes known whether he survived year t;
  - data regarding the survival/rates for year t in the whole Dutch population becomes available;
  - the Lee-Carter model is re-estimated using an additional year of data, and the new corresponding best-estimate future survival probabilities are determined for years $t+1, t+2, \ldots$

We consider the change in the value of pension liabilities from just before to just after the realization of longevity risk at the end of year t. Then, the best-estimate value of the liabilities of a cohort changes (only) due to the combined effect of: uncertainty being resolved regarding who survived and who dies during the year; and, (ii) changes in the value of the liabilities for those who survived, due to the update in best-estimate future survival probabilities.

We use the following notation:

- $V(x)$: the best-estimate value of the liabilities just prior to the realization of longevity risk at the end of year t (i.e., just before it is known whether the participant survives, and just before best-estimate mortality rates are updated), i.e.,

$$V(x) = \widehat{p}_{x,t} \cdot PV(x+1), \tag{3}$$

- n_x: the number of participants in the pension fund aged x at the beginning of the year;
- $\widetilde{N}_x$: the number of participants in the pension fund aged x at the beginning of the year who are still alive at the end of the year ($\widetilde{N}_x \leq n_x$);
- $V_{cohort}(x)$: the aggregate best-estimate value, at the end of year t just prior to the realization of longevity risk, of the liabilities of all individuals belonging to the cohort aged x at the beginning of year t, i.e.,

$$V_{cohort}(x) = n_x \cdot V(x) = n_x \cdot \widehat{p}_{x,t} \cdot PV(x+1).$$

- $\Delta V_{cohort}(x)$: the change in the aggregate best-estimate value of the liabilities of all participants belonging to cohort x at the end of year t, due to the combined effect of micro- and macro-longevity risk.

We start by discussing the change in value of the liabilities for an individual participant. This change depends on whether the participant survives or deceases. Clearly, for a participant that deceases, the best-estimate value reduces to zero. For a participant that survives, the best-estimate value $V(x)$ from (3) changes due to two effects. First, the fact that the participant survived implies that, even when best-estimate projections of future mortality rates do not change, the best-estimate value of the annuity for this participant increases. This occurs because before it is known whether the participant survives or not, the best-estimate value takes into account the probability that the participant will decease, which would imply that the value drops to zero. Once it is known that a participant survives, the zero value of decease does not apply anymore, which increases the value of the liability increases from $\widehat{p}_{x,t} \cdot PV(x+1)$ to $PV(x+1)$. In addition, if an unanticipated update in best-estimate future mortality occurs, the value of the annuity of the participant changes further to $PV(x+1) + \Delta PV(x+1)$, where $\Delta PV(x+1)$ is the increase in the value of the annuity.

Hence, the change in the value for an individual participant is given by:

$$\begin{aligned} \Delta V_{survive}(x) &= PV(x+1) + \Delta PV(x+1) - \widehat{p}_{x,t} \cdot PV(x+1), \\ \Delta V_{decease}(x) &= -V(x). \end{aligned} \tag{4}$$

We now use these results to determine the aggregate change in the best-estimate value of the liabilities changes due to the combined effect of micro- and macro-longevity risk. As mentioned above, micro-longevity risk implies that the fraction of participants in the cohort that will still be alive at the end of the year differs from the ex-ante estimated survival fraction.

Because $\widetilde{N}_x$ participants in cohort x survived, and, hence, $n_x - \widetilde{N}_x$ participants deceased, it follows from (4), that the change in the aggregate value of the liabilities of all participants belonging to cohort x is given by:

$$\Delta V_{cohort}(x) = \widetilde{N}_x \cdot \Delta V_{survive}(x) + (n_x - \widetilde{N}_x) \cdot \Delta V_{decease}(x) \quad (5)$$

$$= \left(\widetilde{N}_x - n_x \cdot \widehat{p}_{x,t}\right) \cdot PV(x+1) + \widetilde{N}_x \cdot \Delta PV(x+1). \quad (6)$$

The decomposition in (6) shows that aggregate change in the best-estimate value of the liabilities of the cohort can be decomposed in two effects:

- the number of participants that survives the year can deviate from the expected number of survivors determined at the beginning of the year, i.e., $\widetilde{N}_x$ can deviate from $n_x \times \widehat{p}_{x,t}$;
- best-estimate survival rates at the beginning of the next year can deviate from best-estimate survival rates at the beginning of the current year due to updating; this implies that for those who survived, the present value of payments in the next year and beyond increases by $\Delta PV(x+1)$.

The required adjustments to accrued rights to compensate for these changes in best-estimate values, and the extent to which these adjustment would lead to transfers of wealth between cohorts, however, depends on the *relative* change in the best-estimate value rather than the absolute change. The relative change in the best-estimate value of the liabilities of the cohort aged x is given by

$$\frac{\Delta V_{cohort}(x)}{V_{cohort}(x)} = \left(\frac{\widetilde{N}_x}{n_x \times \widehat{p}_{x,t}}\right) \times \left(1 + \frac{\Delta PV(x+1)}{PV(x+1)}\right) - 1.$$

To understand the relative impact of micro-longevity risk, we consider the standard deviation of the relative change in the value of the annuity, given the effect of the update in mortality rates on the value of the annuity. Specifically, we let the "true" one-year survival probability of the cohort aged x, which we denote $p_{x,t}$, as well as the effect of the update in best-estimate mortality rates on the annuity values, i.e, $\Delta PV(x+1)$ be given, and we determine the standard deviation of the relative change in the best-estimate value of the liabilities for the cohort, due to micro-longevity risk. Because the actual number of participants from cohort x that will survive follows a binomial distribution $\widetilde{N}_x \sim Binom(n_x, p_{x,t})$, this standard deviation is given by:

$$\begin{aligned} \sigma\left(\frac{\Delta V_{cohort}(x)}{V_{cohort}(x)}\right) &= \left(1 + \frac{\Delta PV(x+1)}{PV(x+1)}\right) \times \sigma\left(\frac{\widetilde{N}_x}{n_x \times \widehat{p}_{x,t}}\right) \\ &= \frac{p_{x,t}}{\widehat{p}_{x,t}} \times \left(1 + \frac{\Delta PV(x+1)}{PV(x+1)}\right) \times \sqrt{\frac{1}{n_x}}\sqrt{\frac{1-p_{x,t}}{p_{x,t}}}. \end{aligned}$$

When $\frac{p_{x,t}}{\widehat{p}_{x,t}}$ is kept fixed, the relative standard deviation is

- decreasing in the true survival probability $p_{x,t}$, and in the size of the cohort, n_x;
- increasing in the relative impact of the mortality update on the annuity value, $\frac{\Delta PV(x+1)}{PV(x+1)}$.

Hence, for a given shock to mortality rates, the degree of uncertainty in mortality losses/gains relative to the best-estimate value will be large for cohorts with a low one-year survival rate $p_{x,t}$, and for cohorts with a low number of participants, i.e., a small value of n_x.

3.3 Results for the benchmark fund

In this section, we illustrate the effects of micro- and macro-longevity risk on differtent cohorts for a benchmark pension fund. The setting is as follows:

- Accrued rights:
  - participants hold an old-age pension annuity; starting at retirement age, the pension annuity pays off at the beginning of every year in which the participant is alive;
  - retirement age is 67;
  - each participant entered the fund at age 20, and accrued 2% of the average wage annually until retirement age. The wage is normalized to 1.

Hence, accrued rights at the beginning of the year are given by:

$$c(x) = 0.02 \cdot (\min\{x, 67\} - 20);$$

- Fund composition:
  - all participants are male;
  - the age composition of the fund is based on the age composition of all pension fund members in the Netherlands.
  - because the degree of uncertainty in the adjustment factor and the returns depends on the size of the fund, we consider funds with the same composition, but with different fund sizes.

In Figure 5, we display some fund characteristics: age composition and aggregate insured rights per cohort and aggregate best-estimate value of liabilities per cohort, both expressed as percentage of the aggregate fund values. The figure shows that both relatively young cohorts and relatively old cohorts represent relatively low fractions of the aggregate best-estimate value of liabilities, whereas cohorts aged between, say, age 55 and age 80 represent higher fractions of the aggregate best-estimate value of liabilities.

The right panel of Figure 6 shows the 95% forecast interval of the change in the aggregate best-estimate value of the liabilities, $\Delta V_{cohort}(x)$, due to macro-longevity risk only

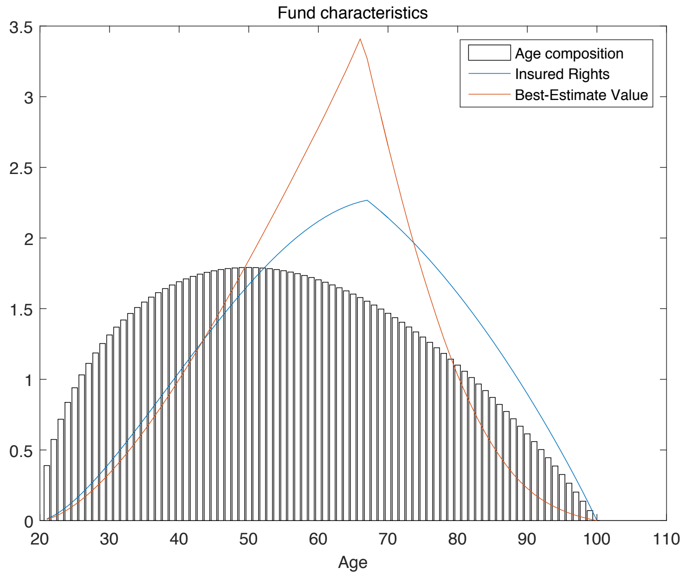

Figure 5: Characteristics of the benchmark fund: fraction of participants as a function of age (histogram), insured rights (blue solid line) and best-estimate value of liabilities (red solid line), both expressed as percentages of the aggregate fund values, displayed as a function of age.

(the “upper” and “lower” solid lines). The upper bound of the forecast interval corresponds to the 2.5% scenario in which mortality rates decrease; the lower bound corresponds to the 97.5% scenario in which mortality rates increase. The dashed lines display 95% forecast interval when micro-longevity risk is included for a fund with 1,000,000 participants. In order to show the relative impact of macro- and micro-longevity risk for different cohorts, we also display the 95% forecast interval when there is only micro-longevity risk i.e., best-estimate future mortality rates are unadjusted. Since the wage is normalized to one, the figure shows the effects in terms of wage-units. The left panel shows the corresponding level (in wage-units) of the best-estimate value of the liabilities.

When macro-longevity risk is ignored (the “middle” curves in the right panel of Figure 6), the expected change in the best-estimate value of the liabilities (the solid line), is zero for each cohort. This occurs because as long as the number of participants that survives, $\widetilde{N}_x$, is equal to the expected number of survivors determined at the beginning of the year, $n_x \times p_{x,t}$, the increase in value of the liabilities for surviving participants will be fully compensated by the decreases in the best-estimate value of the liabilities for those participants that died. Indeed, when $\Delta PV(x+1) = 0$, $\widehat{p}_{x,t} = p_{x,t}$, and $\widetilde{N}_x = n_x \times p_{x,t}$, it holds that $\Delta V_{cohort}(x) = 0$. However, the actual number of participants that survives $\widetilde{N}_x$ can deviate from the ex-ante estimated number $n_x \times p_{x,t}$, which implies that the actual change in the aggregate best-estimate value due to micro-longevity risk can be positive (if more participants survive than anticipated), or negative (if fewer participants survive than anticipated). The dashed lines in the right panel of Figure 6 show the 95% confidence interval of the change in the best-estimate value due to micro-longevity risk (for the fund with 1,000,000 participants). If, in addition, best-estimate future mortality rates change at the end of the year due to updating of best-estimate future mortality rates (a longevity shock), there is an additional change in the value of the liabilities for surviving participants due to the change in the value of their (deferred) annuities (i.e., $\Delta PV(x+1) \neq 0$). The "upper" and "lower" curved lines in the right panel of Figure 6) represent the 95% forecast intervals with micro- and macro-longevity risk (dashed lines) and with only macro-longevity risk (solid lines).

Ceteris paribus, the impact of micro-longevity risk is higher when the ex-ante best estimate value of the liabilities is higher (see the "middle" curves in the right panel of Figure 6). However, the right panel of Figure 6 also shows that for younger cohorts, the impact of micro-longevity risk is small relative to the impact of macro-longevity risk, while the opposite holds for older cohorts. In Table 2 and Figure 7, we display the 95% forecast interval for the change in the best-estimate value of the liabilities of each cohort, expressed as percentage of the best-estimate value before the realization of longevity risk. We display results both with and without micro-longevity risk. The table and figure show that the relative impact of micro-longevity risk is much larger for the older cohorts than for the younger cohorts. This occurs because older cohorts have a lower "true" survival probability $p_{x,t}$. Moreover, for the oldest old, the effect is attenuated because their cohort size n_x is also lower. Both a smaller cohort and a lower survival probability imply that there is a bigger impact of micro-longevity risk.

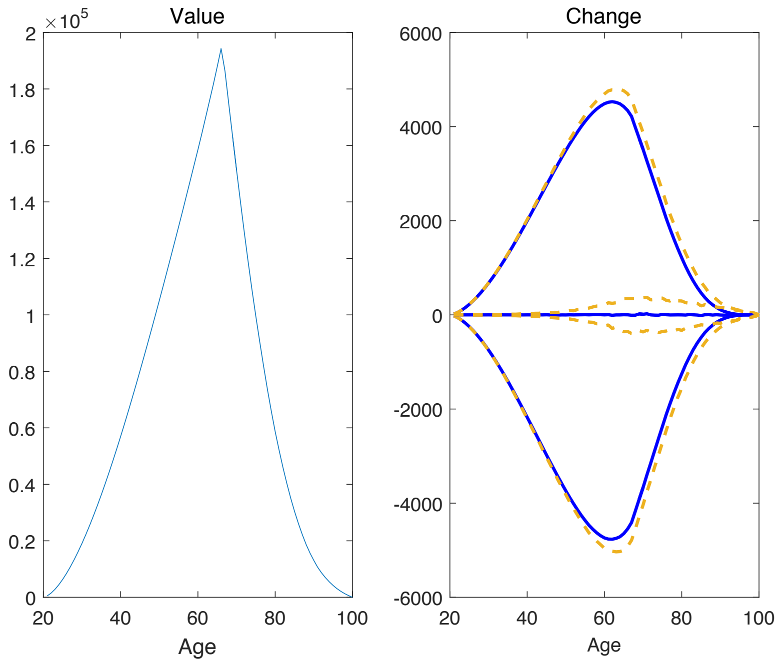

Figure 6: The left panel shows the level of the best-estimate value (in wage-units) of the liabilities for the benchmark fund composition with fund size 1,000,000. The right panel shows the 95% forecast interval for the change in the aggregate best-estimate value 9in wage-units) of the liabilities of a cohort due to macro-longevity risk only (upper and lower solid curved lines); due to micro-longevity risk only (middle dashed curved lines), and due to the combined effect of macro- and micro-longevity risk (upper and lower dashed curved lines), for the benchmark fund. The results are based on 5000 simulations.

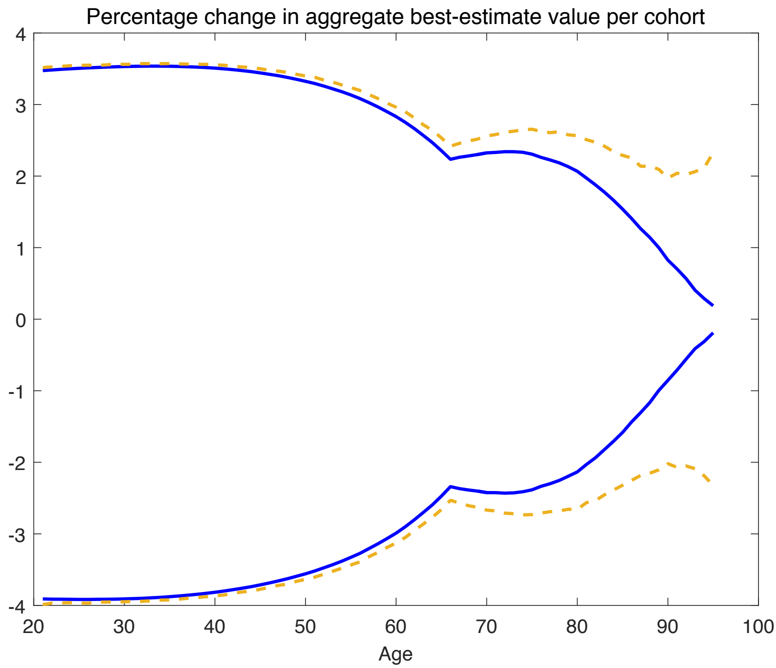

Figure 7: The 95% forecast interval for the percentage change in the aggregate best-estimate value of the liabilities of a cohort due to macro-longevity risk only (solid lines) and due to the combined effect of macro- and micro-longevity risk (dashed lines), for the benchmark fund composition with fund size 1,000,000. The results are based on 5000 simulations.

	Only macro		Macro and micro	
Age	2.5%	97.5%	2.5%	97.5%
25	-3.92	3.51	-3.97	3.55
35	-3.88	3.54	-3.92	3.57
45	-3.71	3.44	-3.77	3.50
55	-3.33	3.13	-3.44	3.24
65	-2.47	2.36	-2.66	2.53
75	-2.38	2.31	-2.73	2.66
85	-1.58	1.54	-2.32	2.29
95	-0.19	0.19	-2.32	2.33

Table 2: The 2.5% and the 97.5% quantiles of the percentage change in the aggregate best-estimate value of the liabilities of a cohort due to macro-longevity risk only and due to the combined effect of macro- and micro-longevity risk, for selected ages.

4 Adjustments of pension rights

We consider a setting in which any change in the aggregate best-estimate value of the liabilities of all participants, caused by micro- and/or macro-longevity risk is compensated immediately via adjustments of the accrued rights. The adjustments of the accrued rights are such that, after adjustment, the aggregate best-estimate value of the liabilities is the same before and after the realization of micro- and macro-longevity risk. This implies that if either more participants survived than expected, or best-estimate future mortality rates are adjusted downwards, the accrued rights of participants are adjusted downwards. We will consider adjustments of accrued rights consisting of two adjustment factors: an adjustment factor aimed at neutralizing changes in the best-estimate value of the aggregate liabilities due to micro-longevity risk, and an adjustment factor aimed at neutralizing changes in the aggregate best-estimate value due to changes in best-estimate future mortality rates used to valuate the liabilities of those participants that survive.
We use the following notation:

- $\gamma_{micro}(x)$: the percentage with which rights of cohort x are increased (decreased if negative) due to micro-longevity risk.
- $\gamma_{macro}(x)$: the percentage with which rights of cohort x are increased (decreased if negative) due to macro-longevity risk.

Combined, the two adjustment factors should be such that the aggregate best-estimate value of the liabilities at fund level after the realization of micro- and macro-longevity risk is the same as the best-estimate value of the liabilities at fund level before the realization of micro- and macro-longevity risk. Formally, this implies that the adjustment factors $\gamma_{micro}(x)$ and $\gamma_{macro}(x)$ for all x need to satisfy the following condition:

$$\sum_x [1+\gamma_{micro}(x)] \cdot [1+\gamma_{macro}(x)] \cdot [V_{cohort}(x) + \Delta V_{cohort}(x)] \\ = \sum_x V_{cohort}(x). \tag{7}$$

The right-hand side of the equation represents the best-estimate value of liabilities at fund level based on mortality projections determined at the beginning of the year. The left-hand side of the equation represents the best-estimate value of the liabilities, after adjustment, and based on best-estimate mortality projections at the beginning of the next year.

There are, of course, infinitely many ways in which this can be achieved. Because micro-longevity risk a non-systematic source of risk that becomes smaller when portfolio size is larger, we consider adjustment mechanisms in which micro-longevity risk is pooled and shared by all participants in the pension fund. Even with relatively small pension funds, the pooling would imply that the required adjustment factor for micro-longevity risk would be relatively small. In contrast, if one would for example consider adjustment mechanisms in which micro-longevity risk is only shared with participants of the same generation, then the required adjustment factor could be very volatile, especially for older generations and for generations with relatively few participants. Therefore, we consider the case where micro-longevity risk is shared with all participants.

The situation for macro-longevity risk is substantially different, which justifies considering adjustment rules in which the adjustment factor can depend on the cohort. The reason is that macro-longevity risk is a systematic source of risk that might have a different impact on different generations. For example, the results in the previous section suggest that the effect of an update in best-estimate future mortality rates on the best-estimate value of the liabilities varies from $+/-3.5\%$ to almost no effect, depending on age. Therefore, we consider a variety of adjustment mechanisms for macro-longevity risk. These mechanisms differ in the extent to which risk is shared with participants of other cohorts.

In the remainder of this section, we first determine the required adjustment factors for macro-longevity risk, assuming that there is no micro-longevity risk, i.e., the actual number of surviving participants of each cohort equals the ex-ante anticipated fraction. We then determine the additional adjustment factor that is required to neutralize the effect of deviations in the number of survivors from the anticipated fraction.

4.1 Required adjustment factors for macro-longevity risk

We consider the case in which the adjustment factors $\gamma_{macro}(x)$ are such that they fully neutralize the effect of changes in best-estimate future mortality rates, if there is no micro-longevity risk, i.e., the actual fraction of participants that survive equals the realized survival fraction in the population.
We use the following notation:

- $\Delta V_{cohort|nomicro}(x)$: the change in the aggregate value of the liabilities of all participants belonging to cohort x due to the shock in best-estimate future mortality rates, in the absence of micro-longevity risk, i.e.,

$$\Delta V_{cohort|nomicro}(x) = (n_x \cdot p_{x,t} - n_x \cdot \widehat{p}_{x,t}) \cdot PV(x+1) + n_x \cdot p_{x,t} \cdot \Delta PV(x+1). \tag{8}$$

Then, the required adjustment factors to neutralize the effect of macro-longevity risk should satisfy the following condition:

$$\sum_x [1 + \gamma_{macro}(x)] \cdot \left[V_{cohort}(x) + \Delta V_{cohort|nomicro}(x)\right] = \sum_x V_{cohort}(x). \tag{9}$$

Equality (9) ensures that the aggregate best-estimate value of the liabilities is the same as before the longevity shock.

There are many ways in which (9) can be achieved. As a benchmark case, we consider the adjustment rule in which participants only share risk with participants of the same cohort. We refer to this rule as the "*Within Cohorts*" rule (WC). Then, the required adjustment factor for cohort x needs to be such that the aggregate value of the liabilities of all individuals in cohort x is the same before and after the realization of longevity risk. In this case, the adjustment factor for cohort x, which we denote $\gamma_{macro,wc}(x)$, needs to satisfy

$$[1+\gamma_{macro,wc}(x)]\cdot\left[V_{cohort}(x)+\Delta V_{cohort|nomicro}(x)\right]=V_{cohort}(x),$$

which implies that for all x, the required adjustment factor is given by:

$$\begin{aligned}\gamma_{macro,wc}(x) &= \frac{V_{cohort}(x)}{V_{cohort}(x)+\Delta V_{cohort|nomicro}(x)}-1\\ &= \frac{1}{1+\frac{\Delta V_{cohort|nomicro}(x)}{V_{cohort}(x)}}-1. \qquad (10)\end{aligned}$$

We also consider adjustment rules in which young cohorts only share risk with individuals of the same cohort, while older cohorts share risk with each other. Specifically, we consider a *cutoff age* x_0, and determine the required adjustment of accrued rights in case cohorts younger than age x_0 only share longevity risk with participants belonging to their own cohort and cohorts aged x_0 or older share longevity risk with each other. This implies that:

- for cohorts aged x_0 or older, the reduction or increase in pension rights for each participant aged x_0 or older is such that after adjustment, the aggregate best-estimate value of the liabilities of all participants aged x_0 or older is the same before and after the realization of longevity risk.

- for cohorts younger than age x_0, the reduction or increase in accrued rights of a participant belonging to cohort x is determined such that the aggregate best-estimate value of liabilities of all participants aged x is the same before and after the realization of longevity risk.

Then, for cohorts aged $x < x_0$, risk is only shared with participants of the same cohort, and so the adjustment factor equals $\gamma_{macro,wc}(x)$. For cohorts aged $x \geq x_0$, the required adjustment factor needs to be such that the aggregate value of the liabilities of all individuals in cohort x_0 and older is the same before and after the realization of longevity risk. This implies that:

$$\begin{aligned} \gamma_{macro,x_0+}(x) &= \gamma_{macro,wc}(x), & \text{for } x < x_0, \\ &= -\frac{\sum_{y \geq x_0} \Delta V_{cohort|nomicro}(y)}{\sum_{y \geq x_0} \left[V_{cohort}(y) + \Delta V_{cohort|nomicro}(y) \right]}, & \text{for } x \geq x_0. \end{aligned} \quad (11)$$

With such adjustment rules, each individual participant aged x_0 or older receives the same reduction or increase in pension rights. The reduction or increase in accrued rights cohorts younger than age x_0 depends on the age of the participant. A special case that we will consider is the case where x_0 equals the minimum age in the fund, which means that risk is shared with all participants in the fund. This rule reflects the way in which accrued rights are adjusted for changes in mortality rates in the new FTK. We refer to this rule as the *Full Risk Sharing Rule* (FRS). The corresponding adjustment factor is given by

$$\gamma_{macro,FRS}(x) = -\frac{\sum_{y \geq x_{\min}} \Delta V_{cohort|nomicro}(y)}{\sum_{y \geq x_{\min}} \left[V_{cohort}(y) + \Delta V_{cohort|nomicro}(y) \right]}, \quad \text{for all } x. \tag{12}$$

In the remainder of the paper, we consider the following four sharing rules:

- the *Full Risk Sharing* (FRS) *Rule* ($x_0 = x_{\min}$): risk is shared with all participants in the fund;
- the $67+$ *Rule* ($x_0 = 67$): for participants younger than age 67, risk is only shared with participants of the same cohort; for participants aged 67 or higher, risk is shared with all participants aged 67 or higher;
- the *Within Cohort Rule*: risk is only shared with participants of the same cohort; this implies that the required adjustment factor for a given participant depends only on the change in the best-estimate value of annuities of the participants belonging to the same cohort;
- the *Only Actives Rule*: the accrued rights of retired participants are not adjusted; longevity risk is fully borne by the active participants. The adjustment factor

for an active participant equals the adjustment factor needed to neutralize the impact of the longevity shock on the value of the liabilities of that cohort (i.e., $\gamma_{macro,wc}(x)$), plus an additional adjustment factor (which is the same for all active participants) to compensate for the change in value of the liabilities of retired participants.

Figure 8 displays the 95% forecast interval for the required adjustment factors for the four adjustment rules, as a function of age. The left panel shows that, as compared to a setting in which each cohort would bear its own risk (the *Within Cohort rule*, solid blue lines), the current nFTK (the *FRS rule*, red dashed lines) *increases* the risk for individuals of age $x > 60$ (wider 95% forecast intervals) and *decreases* the risk for participants aged $x \leq 60$. Hence, under the current system, risk is shifted from those aged below 60 to those aged above 60. Especially for the oldest old, risk would be significantly smaller if they would not share risk with other cohorts. This occurs because (as shown in Figure 7) , the impact of macro-longevity risk is bigger for younger individuals. When the $67+$ *rule* is used (left panel, orange dashed lines), risk transfers between actives and retirees are excluded. However, the degree of risk imposed on the oldest retirees is still significantly larger than when they would not share risk with younger retirees. In the right panel, we consider a case in which all risk is borne by the active participants (the *Only Actives* rule; black dashed lines). As compared to the case where all cohorts bear their own risk

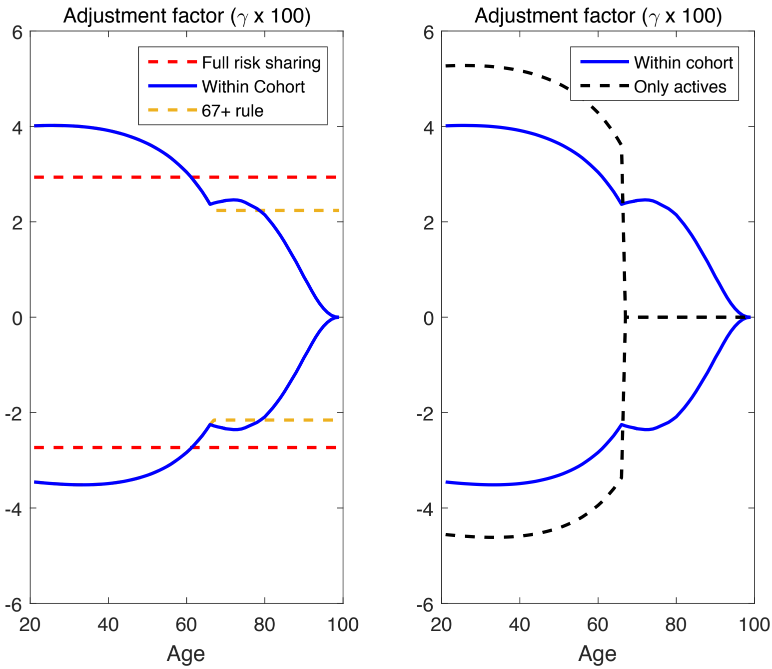

Figure 8: The 95% forecast interval for the factor γ_{macro} by which accrued rights of cohort x need to be adjusted to compensate for the effect of macro-longevity risk, for different adjustment rules and for the benchmark fund composition.

(the blue solid lines); shifting risk of the retirees to the actives fully eliminates the uncertainty for the retirees, and increases the forecast interval for active participants by approximately $+/-1\%$.

4.2 Additional adjustment factor for micro-longevity risk

The adjustment factors in (10), (11), and (12) neutralize the effect of macro-longevity risk on the aggregate best-estimate value of the liabilities, if the actual number of survivors $\widetilde{N}_x$ equals the population average $n_x \cdot p_{x,t}$. Due to micro-longevity risk, however, the actual number of survivors $\widetilde{N}_x$ would typically deviate from the population average. To neutralize the effect of micro-longevity risk, we assume that an additional adjustment to accrued rights is used.

As was the case for the adjustment factor for macro-longevity risk, there are infinitely many ways in which the pension fund could adjust rights to mitigate the effects of micro-longevity risk. One option would be to use the same degree of risk sharing as is used for macro-longevity risk. This would imply, for example, that when the within cohort sharing rule is used, also micro-longevity risk is shared only with participants of the same cohort. This, however, can lead to very high or very low adjustment factors for cohorts with relatively few participants. Specifically, it can be shown that when the within cohort rule is used both for macro-longevity risk and for micro-longevity risk, the required adjustment factor for micro-longevity risk would be given by:

$$\gamma_{micro,wc}(x) = \frac{V_{cohort}(x) + \Delta V_{cohort|nomicro}(x)}{V_{cohort}(x) + \Delta V_{cohort}(x)} - 1 = \frac{n_x \cdot p_{x,t}}{\widetilde{N}_x} - 1.$$

It is easily verified that the relative standard deviation of $1/\gamma_{micro}(x)$ equals $\sqrt{\frac{1}{n_x}} \cdot \sqrt{\frac{1-p_{x,t}}{p_{x,t}}}$. This shows that the standard deviation is high when n_x is small, and/or when $p_{x,t}$ is small. This implies that sharing micro-longevity risk only with participants of the same cohort can lead to large adjustments to accrued rights for older cohorts, because they have lower survival rates, and are typically also smaller. We illustrate this in Figure 9. The figure displays the effect of age and size of cohort on the required additional adjustment factor for micro-longevity risk if both micro-longevity risk and macro-longevity risk are shared only with participants of the same cohort. The figure shows that the adjustment factors can be very large, especially for the oldest old.

To avoid large adjustments due to micro-longevity risk, one could instead consider a mechanism in which, regardless of which sharing rule is used for macro-longevity risk, the additional impact of micro-longevity risk is shared by all participants in the fund. In that case, the adjustment factor is the same for each cohort, and follows from (7). The required adjustment factor γ_{micro} is then given by:

$$(1+\gamma_{micro}) = \left(\frac{\sum_y n_y \cdot p_y \cdot [1 + \gamma_{macro}(y)] \cdot [PV(y+1) + \Delta PV(y+1)]}{\sum_y \widetilde{N}_y \cdot [1 + \gamma_{macro}(y)] \cdot [PV(y+1) + \Delta PV(y+1)]} \right).$$

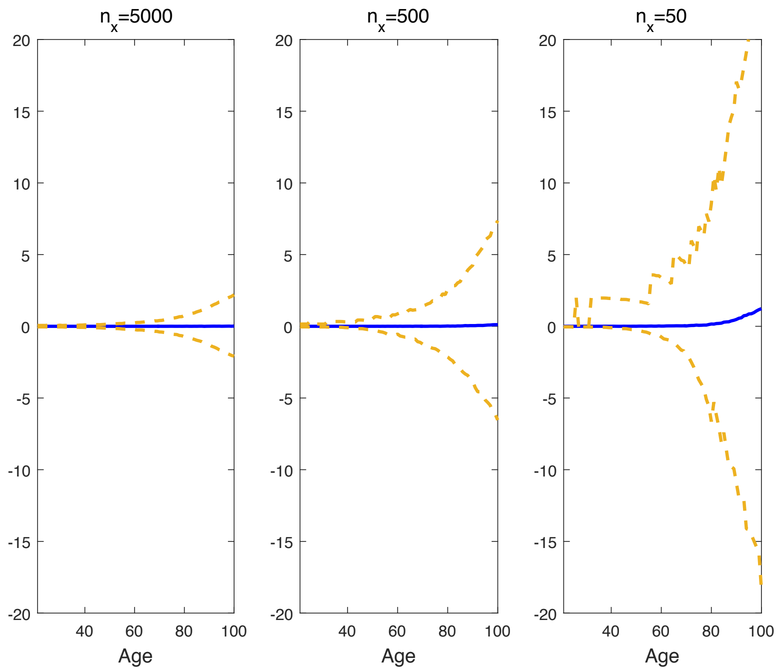

Figure 9: The 95% forecast interval for the required additional adjustment factor for micro-longevity risk if both micro-longevity risk and macro-longevity risk are shared only with participants of the same cohort (($\gamma_{micro,wc}(x)$), the *Within Cohort rule*), as a function of age, for different cohort sizes: 5000, 500, and 50 participants. The results are based on 5000 simulations.

Even for relatively small funds, this leads to adjustment factors that are very small. For the benchmark fund composition, the 95% forecast interval for γ_{micro} is smaller than $[-0.11\%, +0.11\%]$ for all adjustment rules if the fund has 100,000 participants, and is smaller than $[-0.03\%, +0.03\%]$ if it has 1,000,000 participants.

5 Wealth transfers

5.1 Wealth transfers between cohorts

The results from the previous section show that the required adjustment factors for longevity risk can depend strongly on age. Roughly speaking, if each cohort was treated separately (i.e., if the *Within Cohort rule* were used), the required adjustment factor to compensate for the update in mortality rates would be more negative for young cohorts than for old cohorts if mortality rates are adjusted downwards, and would be more positive for young cohorts than for old cohorts if mortality rates are adjusted upwards. This implies that if one uses the same adjustment factor irrespective of age (i.e., the *FRS rule*), wealth transfers can occur between old to young participants. Such wealth transfers can be mitigated or avoided by reducing the extent of risk sharing across cohorts, for example, by using an x_0+ rule. In this section, we quantify transfers of wealth between cohorts for the adjustment rules that we discussed in the previous section.

To quantify wealth transfers between cohorts, we define the "biometric return" for cohort x as the relative change in the best-estimate value of the aggregate future liabilities of all participants belonging to cohort x, i.e., survivors and non-survivors, due to the combined effect of:

(i) survival or death within the year of the individuals in the cohort;

(ii) updating of mortality projections, which implies that the value of the annuity increases further.

(ii) any adjustment that the fund makes to the accrued rights of the participant to compensate for the change in the best-estimate value of the liabilities at the fund level due to micro- and macro-longevity risk.

To focus on wealth transfers caused by updating of mortality rates, we quantify the biometric return in the absence of micro-longevity risk, i.e., when the number of participants that survive the year equals $n_x \cdot p_{x,t}$. In that case, the change in the best-estimate value of the liabilities of cohort x is $\Delta V_{cohort|nomicro}(x)$, and no adjustments are needed to compensate for micro-longevity risk. Therefore, the biometric return for macro-longevity risk equals:

$$R_{cohort}(x) = [1 + \gamma_{macro}(x)] \cdot \left(1 + \frac{\Delta V_{cohort|nomicro}(x)}{V_{cohort}(x)}\right) - 1.$$

Note that this implies that

$$R_{cohort}(x) = \left(\frac{1 + \gamma_{macro}(x)}{1 + \gamma_{macro,wc}(x)}\right) - 1, \text{ for all } x.$$

We note that the aggregate "biometric return" for the fund as a whole is, by construction, equal to zero. This occurs because (9) ensures that any change in the aggregate best-estimate value of the liabilities at fund level is compensated by adjustments in accrued rights. At cohort level, however, the biometric return depends on the adjustment rule that is used, and can be positive or negative. A positive biometric return means that the adjustment rule induces a transfer of wealth to the cohort from other cohorts. A negative biometric return implies a transfer of wealth from the cohort to other cohorts.

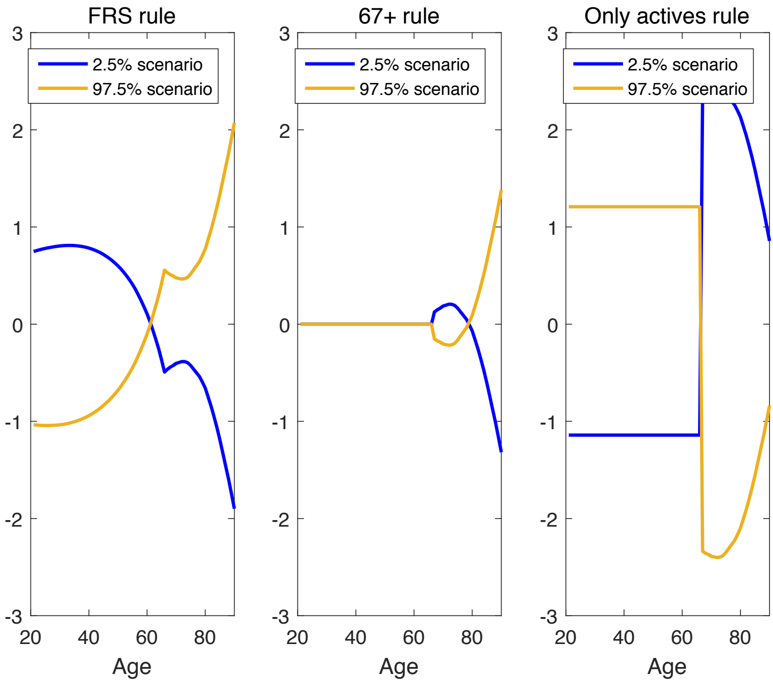

Figure 10: The 95% forecast interval for the biometric return for cohort x, in case longevity risk is shared over all cohorts (*FRS rule*, left panel), in case of the $67+$ *rule* (middle panel), and in case of the *Only Actives rule* (right panel). The bounds of the forecast intervals correspond to the 2.5% scenario (blue lines) and the 97.5% scenario (orange lines).

We display the biometric returns for the *FRS rule* (left panel), the $67+$ *rule* (middle panel) and the *Only Actives rule* (right panel) in Figure 10. The bounds of the forecast intervals correspond to either the 2.5% scenario (blue lines) in which mortality rates decrease or the 97.5% scenario (orange lines) in which mortality rates increase. The figure shows that with the current practice (the *FRS rule*) potential transfers of wealth (positive and negative) are largest for those cohorts for which the "contribution" to the aggregate best-estimate value is smallest. This is the case both for young cohorts and for old cohorts. However, whereas those aged 60 or younger earn positive returns from the adjustment rule in scenarios in which mortality rates decrease (e.g., in the 2.5% scenario; blue lines), those aged 61 or older earn positive returns in scenarios in which mortality rates increase (e.g., in the 97.5% scenario; orange lines). This occurs because, as can be seen in Figure 7, macro-longevity risk has a bigger impact on younger cohorts. Therefore, the young benefit from risk sharing with the old when mortality rates decrease and the opposite holds when mortality rates decrease. Under the $67+$ *rule*, wealth transfers with the active participants are by construction eliminated. There are, however, still wealth transfers (although smaller) between young retirees and older retirees, with the biggest impact for the latter category. Finally, under the *Only Actives* rule, the payments of retirees are not adjusted in response to changes in best-estimate projections. This implies that wealth is transferred away from retirees in scenarios in which their best-estimate mortality rates increase, and wealth is transferred to retirees in scenarios in which their mortality rates decrease.

These results illustrate that ex-post wealth transfers can depend substantially on the adjustment mechanism that is used to compensate for the effects of macro-longevity risk on the value of pension liabilities. However, for all the adjustment rules, ex-ante expected wealth transfers are negligible. This occurs because shocks with positive and negative effects of the same magnitude occur with almost the same probability.

5.2 Wealth transfers between survivors and non-survivors

The previous section investigated aggregate wealth transfers across generations. Also within a generation, however, transfers of wealth occur between participants who survive and those who die.

To investigate the magnitude of these transfers, we let the biometric return for an individual participant be the value $R(x)$ that satisfies

$$[1+\gamma_{micro}(x)]\cdot[1+\gamma_{macro}(x)]\cdot[V(x)+\Delta V(x)] = [1+R(x)]\cdot V(x),$$

which implies that

$$R(x) = [1+\gamma_{micro}(x)]\cdot[1+\gamma_{macro}(x)]\cdot\left(1+\frac{\Delta V(x)}{V(x)}\right) - 1.$$

This return depends on whether the participant survives or dies, and is given by

$$
\begin{aligned}
R(x) &= [1+\gamma_{micro}(x)]\cdot[1+\gamma_{macro}(x)]\left(\frac{1}{\widehat{p}_{x,t}}\right)\left(1+\frac{\Delta PV(x+1)}{PV(x+1)}\right)-1 \\
&\quad \text{for a survivor,} \\
&= -1, \\
&\quad \text{for a non-survivor.}
\end{aligned}
$$

For a survivor, the return can be disentangled into three effects:

- the term $[1+\gamma_{micro}(x)]\cdot[1+\gamma_{macro}(x)]$ reflects the return on adjustment of accrued rights,
- the term $\frac{1}{\widehat{p}_{x,t}}-1$ reflects the “return on survival”, i.e., the so-called *survival credit*;
- the term $1+\frac{\Delta PV(x+1)}{PV(x+1)}$ reflects the “return on adjustment of best-estimate future mortality rates”.

We display the biometric returns of survivors in Figure 11, for the *FRS rule* (left panel), the *Only Actives rule* (middle panel), and the *Within Cohort rule* (right panel).

Comparing the cohort level returns displayed in Figure 10 and the individual returns of survivors in Figure 11 shows that the contribution of the survival credit to the total return is substantial, especially for older participants. For individuals aged 70 or older, the effects of downwards or upwards adjustments of pension rights to compensate for macro-longevity shocks are small relative to the rather large positive return “earned” from surviving. Hence, for these age groups, the differences between the adjustment rules are relatively small.

We note that because we only consider old-age pension annuities, the value of the liabilities for a participant who deceases drops to zero. Hence, our analysis ignores the effects of returns earned on partner pensions. For participants with a partner pension, a strictly positive return would be earned on the value of the partner pension in case if decease, and the positive return on the participant’s annuity would be reduced by a negative return on the partner annuity in case of survival.

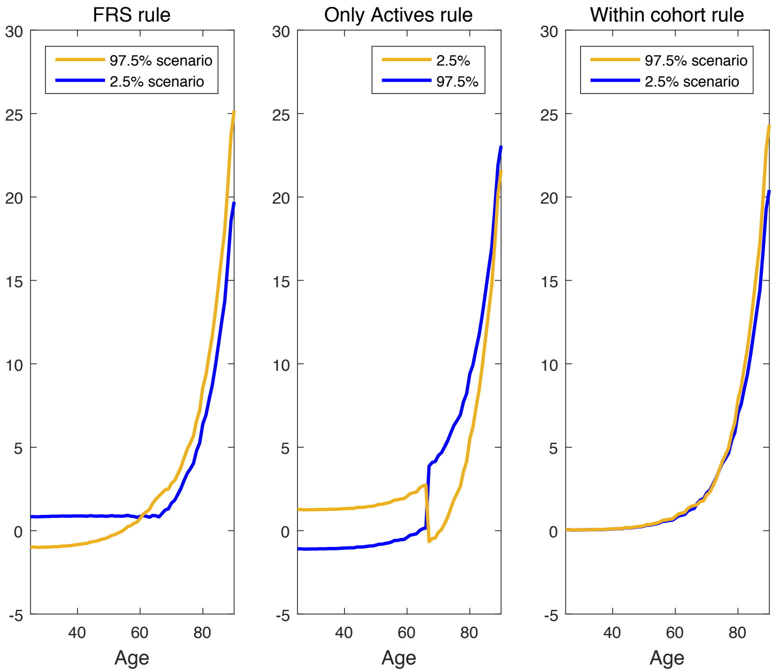

Figure 11: 95% forecast interval of the return for an individual survivor in case macro-longevity risk is shared over all cohorts (left panel), in case of the *Only Actives rule* (middle panel), and in case of the *Within Cohort rule* (right panel). The bounds of the forecast intervals correspond to the 2.5% scenario (blue lines) and the 97.5% scenario (orange lines).

6 Conclusion

We have analyzed the effects of adjustment mechanisms meant to to neutralize the effects of longevity risk on the value of the pension liabilities. We find that the choice of adjustment mechanism can have a substantial impact on the risk imposed on different generations, and on ex-post wealth transfers between generations. We have modeled a setting in which at the end of each year, best-estimate mortality rates are (re)-estimated using the Lee-Carter approach. We find that the impact of changes in best-estimate future mortality rates is highest for younger cohorts and becomes negligible for the oldest old. This in turn implies that in the current system in which risk is shared over all participants via age-independent adjustments, significant transfers of wealth can occur from the old to the young when mortality rates decrease, and from the young to the old when mortality rates increase. Also, under the current system, risk is shifted from the young to the old. One way to avoid such transfers of risk and wealth between actives and retirees could be to increase retirement age for the active participants when their mortality rates are adjusted downwards.

We do note that while the one-factor Lee and Carter approach that we used implies that the impact of macro-longevity risk is almost monotonically decreasing in age, and shocks for different ages are perfectly correlated, this may not be the case when other forecast approaches are used (for example when a multi-factor model would be used). Moreover, changes in forecast method, as occurred in the 2010 and 2014 AG forecasts, can have unpredictable effects. One cannot exclude that in such cases, reducing the degree of risk sharing between young and old could increase the degree of risk for the old. Finally, we note that our analyses makes some simplifying assumptions in that we ignore partner pensions, and we assume that the effect of an update in mortality forecasts has to be implemented immediately, instead of over a period of 10 years. We ignore these effects, also at the fund level.

A Lee and Carter best-estimates

A.1 Lee-Carter based best-estimates

In order to be able to determine the best-estimate value of annuity payments, best-estimates are needed for the future survival rates of all the participants in the fund. In this section, we consider a given year t, and determine best-estimates for the one-year survival probabilities in years $t, t+1, t+2, \ldots$, as a function of age. We use the following notation:

- t_0: the first year for which mortality data is used in the estimation procedure, $t_0 < t$;
- $p_{x,s}$: the "true" probability that an individual aged x at the beginning of year s survives at least one year.

At the beginning of year t, the one-year survival probabilities are known for years $s = t_0, t_0+1, \ldots, t-1$, and need to be forcasted for years $s = t, t+1, t+2, \ldots$. We consider the case where future survival rates are forecasted using the Lee and Carter (1992) model. According to the Lee-Carter model, we have

$$p_{x,s} = \exp\left(-m_{x,s}\right), \text{ for } s \geq t_0, \tag{13}$$

where the (raw) central death rate $m_{x,s}$ is decomposed in an age, time, and residual idiosyncratic effect (after taking log-s)

$$\log(m_{x,s}) = \alpha_x + \beta_x \times \kappa_s + \epsilon_{x,s}, \text{ for } s \geq t_0, \tag{14}$$

where α_x captures the age effect, κ_s represents the time effect, β_x reflects the sensitivity of age class x to the time effect, and $\epsilon_{x,s}$ is the residual idiosyncratic effect (assumed to have mean zero and to be uncorrelated with κ_s). For identification purposes, β_x and κ_s are normalized: $\sum_s \kappa_s = 0$ and $\sum_x \beta_x = 1$. In a first round, $\{\alpha_x\}$, $\{\beta_x\}$, and $\{\kappa_s\}$ are estimated using Singular Value Decomposition. In a second round, $\{\kappa_s\}$ is modeled as a random walk with drift (or an $ARIMA(0,1,0)$-process), given by

$$\kappa_s = \kappa_{s-1} + \delta + \eta_s, \tag{15}$$

where δ is the drift term, and η_s a residual, assumed to be i.i.d. normally distributed with mean zero and variance σ_η^2. Given estimates for $\{\alpha_x\}$, $\{\beta_x\}$, and δ, using data up to and including year $t-1$, we can construct the best estimates $\widehat{p}_{x,t+\tau}$, for $\tau \geq 0$:

- first, we use (15) to determine the best-estimate value of $\widehat{\kappa}_{t+\tau}$, by setting $\eta_{t+\tau} = 0$ for all τ:

$$\widehat{\kappa}_{t+\tau} = \kappa_{t-1} + \widehat{\delta} \times (\tau + 1)$$

- next, we determine the best-estimate probability $\widehat{p}_{x,t+\tau}$ by substituting the value of $\widehat{\kappa}_{t+\tau}$ in (14), setting $\epsilon_{x,t+\tau} = 0$, and substituting the result in (13).

In our illustration we take $t_0 = 1972$, $t - 1 = 2009$, and $x \in [20, 110]$, i.e., the parameters are estimated using Dutch male mortality data from 1972 to 2009 with age range between 20 and 100 years, where the age class 110 includes all 110+-ages. We find $\widehat{\delta} = -2.07$. Figure 12 shows the estimates $\widehat{\beta}_x$ (after smoothing).

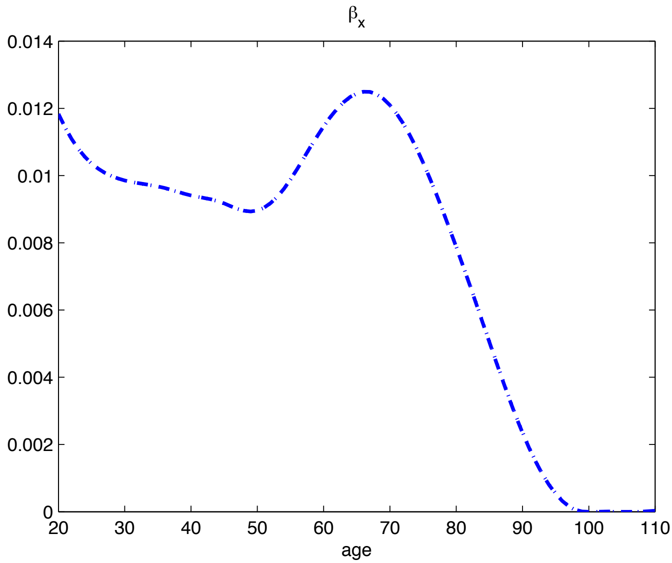

Figure 12: This figure shows the estimates $\widehat{\beta}_x$ as a function of age x (after smoothing).

Whereas $\widehat{\kappa}_{t+\tau}, \tau = 0, 1, 2, \ldots,$ reflects the projected “common time trend” in mortality, the estimated parameters $\widehat{\beta}_x$ reflect the extent to which individuals of age x respond to the common time trend. Figure 12 shows that for individuals aged 20 or higher (the typical population of a pension fund or insurer), the effect of the common time trend on age-specific mortality is highest for individuals between age 50 and 80, and decreases rapidly for higher ages. This suggests that over the period on which the model is estimated, mortality in this age group has decreased more than in the other age groups.

A.2 Forecast interval for re-estimated best-estimate probabilities

We assume that the realized mortality in year t corresponds to the value of κ_t given by

$$\kappa_t = \kappa_{t-1} + \delta_{shock}, \tag{16}$$

and we consider the 95% forecast interval for δ_{shock}. The upper bound of the 95% confidence interval is given by $\widehat{\delta} + q_{0.975}$, with $q_{0.975}$ the 97.5% quantile of the $N(0, \widehat{\sigma}^2_{\widehat{\delta}})$-distribution, where $\widehat{\sigma}^2_{\widehat{\delta}}$ denotes the estimated (asymptotic) variance of $\widehat{\delta}$. The lower bound of the 95% confidence interval is given by $\widehat{\delta} + q_{0.025}$, with $q_{0.025}$ the 2.5% quantile of the $N(0, \widehat{\sigma}^2_{\widehat{\delta}})$-distribution. In our benchmark illustration, $t = 2010$, and the hypothetical true “data” for 2010 ($p_{x,2010}$ for all x) are obtained by combining (16) with the estimated version of (14) (with error terms set to zero) for $t = 2010$, and using (13).

Re-estimation of the model using this new “data” (i.e., using years the years 1973-2010 instead of 1973-2009) yields almost the same $\widehat{\beta}_x$-s (not plotted), but the new estimate of $\widehat{\delta}$ (see (15)) in case of the 2.5%-shock becomes $\widehat{\delta} = -2.30$, i.e., the time trend becomes steeper, whereas in case of the 97.5%-shock we get $\widehat{\delta} = -1.84$, i.e., the time trend becomes less steep. Figure 13 shows the estimated κ_τ-s, the projected $\kappa_{t+\tau}$, $\tau \geq 0$ (before the shock), and the projected $\kappa_{t+\tau}$, $\tau \geq 1$ (after the shock) (after a renormalization for comparison purposes).

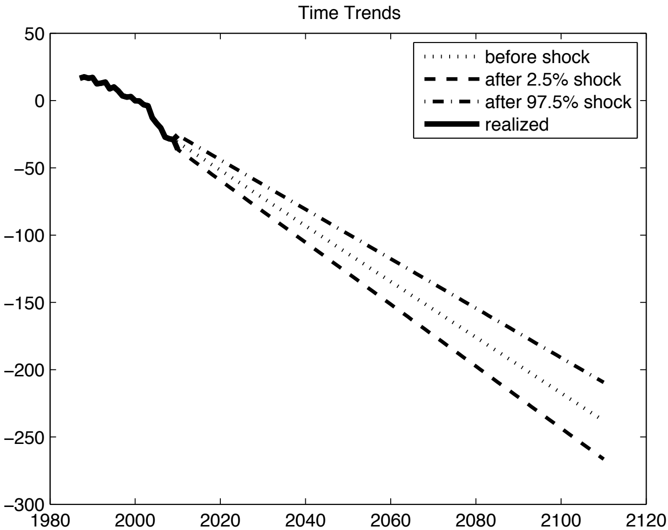

Figure 13: This figure shows shows the estimated κ_τ-s, the projected $\kappa_{t+\tau}$, $\tau \geq 0$ (before the shock), and the projected $\kappa_{t+\tau}$, $\tau \geq 1$ (after the shock) (after a renormalization for comparison purposes).

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Risk sharing rules for longevity risk: impact and wealth transfers

Actuarial gains or losses at the fund level are covered by adjustments of the accrued rights of the surviving participants. It is common practice that institutes such as AG or CBS frequently revise best-estimate projections of future mortality rates. Such updates can lead to non-negligible changes in the best-estimate value of pension liabilities. Anja De Waegenaere, Bertrand Melenberg (both TiU) and Thijs Markwat (Robeco) consider a number of rules for sharing longevity risk that differ in the extent to which longevity risk is shared within or over cohorts, and investigate the impact of each adjustment rule on the accrued rights of participants, and on wealth transfers between generations.

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