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Variable annuities with financial risk and longevity risk in the decumulation phase of Dutch DC products

Bart Dees
Frank de Jong
Theo Nijman

DESIGN PAPER 168

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CONTENTS

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Affiliations

Bart Dees – Tilburg University and Nationale Nederlanden
Frank de Jong – Tilburg University
Theo Nijman – Tilburg University

Abstract

This paper develops a general framework in which the stock market risk, interest rate risk, inflation risk and longevity risk of variable pension products can be quantified. The paper starts by analyzing the risk of a basic pension product, taking each of these risk factors into account. Under the Koijen et al. (2010) model, we show that interest rate risk can be substantial for the participant, and we derive the interest rate risk hedge. Under the additional assumption of a Lee-Carter model, we conclude that financial market risk is dominant compared to longevity risk. The paper ends by showing that the results can be generalized for a wide variety of pension products. A pension product which includes smoothing of financial shocks reduces the average year-on-year volatility substantially compared to a basic variable annuity.

Samenvatting

Analyse van de inkomensrisico's in variabele uitkeringen
In dit paper analyseren we de inkomensrisico's van variabele uitkeringen ingevolge de Wet Verbeterde Premieregeling (WVP). Deze risico's kunnen het gevolg zijn van fluctuaties op financiële markten of van veranderingen in (ingeschatte) sterftekansen. De eerste belangrijke bevinding van dit paper is dat het financieel marktrisico bijna altijd veel groter is dan het effect van veranderingen in sterftekansen. Dit langlevenrisico kan wél substantieel zijn bij een vaste pensioenuitkering. De pensioenuitkering van een vaste annuïteit zonder verzekering van het langlevenrisico ligt vijftien jaar na de pensioendatum in pessimistische scenario's 2,6 procent lager dan dat van een vaste annuïteit met verzekering van dat langlevenrisico als we de verzekeringspremie buiten beschouwing laten.

De tweede bevinding betreft het kwantificeren van de implicaties van verschillende strategieën om het renterisico in variabele pensioenproducten te beheersen. We laten zien dat een jaarlijkse herbalancering significante onzekerheid toevoegt aan de pensioenuitkering, terwijl een adequate rentehedge bijna dezelfde pensioenuitkering genereert als een situatie zonder renterisico.

De derde bevinding is dat het over meerdere jaren spreiden van uitkeringsschokken die ontstaan als gevolg van financieel marktrisico tot sterke vermindering leidt van de schommelingen van jaar op jaar in pensioeninkomen. In het bijzonder kan dit aantrekkelijk zijn voor een deelnemer bij wie de preferenties zich kenmerken door gewoontevorming. Wij concluderen dat de jaar-op-jaar-verandering voor een pensioenproduct met een aandelenexposure van 35 procent en een spreidingsperiode van tien jaar 1,2 procent is, terwijl de volatiliteit van jaar op jaar van een pensioenproduct met eenzelfde verwachte pensioenuitkering zonder spreiding van financiële schokken 3,1 procent is.

1 Introduction

Guaranteed pension products in the decumulation phase are being debated worldwide, see Balter et al. (2018). The European Insurance and Occupational Pensions Authority (EIOPA) has furthermore challenged the sustainability of such products. This has resulted in proposals for a Pan European Personal Pension Product (PEPP) available for every European resident, which would no longer aim at guaranteed pension income. In the implementation process, some lessons might be learned from the recent developments and challenges that the Dutch pension system has faced and indeed continues to face. Dutch Defined Contribution (DC) schemes include the option nowadays of taking investment risks to decumulate pension capital, using life-long variable annuities that carry both financial market risk and longevity risk. Pension products under the new legislation - (*Wet Verbeterde Premieregeling* WVP) - can offer a significantly higher first pension payment compared to a pension product without equity exposure.[1]. However, this comes at the cost of uncertainty regarding pension income.

As from 2019, pension providers in the Netherlands are required to show retirees the pension income distribution (in nominal and real terms) using a uniform economic scenario set, based on Koijen, Nijman and Werker (KNW, 2010). However, not all risks are covered by this legislation. For example, macro-longevity risk is not included in the KNW scenario set. This implies that pension providers can leave this risk in the pool without quantifying the increased risk for participants. Based on the introduction of some stylized pension products, this paper provides guidelines on how to interpret the risks associated with these WVP pension products. Step by step, we take risks related to stocks, bonds, inflation, and longevity into account. This project is timely in showing how pension providers can communicate to participants with respect to micro- and macro-longevity risk since this is not yet included in the consumer information that is prescribed. We extend this information so that all future retirees can make a well-informed choice between a fixed and variable annuity.

To analyze the risks in these variable annuity pension products, this paper develops an integrated framework in which we can quantify the financial and longevity risks for a wide variety of variable annuities. We develop a framework in which we can quantify the

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[1] Currently, the market for variable annuities in the Netherlands is relatively small. In a survey conducted in 2017 by the Authority for the Financial Markets (AFM), 6% of 15,000 retirees chose the variable annuity, see https://www.afm.nl/nl-nl/nieuws/2019/apr/wvp-onderzoek. However, this market is expected to grow rapidly. More retirees are faced with the decision for a variable annuity; currently 1.3 million employees participate 'in premie- of kapitaalregelingen' corresponding to 20% of pension plan participants. The number of participants in these schemes has doubled compared to 2009, and their participation is expected to grow further, from 6% to 19% according to the AFM.

risk of pension products under almost any financial model, and in which we can account for stock market risk, interest rate risk, inflation risk, and longevity risk. Finally, we develop some intuition as to which product features can be attractive for different types of participants, although without performing a formal welfare comparison between pension products.

This paper uses the 'money pot' approach to analyze pension products. This involves modeling the problem as if we set aside a fraction of accumulated pension wealth (the money pots) for the consumption at each age. This method of modeling pension products is inspired by Balter and Werker (2020). Their methodology has several advantages. In particular, it gives the participant intuition for product characteristics, such as the assumed interest rate and smoothing of financial shocks. Within this approach, incorporating economic risk factors (i.e. financial market risk, longevity risk) is a matter of scaling the money pots.

To obtain analytical expressions for the pension income distribution, and to provide intuition for these expressions, we start the analysis by quantifying the risks of a basic variable annuity (i.e. no smoothing, no guaranteed benefit level) in a Black and Scholes financial market. Contrary to Balter and Werker (2020), we assume an unknown date of death, which we model using deterministic (cohort) survival probabilities. We will present the risks associated with WVP pension products in line with the mandatory communication by Dutch pension providers. This means that the risks associated with pension products will be communicated via pessimistic, expected, and optimistic scenarios[2]. We then extend the analysis of Balter and Werker (2020) by analyzing the risk of pension products under the KNW model. This is the underlying model of the scenario set prescribed by the regulatory authorities. On the one hand, this allows us to quantify the risk of pension products in a setting with time-varying stock returns and to add interest rate risk and inflation risk as economic risk factors. On the other hand, it allows us to quantify the risk of pension products in line with Dutch legislation.

Using a Lee-Carter (1992) model, De Waegenaere et al. (2019) outline how to calculate the implications of a one-year micro- and macro-longevity shock for both pension funds and WVP contracts. They do not consider financial market risk. We extend their setting by integrating both risk factors in a multi-period setting, to present the pension income distribution under financial market risk and longevity risk. We can then quantify the additional risk of macro-longevity in a basic variable annuity that currently only quantifies financial market risk.

We repeat this analysis for a wide variety of pension products, for example products that incorporate smoothing, a guaranteed benefit level, and a high-low setting, where the re-

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[2] This reflects the 5%, 50%, and 95% quantiles, respectively.

tiree can get a higher pension income in the initial years of retirement. We also analyze the impact of smoothing of financial shocks.

The first main finding of this paper is that financial market risk dominates the macro-longevity risk in variable annuities. However, the stand-alone longevity risk can be substantial in fixed annuities. Pension income for a variable annuity with an asset allocation of 35% with or without longevity insurance is approximately similar in a 5% quantile in the absence of an insurance premium. Pension income for a fixed annuity without longevity insurance is 2.6% lower than a fixed annuity with longevity insurance in a 5% quantile fifteen years after retirement in the absence of an insurance premium. The second main finding is the quantifiability of the financial market risk for a wide variety of pension products, when the financial market model is able to generate scenarios for stock, bond, and inflation returns. In particular, we show the implications of different strategies regarding interest rate risk in variable annuities. We show that a yearly rebalancing strategy adds significant uncertainty to the pension income stream, whereas a perfect hedge yields almost the same pension income stream as in the basic setting. The third finding is that smoothing of financial market risk, as proposed by Balter and Werker (2020), reduces the average year-on-year volatility of pension income. This can be an attractive pension product for an agent who exhibits habit formation. We conclude that the average year-on-year volatility for a pension product with an asset allocation of 35% and a smoothing period of ten years is 1.2%, whereas the average year-on-year volatility for a pension product that gives the same expected income without smoothing is 3.1%.

Our work is related to Bonekamp et al. (2017) and Balter and Werker (2020), who show how to incorporate stock market risk in WVP variable annuities. Their analysis was conducted in a simple financial market model without interest rate risk and inflation. They show that, for a variable annuity with 35% equity exposure and a maximum assumed interest rate, the expected pension income stream is 14% higher than for a fixed annuity. In WVP pension products, macro-longevity risk has been quantified by De Waegenaere et al. (2019), assuming a Lee-Carter model, as a one-year longevity shock. Their focus on a one-year longevity shock means that their paper did not quantify the aggregate macro-longevity risk for pension payments more than one period into the future. They find for a fixed annuity that a one-year longevity shock can lead to roughly 1.1% pension income drop in a 2.5% quantile for a participant at retirement age without risk sharing. Balter et al. (2019) calculated macro-longevity risk based on multiple historical realized updates in the longevity tables. There is reason to question how informative these historical updates are for future longevity shocks. They calculate that a participant at retirement age in 2007 would incur a pension income drop of approximately 10% in 2010 based on increased life expectancy. They find an even sharper drop in pension income for the updates in 2013 and 2016. Steenkamp (2016) shows, using a model assumed by the Dutch Actuarial Association, that pension income of a fixed annuity without longevity insurance in a 5% percentile at the age of 120 is 2.5 percentage points lower in terms of replacement rate compared to a fixed annuity with longevity insured for a 5% premium.

This paper also fits within the broader literature on variable annuities. Davidoff et al. (2005) derive conditions under which it is optimal to annuitize pension wealth. Koijen et al. (2011) show that adding equity exposure to the annuity leads to greater welfare in many cases. Balter et al. (2018) show where and to what extent variable annuities are available internationally, and they describe an international transition from guaranteed pension products to variable annuities. For example, Horneff et al. (2015) show that variable annuities, in the form of Guaranteed Minimum Withdrawal Benefits, are one of the fastest growing financial innovations in the US and are preferred above fixed annuities. Chen et al. (2015) also identify that a retiree might prefer a variable pension product with guarantees. Maurer et al. (2013) show that in many cases it can be attractive for participants to bear the systematic longevity risk in variable annuities themselves, since insuring is costly due to solvency requirements. Boon et al. (2019) find similar results with respect to bearing the longevity risk in group self-annuitization products.

The structure of this paper is as follows. Section 2 quantifies the risk of variable annuities in a standard financial market model. In section 3 we develop a general framework in which we can express the risk of pension products under any financial market model. In section 4 we extend this analysis by taking into account (macro-) longevity risk as a risk factor in these variable annuities. In section 5 we show that the results from earlier sections can be applied to a wide variety of variable annuities (high-low, smoothing, and products with guaranteed benefit level). Section 6 provides conclusions.

2 Pension income distribution with stock market risk

In this section we present the pension income distribution for a basic variable annuity, taking into account financial market risk only. Balter and Werker (2020) and Bonekamp et al. (2017) provide an elaborate description of the setting, assuming a deterministic date of death. This section starts by taking into account deterministic (cohort) survival probabilities. In the empirical results, we use gender-neutral survival probabilities from the Dutch Actuarial Association (AG, 2018).[3]

At retirement age T, a person has accumulated pension wealth W_T. This person can decide on the investment mix w. The Black and Scholes financial market contains an asset with a return at the risk-free rate r and an asset with an uncertain return. The return of this asset is log-normal with mean $r + \lambda\sigma - \frac{1}{2}\sigma^2$, volatility σ, and sharpe ratio λ. We set the maximum age for this person at L. We allocate the available pension wealth to $L - T$ money pots, denoting this by $V_h(T)$. We define $V_h(T)$ as the part of W_T that we set aside for consumption at age $T + h$. The assumed interest rate AIR determines the allocation to money pots, through the allocation rule.[4] The higher the AIR, the larger the fraction of W_T that will be allocated to $V_h(T)$ for smaller h. This is typically referred to as front loading. We allow the assumed interest rate to be horizon-dependent (AIR_h). The assumed interest rate and the money pot allocation satisfies

$$V_h(T) = W_T \cdot \frac{p_h(T)\exp(-h \cdot AIR_h)}{\sum_{k=0}^{L-T-1} p_k(T)\exp(-k \cdot AIR_k)} \tag{1}$$

where $p_h(T)$ is the probability that a person is still alive h years after retirement. The return on money pot $V_h(T)$, h periods after retirement age, follows a log-normal distribution with mean $h(r + w\lambda\sigma - \frac{1}{2}w^2\sigma^2)$ and variance $hw^2\sigma^2$. This implies the expectation and quantiles for the pension income distribution.

$$\begin{aligned} E_t(V_h(T+h)) &= V_h(T) \cdot \exp(h \cdot (r + w\lambda\sigma)) \cdot \left(\frac{1}{p_h(T)}\right) \\ &= W_T \cdot \frac{\exp(-h \cdot AIR_h)\exp(h \cdot (r + w\lambda\sigma))}{\sum_{k=0}^{L-T-1} p_k(T)\exp(-k \cdot AIR_k)} \end{aligned} \tag{2}$$

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[3] To simply the computation, a maximum age of 100 will be assumed. In all figures the pension income stream will be presented up to the age of 90. Note that this way of presenting pension income distribution is in line with the communication by pension providers.

[4] The *AIR* can be expressed as the sum of the risk-free rate and a parameter that is often referred to as fixed decrease in the Dutch policy discussions.

$$Q_t^{\alpha}(V_h(T+h)) = V_h(T)\cdot \exp\left(h\cdot(r+w\lambda\sigma-\frac{1}{2}w^2\sigma^2)+z_{\alpha}\sqrt{h}w\sigma\right)\cdot\left(\frac{1}{p_h(T)}\right)$$
$$= W_T\cdot\frac{\exp(-h\cdot AIR_h)\exp\left(h\cdot(r+w\lambda\sigma-\frac{1}{2}w^2\sigma^2)+z_{\alpha}\sqrt{h}w\sigma\right)}{\sum_{k=0}^{L-T-1}p_k(T)\exp(-k\cdot AIR_k)} \tag{3}$$

Formula (2) shows that, given a constant asset allocation (w) in order to obtain a flat consumption pattern in expectation, the AIR should be set as

$$AIR_{mean} = r + w\lambda\sigma \tag{4}$$

Note that the AIR in (4) is independent of the horizon. In the Dutch setting there is a restriction on the assumed interest rate set by the regulatory authorities, such that in expectation the pension income stream is non-decreasing.

We can plot the pension income distribution of a basic variable annuity with w=35 % and AIR=2.01 % calculated in line with (4). Table 1 reports the parameter assumptions.[5]

Name	Parameter	Value
Retirement age	T	67
Pension wealth	W_T	233,000
Risk-free rate	r	0.43%
Volatility of stock returns	σ	16.75%
Excess stock returns	$\lambda\sigma$	4.52%

Table 1: Overview of parameter values

In line with Dutch pension providers, we scale pension income to a monthly basis. We consider an individual[6] who has accumulated a deterministic amount of wealth at retirement age. Figure 1 presents the pension income stream of this participant from retirement age onwards.[7]

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[5] We set the parameters in such a way as to create equivalence with the current calibration of the KNW model prescribed by the regulatory authorities.

[6] For simplicity purposes, we assume that this individual does not have a partner to allow us to abstract from partner pension.

[7] In line with the communication by Dutch pension providers, state pension income is not included in these figures.

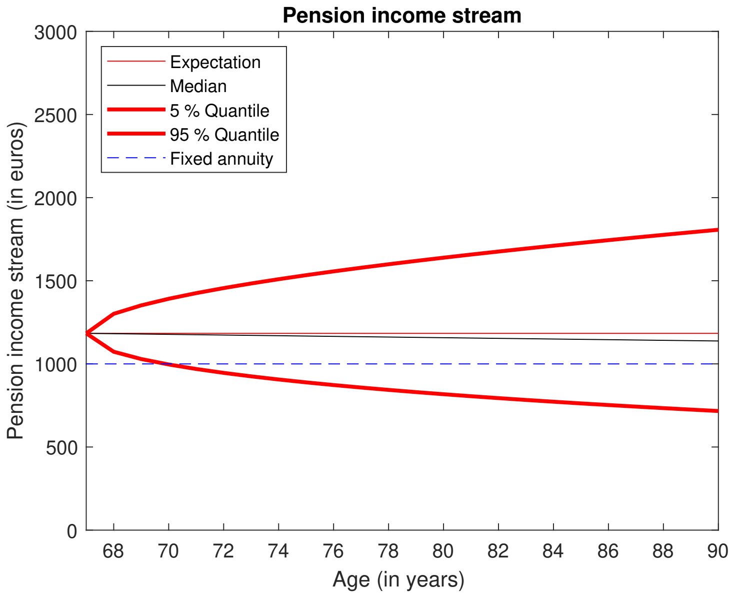

Figure 1: Pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, and parameter assumptions in line with Table 1.

Note that we get a constant expected pension income stream by setting the assumed interest rate in line with (4). This implies that median pension income decreases, as a low probability on a high pension income stream heavily influences the expected pension income stream in the skewed distribution (log-normal). Grebenchtchikova et al. (2017) present conditions under which this variable annuity is optimal, assuming an individual with constant relative risk aversion preferences. Figure 1 shows that the variable annuity has a significantly higher mean payment compared to a fixed annuity. As a rule of thumb, we approximate (1) with h=0 and calculate this higher pension income (in percentage terms) by multiplying it with the duration (approximately 10) with the difference between AIR and risk-free rate (i.e. 10 · 1.58% = 15.8%).

Assume that we set the assumed interest rate equal to the risk-free rate ($AIR = r$). The first pension payment is then equal to that of a fixed annuity. The pension income is then expected to grow by the excess returns $w\lambda\sigma$. Figure 2 shows this result.

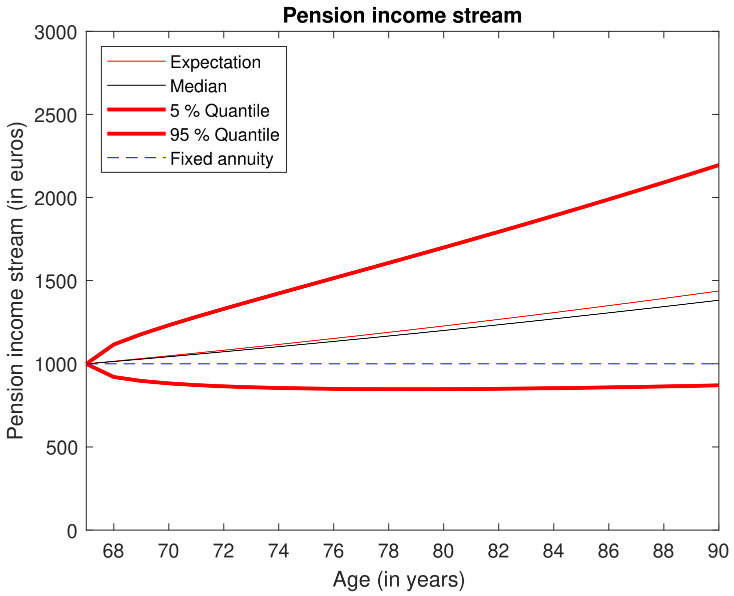

Figure 2: Pension income distribution in a Black and Scholes financial market with w=35%*, AIR=r=0.43*%*, and parameter assumptions in line with Table* 1.

In sections 3 and 4 we focus on a pension product with constant asset allocation, taking into account interest rate risk, inflation risk, and/or longevity risk. We compare this to the basic variable annuity in Figure 1. In section 5 we will discuss the risks for several non-basic pension products, a high-low pension product, a pension product with a guaranteed benefit level, and a pension product that incorporates smoothing of financial shocks.

3 Pension income distribution with interest rate and inflation risk

In this section we analyze the risk of pension products, in line with the Koijen et al. (2010) model (KNW model). This is the underlying model prescribed by the Dutch regulatory authorities, and Dutch pension providers need to quantify the risk of pension products in accordance with this model. Schotman et al. (2020) used this model to make welfare comparisons among different pension products, where they extend Bonekamp et al. (2017), by also taking interest rate risk into account as well. The framework that we introduce in this section to calculate the risk of pension products applies to any financial market model, so long as the model can generate scenarios for stock, bond, and inflation returns.

One of the major changes compared to the Black-Scholes model in Section 2 is that we no longer assume a constant interest rate. In linear affine models the yield y_t^h, which is a function of the state variables X_t and $A(h)$ and $B(h)$ (see Brennan and Xia (2002)), satisfies

$$y_t^h = \frac{-A(h) - B(h)X_t}{h} \tag{5}$$

To allocate wealth to money pots accordingly, defined in (1), we replace the constant interest rate in (4) by the yield as follows

$$AIR_h = y_0^h + w\lambda\sigma \tag{6}$$

We define a recursive relation for each money pot to calculate the pension income stream. We let this recursive relation run over horizon j, where obviously $1 \leq j \leq h$. This is presented in a general form, independent of the scenario set, for different investment strategies.

Investment strategy 1 (time-varying stock returns, one year bonds): We start to extend the results by taking into account a time-varying return on stocks S, and we invest $1 - w$ recursively in a one-year bond. The price of a nominal zero coupon bond at time t with a single payout at time $t + h$ is defined as $P(X_t, t, h)$.

$$\begin{aligned} V_h(T+j) = \Bigg(\Bigg\{ & w \cdot V_h(T+j-1) \cdot \underbrace{\frac{S_j(X_j)}{S_{j-1}(X_{j-1})}}_{\text{stock return}} \\ & + (1-w) \cdot V_h(T+j-1) \cdot \underbrace{\frac{1}{P(X_{j-1}, j-1, 1)}}_{\text{one year bond return}} \Bigg\} \Bigg) \cdot \left(\frac{1}{p_1(T+j-1)} \right) \end{aligned} \tag{7}$$

For application in this project, we insert the stochastic scenarios for stocks from the KNW model. In the prescribed parameterization of the model there is an increasing (expected) return on stocks, due to an increasing (expected) nominal instantaneous interest rate. We calculate the (one-year) bond prices implied by the state variables from the model.

Investment strategy 2 (partial interest rate hedge): We invest $1 - w$ of each money pot that is needed h periods from retirement onwards in a bond with a maturity of h years. The corresponding price is $P(X_{j-1}, j-1, h)$ at time $j-1$. After one year, at time j, the price of this bond is equal to $P(X_j, j, h-1)$. This we incorporate as follows by changing the 'one-year bond return' in (7) to a matching portfolio

$$\frac{P(X_j, j, h-j)}{P(X_{j-1}, j-1, h+1-j)} \tag{8}$$

Under this investment strategy we are still exposed to interest rate risk via the stock market, so we refer to this as partial interest rate hedge.

Investment strategy 3 (full interest rate hedge): This strategy invests the full present value of the money pot $V_h(T)$ in a bond with maturity h and thus hedges all the long-term interest rate risk of the money pot $V_h(T)$. Additionally, we allocate a fraction w towards the stock market, and we have a short position of fraction -w in a short-term (one-year) bond. Because the risk premium on stocks in our model is constant, the excess stock return (stock return minus the short-term bond return) carries no interest rate risk. We calculate the pension income stream by letting the following recursive relation run over j, where obviously $1 \leq j \leq h$.

$$\begin{aligned} V_h(T+j) = \Bigg(\Bigg\{ & \underbrace{V_h(T+j-1)\cdot \frac{P(X_j, j, h-j)}{P(X_{j-1}, j-1, h+1-j)}}_{\text{return on matching bonds}} \\ & \underbrace{+\, w\cdot V_h(T+j-1)\cdot \left(\frac{S_j(X_j)}{S_{j-1}(X_{j-1})} - \frac{1}{P(X_{j-1}, j-1, 1)}\right)}_{\text{excess return on short position}} \Bigg\}\Bigg)\cdot \\ & \left(\frac{1}{p_1(T+j-1)}\right) \end{aligned} \tag{9}$$

Pension income in real terms: We add inflation Π to the model. In our application, inflation is only relevant for converting the pension income stream from nominal to real terms. This implies that we abstain from investment options in inflation-linked bonds. We do this by multiplying the general recursive relation, defined in (7) by

$$\left\{\frac{\Pi_j(X_j)}{\Pi_{j-1}(X_{j-1})}\right\}^{-1} \tag{10}$$

We will take w=35 %, the assumed interest rate in line with (6), and the parameters and state variables in the model are those from the third quarter of 2019. We refer to the pension product described in section 2 as basic in the upcoming figures.

In Figure 3 we extend the setting by taking into account time-varying stock returns and invest $1-w$ in one-year bonds.

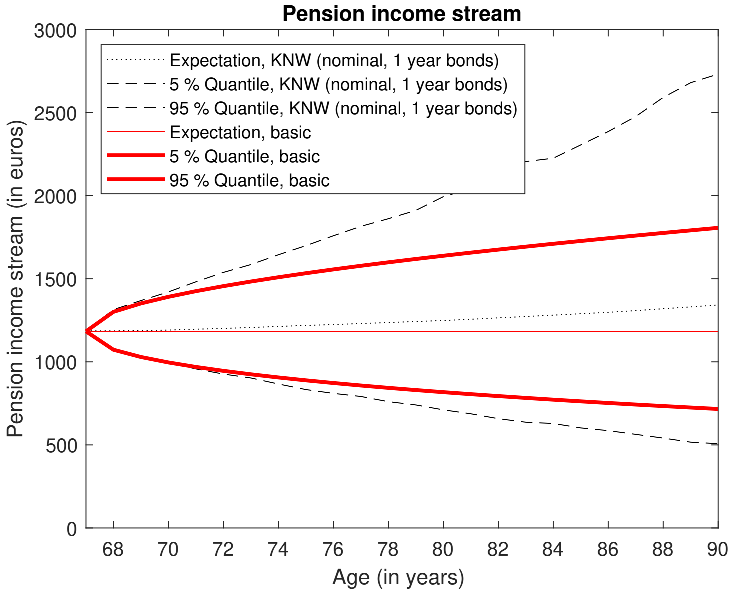

Figure 3: Pension income distribution in a KNW financial market with w=35%, AIR$_h$ in line with (6) and the setting extended by time-varying expected stock returns and one-year bond returns in line with (7). This is defined as investment strategy 1. Pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01% and parameter assumptions in line with Table 1. This is defined as the basic variable annuity.

Note that we calibrated the risk-free rate from Table 1 such that the first pension income in the KNW setting is similar to that in the Black and Scholes setting. Figure 3 shows that the expected pension income stream is no longer constant but increases. This is because the (nominal) instantaneous interest rate and the return on one-year (nominal) bonds are expected to increase over time. More specifically, the term structure of interest rates is expected to be higher in the future than the initial term structure that was used in the allocation of accumulated pension wealth towards money pots.

The volatility of stock returns in the KNW model is 16.75%[8], with the parameters being based on Draper (2014) and prescribed by the Dutch regulatory authorities. This is identical to the volatility of stock returns in the Black Scholes setting (see Table 1).

In Figure 4 we extend the setting by considering investing in the bond portfolio that partially hedges the interest rate risk.

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[8] $\sigma_S = \sqrt{\sigma^2_{S(1)} + \sigma^2_{S(2)} + \sigma^2_{S(3)} + \sigma^2_{S(4)}} = \sqrt{(-0.53)^2 + (-0.76)^2 + (-2.1)^2 + (16.59)^2} \approx 16.75\%$

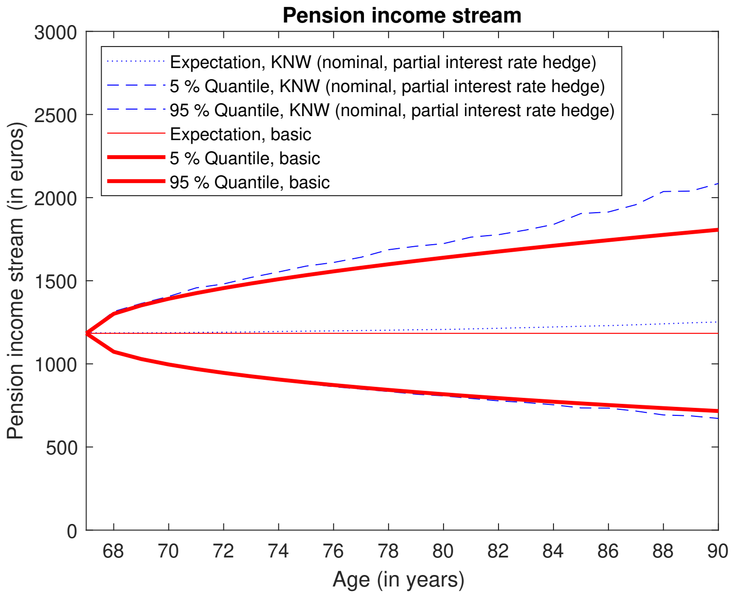

Figure 4: Pension income distribution in a KNW financial market with w=35%, AIR_h in line with (6), setting extended by partial interest rate hedge by replacing the one-year bond return in (7) by the matching portfolio of (8). This is defined as investment strategy 2. Pension income distribution in a Black and Scholes financial market with w=35%, $AIR=AIR_{mean}=2.01\%$, and parameter assumptions in line with Table 1. This is defined as the basic variable annuity.

Figure 4 shows a small increase in expected pension income. However, the increase is smaller compared to the previous setting. This is because the bond portfolio will not profit from the expected increase in the return of one-year bonds, since this is matched. Still, there is some interest rate exposure via the allocation towards the stock market because of the nominal instantaneous interest rate. Therefore, we refer to this setting as the partial interest rate hedge.

In Figure 5 we extend the setting, also hedging against changes in the nominal instantaneous interest rate. Therefore, we refer to this setting as the full interest rate hedge.

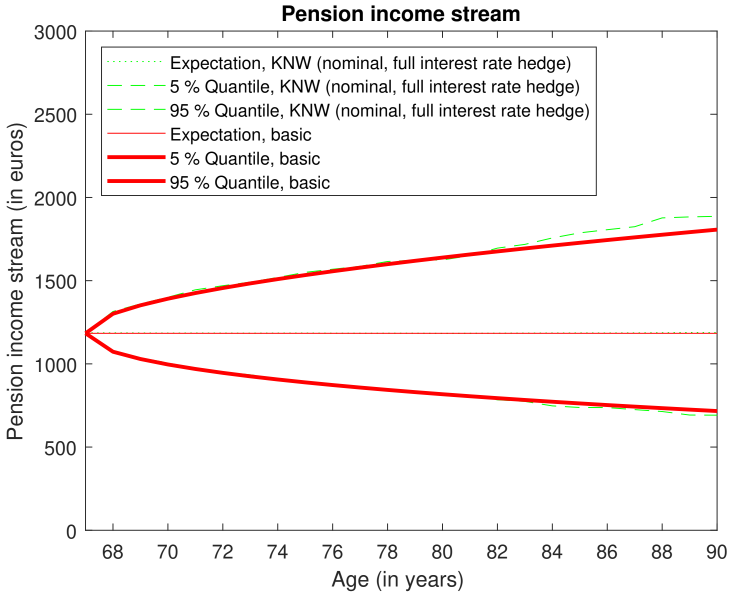

Figure 5: Pension income distribution in a KNW financial market with w=35%, AIR_h in line with (6), setting extended by full interest rate risk hedge in line with (9). This is defined as investment strategy 3. Pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR_{mean}=2.01%, and parameter assumptions in line with Table 1. This is defined as the basic variable annuity.

Figure 5 shows that we can get a constant pension income stream under the KNW model in expectation. This result more or less overlaps with the Black and Scholes setting. The conditions under which such a pension income distribution is optimal, assuming CRRA preferences, are identified in Grebenchtchikova et al. (2017).

In Figure 6 we express the pension income stream in real terms to determine the purchasing power of the pension income. This we do by multiplying inflation (9) with the pension income stream following the full interest rate hedge strategy (10).

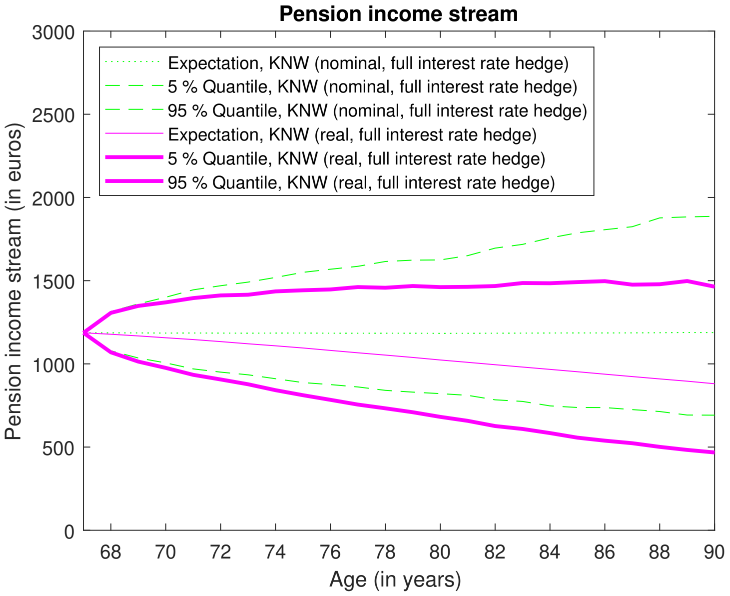

Figure 6: Pension income distribution in a KNW financial market with w=35 %, AIR_h in line with (6), setting extended by comparing the pension income following the full interest rate hedge strategy in nominal (9) and real terms, where we need to multiply by (10).

Figure 6 shows that in nominal terms the expected pension income is constant, whereas in real terms this is no longer the case. In particular, we observe a sharp decrease in real expected pension income. Therefore, Figure 6 shows that communication in nominal or real terms, as mandated for Dutch consumers, really matters.

Although currently not required, a different goal could be to require a constant expected pension income in real terms. We can achieve this by lowering the assumed interest rate in (1). Then we will end up with a horizon-dependent assumed interest rate, since the expected inflation increases over time. A way to achieve a constant pension income stream in real terms is by defining an investment strategy with adequate allocation towards real bonds. We do not present this because perfect inflation-linked bonds are not available for the Netherlands.

4 Pension income distribution with longevity risk

In this section we consider longevity risk. We distinguish between micro- and macro-longevity risk. Micro-longevity risk quantifies the risk related to uncertainty as to the time of death if survival probabilities are known with certainty, while macro-longevity risk is due to uncertain future survival probabilities (Hari et al., 2008). Macro-longevity risk (changes in survival probabilities) is fundamentally different because it does not diversify. We assume that longevity risk is shared within one's own age group[9]. We also assume that longevity risk is uncorrelated with financial market risk that is described in the previous sections.

Throughout this section we assume a pension fund that has $J(T)$ participants at retirement age T and no new inflow. This means that we plot the pension income stream of a participant at retirement age in this simplified pension fund[10]. In subsection 4.1 we will quantify the micro-longevity risk, shared within one's own age group, for different numbers of participants in the pension fund and different asset allocations. In subsection 4.2 we will quantify the macro-longevity risk, shared withing one's own age group, for different asset allocations. In this setting, the size of the pool is irrelevant since macro-longevity risk does not diversify, contrary to micro-longevity risk. Therefore, we assume that the pool of participants is large enough such that micro-longevity risk is diversified. In section 2 we were able to present the pension income stream using analytical solutions. In this section, we need simulation and use 10,000 scenarios. To keep the setting as simple as possible, we return to the Black and Scholes setting of section 2.

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[9] We do not consider risk-sharing mechanisms.

[10] This means that this set-up implies that the pool becomes smaller over time.

4.1 Pension income distribution with micro-longevity risk

In De Waegenaere et al. (2019) the one-year implications of a micro-longevity shock for a fixed annuity are calculated under several risk sharing mechanisms and different compositions and sizes of the pension fund. Their recommendation is to spread this risk over all participants in the pension fund (accumulation and retirement phase), since this risk diversifies for a large group of participants.

We extend the setting of De Waegenaere et al. (2019) by taking into account multiple periods. We start by simulating the remaining number of participants $J(T+j)$, with age $T+j$, in the pool recursively from the binomial distribution.

$$J(T+j) \sim \text{BIN}\Big(J(T+j-1), p_1(T+j-1)\Big) \tag{11}$$

We can then simulate the pension income stream, taking into account financial market risk and micro-longevity risk shared within one's own age group by the following iterative relation for $1 \leq j \leq h$, where $R^{\text{fin}}(T+j-1)$ is the financial return at age $T+j-1$ and $J(T+j)$ is simulated from (11).

$$V_h(T+j) = \left\{ V_h(T+j-1) \cdot R^{\text{fin}}(T+j-1) \cdot \frac{1}{p_1(T+j-1)} \right\} \cdot \underbrace{\frac{p_1(T+j-1) \cdot J(T+j-1)}{J(T+j)}}_{R^{\text{micro}}(T+j)} \tag{12}$$

Note that for a large pool of participants, the variable that denotes the micro-longevity risk $R^{\text{micro}}(T+j)$ is close to 1. Note also that we can easily take interest rate and inflation risk into account by inserting for $R^{\text{fin}}(T+j-1)$ in (12) what we have derived in Section 3. The pension income stream is presented for different asset allocation strategies w and different sizes of the pool of participants $J(T)$ uassuming no new inflow, as defined in Table 2. Please note the scale difference on the vertical axis for an annuity with w=0% (Figure 7-8 versus an annuity with w=35% (Figure 9-10).

	w	AIR	$J(T)$
Figure 7	w=0%	$AIR=r$	$J(T)$=500
Figure 8	w=0%	$AIR=r$	$J(T)$=2,500
Figure 9	w=35%	AIR=2.01%	$J(T)$=500
Figure 10	w=35%	AIR=2.01%	$J(T)$=2,500

Table 2: *Overview of different cases of financial market risk and micro-longevity risk.*

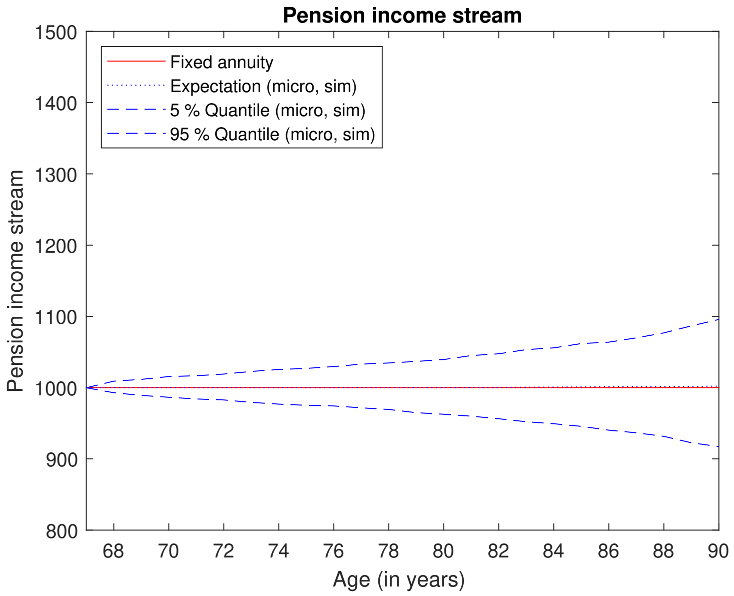

Figure 7: Simulated pension income distribution in a Black and Scholes financial market with w=0%, AIR=r=0.43%, J(T)=500, and parameter assumptions in line with Table 1. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=0%, AIR=r=0.43%, parameter assumptions in line with Table 1, implicitly assuming J(T)=∞.

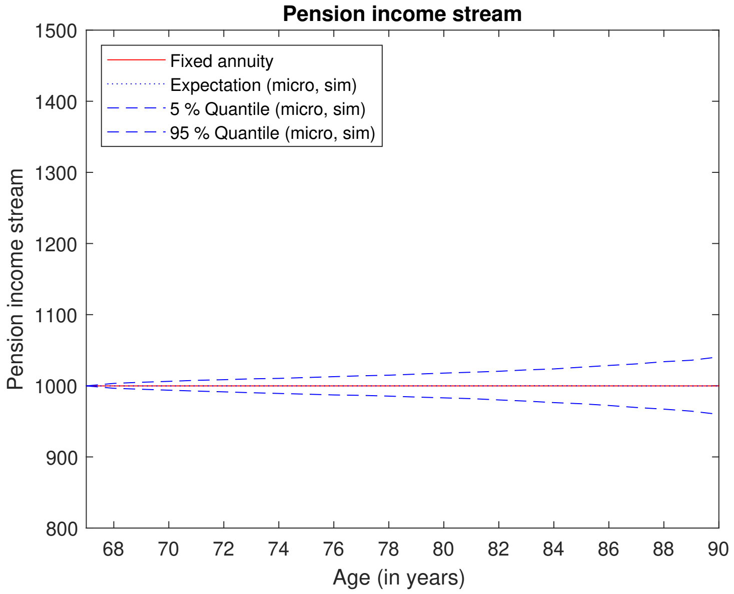

Figure 8: Simulated pension income distribution in a Black and Scholes financial market with w=0%, AIR=r=0.43%, J(T)=2,500, and parameter assumptions in line with Table 1. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=0%, AIR=r=0.43%, parameter assumptions in line with Table 1, implicitly assuming J(T)=∞.

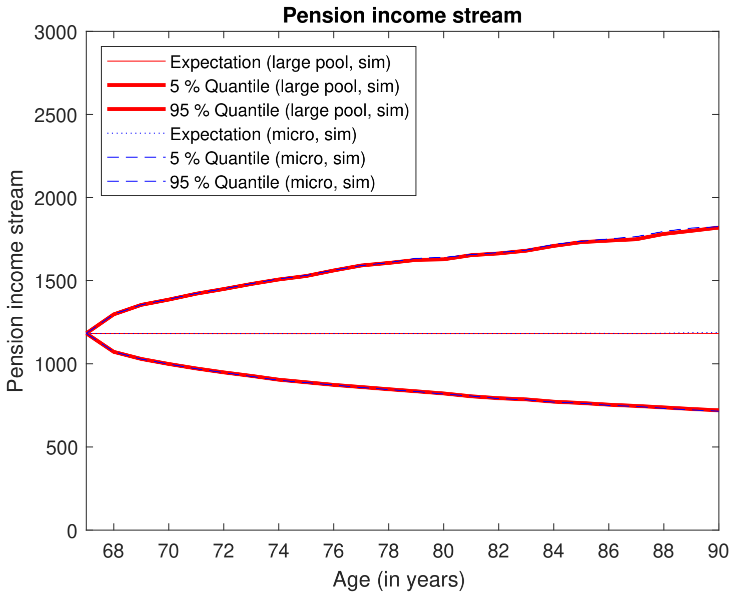

Figure 9: Simulated pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, J(T)=500, and parameter assumptions in line with Table 1. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, parameter assumptions in line with Table 1, implicitly assuming J(T)=∞.

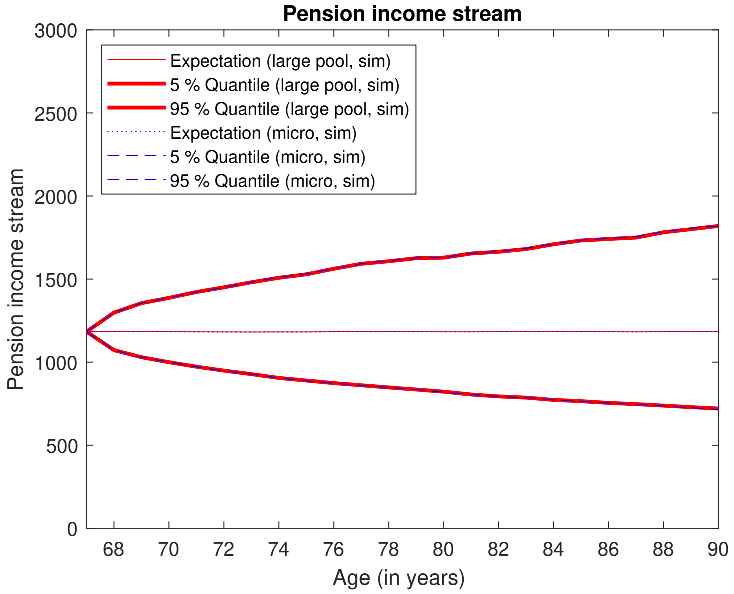

Figure 10: Simulated pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, J(T)=2,500, and parameter assumptions in line with Table 1. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, parameter assumptions in line with Table 1, implicitly assuming J(T)=∞.

If the participant opts for the fixed annuity, micro-longevity risk can be substantial in a small pool of participants (with no new inflow). This result is in line with De Waegenaere et al. (2019). If the participant chooses the variable annuity, then the micro-longevity risk is dominated by the financial risk already for a small pool of participants. The group of participants that currently have a variable annuity is still relatively small (Hers et al., 2019).

4.2 Pension income distribution with macro-longevity risk

It is well known, the (population) life expectancy in the overall Dutch population has grown substantially in the last century, and this trend is expected to continue in the coming years. According to AG (2018), a man currently 65 years old has an average remaining life expectancy of 20.3 years; for a woman this is 23.1 years. In 2069, a 65-year-old man is projected to have a remaining life expectancy of 25.6 years; for a woman this is 28.0 years. This is a significant increase, although these projections obviously contain a measure of uncertainty. A real life example is the increased mortality rate because of COVID-19, which may lead to an overall decrease in future life expectancy. For the variable annuities considered in this setting it is important to consider the uncertainty concerning the aggregate life expectancies of retirees.

In this paper a Lee-Carter (1992) model is assumed. This is a somewhat simpler model than the model used by AG, but nevertheless a highly accepted longevity model in the literature. However, of course longevity shocks can occur that fall outside the scope of this model. Richards et al. (2014) quantify longevity risk by simulating data from the current calibration of the longevity model. The longevity trend risk is then measured by re-estimating the model including the simulated data. De Waegenaere et al. (2019) use a similar approach in analyzing macro-longevity risk. Their paper only took one longevity shock into account for a fixed annuity. Abstracting from equity exposure, the implications of a one-year shock lead to a drop of approximately 1.1% in pension income in a 2.5% quantile for a participant at retirement age without risk sharing. Balter et al. (2019), however, argue, using historical data[11] from the Danish setting, that the macro-longevity risk can be significant in variable annuities. This should be interpreted as an extremely negative scenario that occurred in the past and is not representative regarding expected future longevity shocks. Still, they calculate, for a participant at retirement age in 2007 with an annuity bearing longevity risk, a decrease in pension income of more than 10% after the updates in 2010, 2013, and 2016. Piggot et al. (2005) calculate the longevity risk in group self-annuitization products (GSA) and use the changed expectation adjustment (CEA) factor to adjust for mortality changes. This factor reflects the interpretation of the changed value of the annuity based on a mortality update. Steenkamp (2016) shows under the AG model that the pension income of a fixed annuity in a 5% quantile is 2.5 percentage points lower in replacement rate at the age of 120 if the longevity risk is not insured.

In this paper, in order to be in line with the modeling approach of financial market risk, we choose not to recalibrate the parameters from the Lee-Carter model based on new years of simulated data. We also do not allow for revision of the KNW model and the in-

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[11] Therefore, Balter et al. (2019) differ for obvious reasons from Richards et al. (2014).

put parameters. In reality, every five years a parameters committee reconsiders the financial market model and calibration in order to be in line with financial market expectations at that point in time. In that sense we differ from the actuarial literature described above.

The pension income stream can be defined by the following recursive relation, where $1 \leq j \leq h$, where $p_1^{\text{old}}(T+j-1)$, and $p_1^{\text{new}}(T+j-1)$ represent the one-year survival probability at age $T+j-1$ under the old and new survival tables, respectively.

$$V_h(T+j) = \left\{ V_h(T+j-1) \cdot R^{\text{fin}}(T+j-1) \cdot \frac{1}{p_1^{\text{old}}(T+j-1)} \right\} \cdot \underbrace{\left(\frac{p_1^{\text{old}}(T+j-1)}{p_1^{\text{new}}(T+j-1)} \right)}_{R^{\text{macro}}} \qquad (13)$$

The Appendix contains a description of the Lee-Carter model, where we present calibration results. Note that the variable denoting the macro-longevity risk $R^{\text{macro}}(T+j)$ is expected to be close to 1. This reflects the interpretation that ex ante we do not expect deviations from the best estimate of future survival probabilities. Note that we can easily take into account interest rate risk and inflation risk by inserting for $R^{\text{fin}}(T+j-1)$ in (12) what we derived in Section 3.

Therefore, we can present the pension income stream, taking into account financial market risk and macro-longevity risk shared within one's age group[12]. The pension income stream will be calculated for an equity exposure of w=0% and w=35% in Figures 11 and 12, respectively.

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[12] In Figure 11 and Figure 12 a pension product, in which the macro-longevity risk is borne by the pension provider, is compared to a pension product in which this risk is borne by the pool of participants. If the macro-longevity risk is borne by the pension provider a premium needs to be paid. For simplicity purposes, we abstract from this by setting it at 0%.

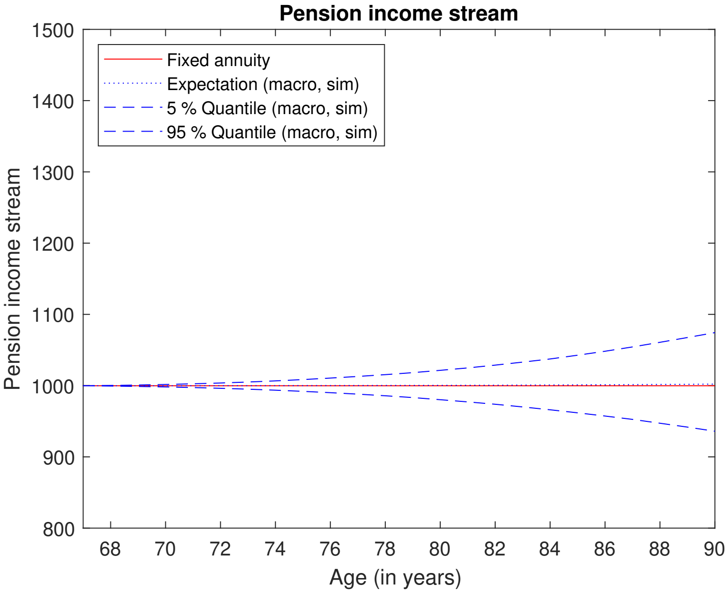

Figure 11: Simulated pension income distribution in a Black and Scholes financial market with w=0%, AIR=r=0.43%, parameter assumptions in line with Table 1*, implicitly assuming $J(T)=\infty$, and including macro-longevity risk. In the Lee-Carter model, we have calibrated the expected life improvements and volatility of life improvements with C=-1.8979 and* $\sigma_k = 2.3198$*, respectively. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=0%, AIR=r=0.43%, parameter assumptions in line with Table* 1*, implicitly assuming $J(T)=\infty$.*

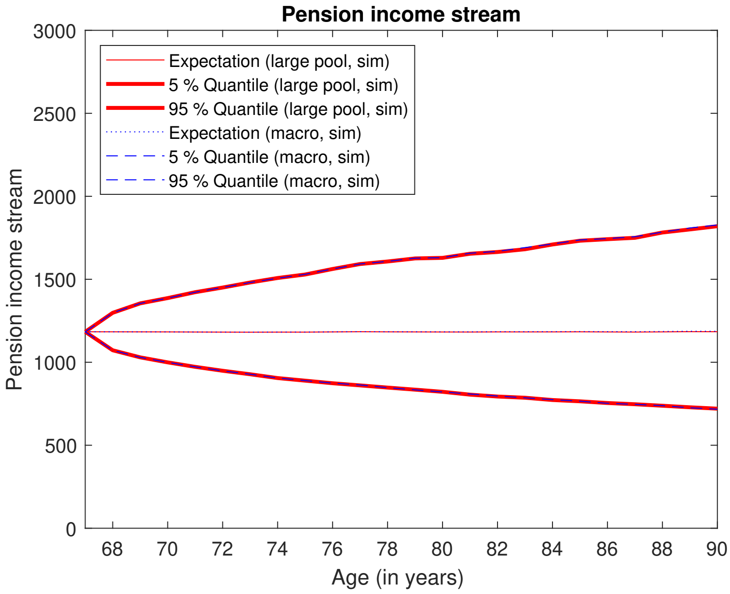

Figure 12: Simulated pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, parameter assumptions in line with Table 1*, implicitly assuming J(T)=∞, and including macro-longevity risk. In the Lee-Carter model, we have calibrated the expected life improvements and volatility of life improvements with C=-1.8979 and* σ_k = 2.3198*, respectively. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, parameter assumptions in line with Table* 1*, implicitly assuming J(T)=∞.*

Figure 12 shows that, for higher equity exposure, the financial market risk dominates the quantiles for the pension income distribution[13]. However, the stand-alone longevity risk is substantial (see Figure 11). Gielen and De Waegenaere (2014) quantify the cost of insuring longevity risk, within the Solvency II framework, as 4.6% in excess of the fair annuity price. We can easily extend Figures 11 and 12 with a premium for insuring longevity risk of around 4.6% and conclude that bearing this risk is attractive for the participant.

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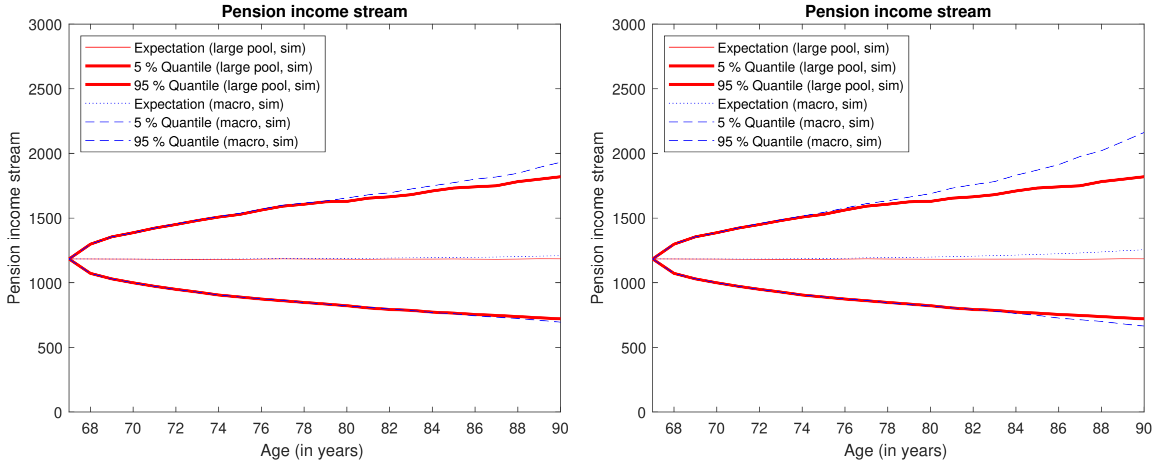
[13] Overlapping quantiles obviously do not exclude the possibility, in individual scenarios where financial returns are in line with expectations, that an increase in life expectancy would lead to a significant decrease in pension income.

4.3 Pension income distribution with macro-longevity risk, robustness

The previous analysis was based on a Lee-Carter model, with historically calibrated expected longevity improvements and calibrated volatility of historical changes in survival probabilities. Of course, there could be much larger changes, and we therefore investigate the robustness of our results to the estimates. We therefore also run simulations that reflect much higher volatility of the survival probabilities. We quantify the macro-longevity risk by assuming a higher volatility of life improvements, for example $\tilde{\sigma}_k = 3 \cdot \sigma_k$, $\tilde{\sigma}_k = 5 \cdot \sigma_k$. This is presented in Figures 13*a* and 13*b* for an asset allocation of *w*=35%, abstracting from micro-longevity risk. We then see that longevity risk becomes a more important risk factor, although marginal differences can be observed in the 5% quantile.



(a) Volatility of life improvements in Lee-Carter set to $\tilde{\sigma}_k = 3 \cdot \sigma_k$.

(b) Volatility of life improvements in Lee-Carter set to $\tilde{\sigma}_k = 5 \cdot \sigma_k$.

Figure 13: Simulated pension income distribution in a Black and Scholes financial market with w=35%, AIR=AIR_{mean}*=2.01%, parameter assumptions in line with Table 1, implicitly assuming* $J(T)=\infty$*, and including macro-longevity risk. We have increased the volatility in the Lee-Carter model by* $\tilde{\sigma}_k = 3 \cdot \sigma_k$ *in Figure 13a and by* $\tilde{\sigma}_k = 5 \cdot \sigma_k$ *in Figure 13b. This is compared to the pension income distribution of a basic variable annuity calculated in a Black and Scholes financial market with w=35%, AIR=*AIR_{mean}*=2.01%, parameter assumptions in line with Table 1, implicitly assuming* $J(T)=\infty$*.*

5 Extensions of the pension income distribution to additional product features

In this section we present an analysis of the dynamics of a high-low pension product. Also, we discuss a guaranteed benefit level pension product that, is a combination of a variable and a fixed annuity. We end this subsection with a description of a pension product that incorporates smoothing of financial shocks. We analyze these pension products in a Black and Scholes financial market without longevity risk.

5.1 High-low pension product

In a high-low pension product the retiree can get a higher pension income during the initial years of retirement. As a consequence, at a later age the retiree receives less pension income compared to a basic variable annuity. In the Dutch institutional setting, there are two important restrictions in a high-low pension product.

1. A high-low construction implies that there is some variation between the highest and lowest pension income levels. The difference between the highest and lowest pension income levels is maximized at 100:75. This means that the lowest payment must be at least 75% of the highest payment.
2. The period that a person can acquire a higher pension income stream is not maximized. However, for practical reasons pension providers typically set this at 5 or 10 years.

To allocate the wealth to money pots, defined in (1), we should introduce some notation. We define $\mathbb{1}_{low}$ as an indicator function with value 1 when we are in the low period and with value 0 when we are in the high period. z_h will be a function of the length of the high period and the relative difference in pension income between the high and the low period. We assume that the lowest pension income is 75% of the highest pension income. We then define $z_h\mathbb{1}_{low}$ as follows, where the derivation can be found in the Appendix.

$$z_h\mathbb{1}_{low} = -\frac{1}{h}\log(0.75) \tag{14}$$

After this, the pension income distribution can be easily calculated using (2) and (3) by increasing the assumed interest rate in (4) with $z_h\mathbb{1}_{low}$, which changes the allocation towards money pots in (1).

$$\text{AIR}_h = r + w\lambda\sigma + z_h\mathbb{1}_{low} \tag{15}$$

We assume w=35%, assumed interest rate in line with (15), and a product where the pension income is lower after 10 years. Figure 14 illustrates this.

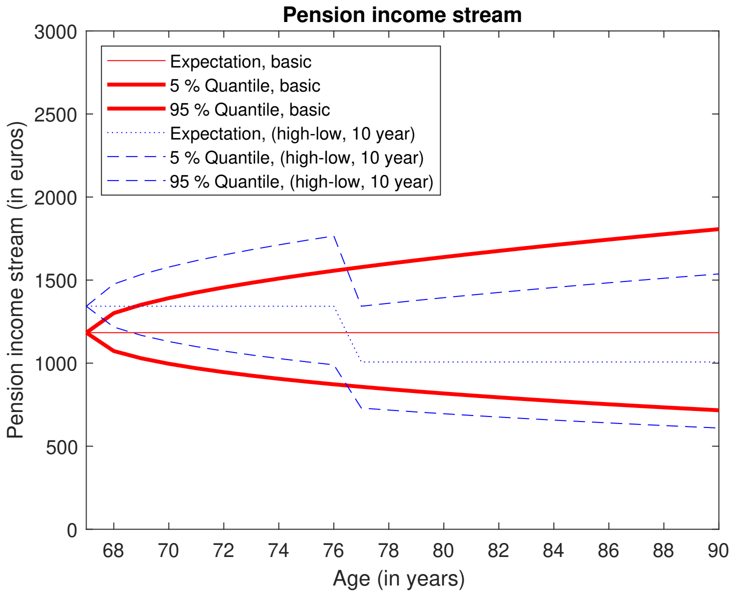


Figure 14: Pension income distribution of a high-low product with lower income after 10 years, in a Black and Scholes financial market with w=35%, AIR in line with (15), and parameter assumptions in line with Table 1. The pension income distribution of the basic variable annuity is calculated in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, and parameter assumptions in line with Table 1.

Figure 14 shows that the expected pension income for a high-low pension product is no longer constant. The shorter the high period, the higher the pension income compared to a basic variable annuity. As a consequence, in later years the total pension income distribution (high-low) is lower compared to a basic variable annuity.

5.2 Pension product with guaranteed benefit level

Guaranteed pension products are under discussion everywhere. Cochrane (2007) derives that for an agent who exhibits a subsistence level a pension product with a guaranteed benefit level is to be preferred. In the setting of Van Bilsen et al. (2019), the reference level leads to a demand for guarantees. Also, Chen et al. (2015) conclude that a variable annuity with a guaranteed component can be optimal. Horneff et al. (2015) show the existence of variable annuities with a guaranteed income in the American setting. Calvet et al. (2019) show that focus on the guaranteed component in a financial product can increase the overall allocation towards the stock market.

In the Dutch setting, everyone in principle implicitly has a guaranteed pension income via the state pension of roughly 1,000 euros per month. The exact amount depends on household composition. In addition, some pension providers offer a pension product with a guaranteed benefit level, where they allocate the accumulated pension assets as a linear combination of a fixed and variable annuity. The provider allocates a fraction $1 - v$ to a fixed annuity and a fraction v to a variable annuity. Hence, participants can increase the guaranteed component by decreasing v in line with their personal preferences. The pension income distribution can then be calculated, using (2) and (3), by making a linear combination of a fixed annuity with AIR=r and a variable annuity with AIR, for example in line with (4). This product is also analyzed in Balter and Werker (2020). We assume r=0.43% and $\lambda\sigma$=4.52% as defined in Table 1.

We take a pension product with guaranteed benefit level with v=35% and w=100%, where w refers to the fraction allocated to stocks in the variable part of the pension product. To get a constant expected pension income stream, the assumed interest rate in the variable part is 4.95 %, in line with (4). This pension product is compared to the basic variable annuity with v=100 %, w=35%, and an assumed interest rate of 2.01% in line with (4). Figure 15 shows the results.[14]

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[14] In Figure 15 the results will be presented until the maximum age of 100. We do this in order to show explicitly that the pension income of a pension product with guaranteed benefit level is never below the guarantee.

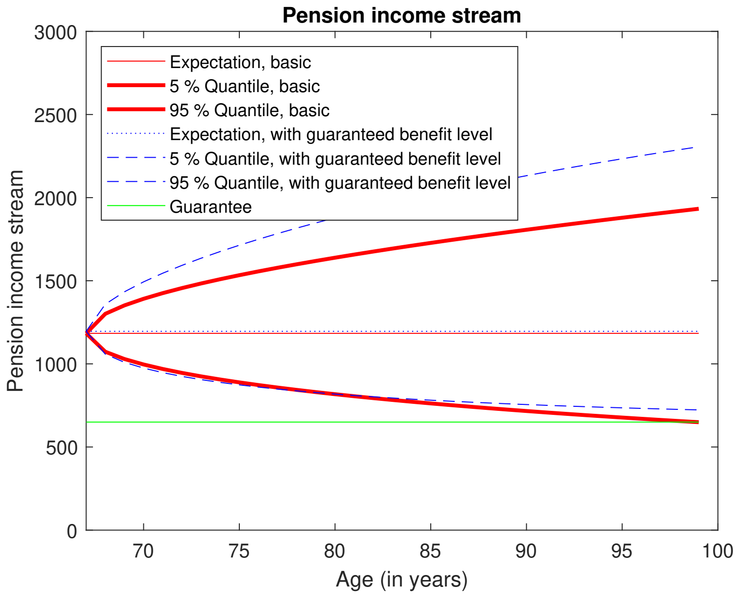
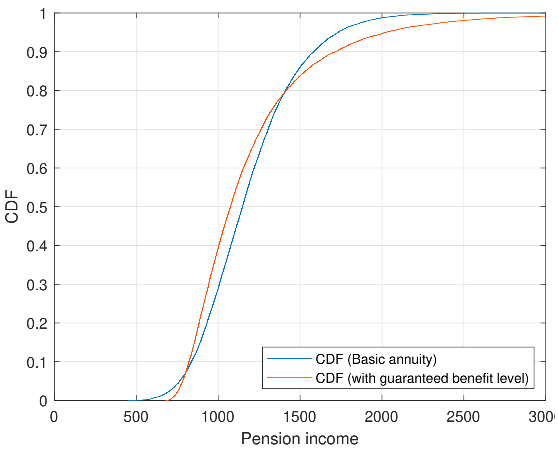


Figure 15: Pension income distribution of a product with guaranteed minimum benefit level, in a Black and Scholes financial market with v=35%, w=100%, AIR = AIR_{mean} = 4.95%, *and parameter assumptions in line with Table* 1. *The pension income distribution of the basic variable annuity is calculated in a Black and Scholes financial market with w=35%, AIR=*AIR_{mean}*=2.01%, and parameter assumptions in line with Table* 1.

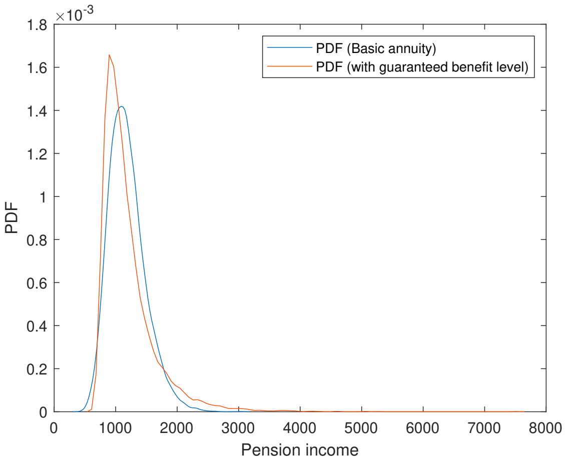
A pension product with a guaranteed benefit level obviously leads to a guaranteed component, as can be seen from Figure 15. This implies that a pessimistic scenario (and lower quantiles) in a product with a guaranteed benefit level can never be lower than the guaranteed component. This is a clear advantage compared to a basic variable annuity, where the participant can end up with less than the guaranteed component in the competing product. For example, in 29 and 118 scenarios out of 10,000, the basic variable annuity is below this guarantee at the age of 80 and 85, respectively.

Since a pension product with a guaranteed benefit level does not need to rebalance between stocks and bonds, the related optimistic pension income exceeds the optimistic pension income in a basic variable annuity. Also, note that this pension product is expected to yield a higher pension income compared to a basic variable annuity. The difference is approximately 1%.

The above suggests that a pension product with a guaranteed benefit level is always better than a similar basic variable annuity, in terms of *v* and *w*. This is obviously not the case, as we will illustrate by showing the probability distribution function (PDF) and the cumulative distribution function (CDF) of the pension income at the age of 85 in Figures 16*b* and 16*b*, respectively.



(a) Cumulative Distribution Function of pension income at the age of 85, of pension products presented in Figure 15*.*



(b) Probability Distribution Function of pension income at the age of 85, of pension products presented in Figure 15*.*

The CDF in Figure 16*a* shows that, in approximately the 8% quantile to the 80% quantile, the basic variable annuity yields a higher pension income compared to the product with guaranteed benefit level at the age of 85. This implies, among other things, that at the age of 85 the median pension income of a basic variable annuity is higher than the median pension income of a pension product with guaranteed benefit level. Similar conclusions can be drawn from the PDF in Figure 16*b*.

5.3 Smoothing of financial shocks in pension products

Balter and Werker (2020) describe a pension product which includes smoothing of financial shocks. Smoothing of financial shocks in a pension product reduces the average year-on-year volatility of pension income. This can be attractive for participants who exhibit habit formation (see, for example, Van Bilsen et al. (2019)).
In line with Balter and Werker (2020) we define N as the smoothing period. In each time period we need to determine the remaining investment horizon of all money pots. If this remaining investment horizon is shorter than the smoothing period, we will not have the asset allocation w for this money pot. Instead, the asset allocation will be a fraction of w. This fraction is $\frac{1+h-j}{N}$, where h refers to the horizon of the money pot, while j indicates the time. Generalizing, we can present the asset allocation at time $j-1$, for a pension income stream during h periods from retirement age onwards, as

$$w_{j-1}(h) = w \cdot \min\left(1, \frac{1+h-j}{N}\right), \; j = 1, \ldots, h \tag{16}$$

which shows that we will end up with a horizon-dependent asset allocation strategy. This means that we no longer have a constant asset allocation during the retirement phase. We can calculate[15] the expectation of the pension income distribution as follows:

$$E_t(V_h(T+h)) = V_h(T)\exp\left(\sum_{j=1}^{h}\left(r + w_{j-1}(h)\lambda\sigma\right)\right) \cdot \left(\frac{1}{p_h(T)}\right) \tag{17}$$

When we insert the definition of $V_h(T)$, defined in (1), in (17), we see that the expected pension income stream is constant if the assumed interest rate satisfies the following:

$$AIR_h = r + \lambda\sigma \cdot \frac{1}{h}\sum_{j=1}^{h} w_{j-1}(h) \tag{18}$$

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[15] The return on money pot $V_h(T)$, h periods from retirement age onwards, still follows a log-normal distribution. The mean and variance of the log return are $\sum_{j=1}^{h} r + w_{j-1}(h)\lambda\sigma - \frac{1}{2}w_{j-1}^2(h)\sigma^2$ and $\sum_{j=1}^{h} w_{j-1}^2(h)\sigma^2$, respectively.

Figure 17 presents the horizon-dependent assumed interest rate that will yield a constant expected pension income in (17).

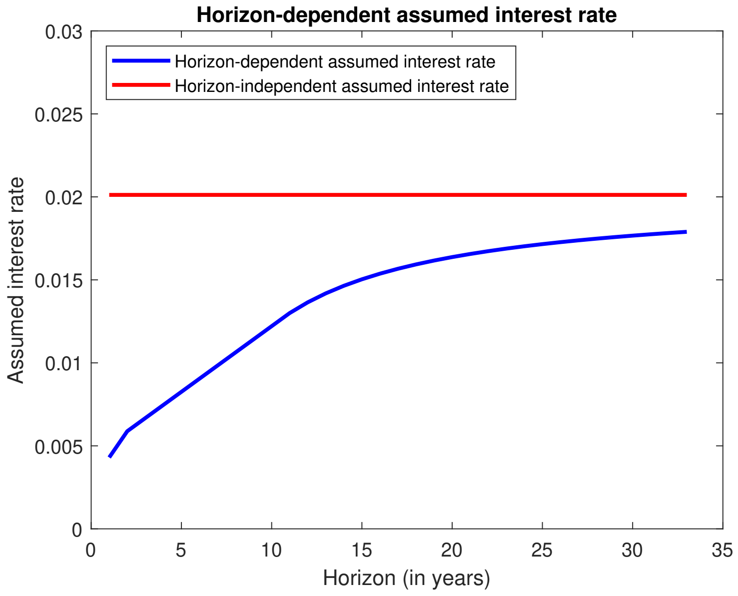

*Figure 17: Horizon-dependent assumed interest rate per money pot from (*18*), with w=35%, N=10 and parameter assumptions in line with Table* 1*.*

Figure 17 shows that the assumed interest rate, defined in (18), increases as the horizon extends farther in the future. Intuitively this means that, for pension payments farther in the future, a higher assumed interest rate can be used, because a higher equity exposure is chosen for these money pots since more time is left to smooth financial shocks. Also, the assumed interest rate in the case of smoothing of financial shocks is for any horizon below the level of the assumed interest rate in the case without smoothening. At some point in time when the money pot tends to expire, we need to reduce the equity exposure (in line with (16)). If this is a money pot for a payment with a distant horizon, we can approach the assumed interest rate in the case without smoothing. Figure 17 shows this, where we add a horizontal line of the assumed interest rate of 2.01% in the case without smoothing of financial shocks.

A pension provider can calculate the expected pension income stream, to act in accordance with the law, by choosing the assumed interest rate from (18) and calculate the expectation of the pension income stream in line with (17).

The pension income streams (with and without smoothing of financial shocks) are presented in Figure 18.

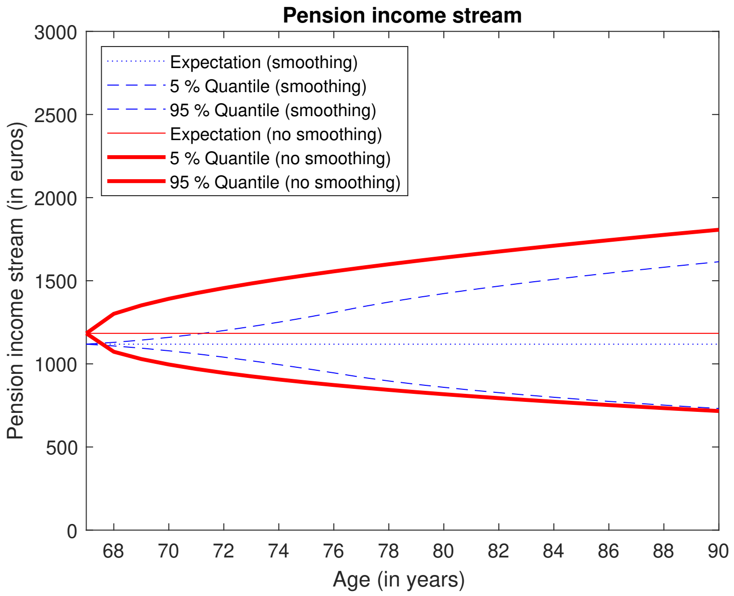

*Figure 18: Pension income distribution of a product which includes smoothing, in a Black and Scholes financial market with w=35%, N=10, AIR horizon-dependent in line with (*18*), and parameter assumptions in line with Table* 1*. The pension income distribution of the product without smoothing (=basic variable annuity) is calculated in a Black and Scholes financial market with w=35%, AIR=AIR$_{mean}$=2.01%, and parameter assumptions in line with Table* 1*.*

In Figure 18 we show that the retiree will have lower initial pension income compared to the case without smoothing. The expected pension income stream is constant, as prescribed by Dutch law.

We also determine the constant asset allocation w (which includes smoothing, implying a horizon-dependent asset allocation) that leads to the same expected pension income as the constant asset allocation $\tilde{w}$. We will do this in three steps as described below.

$$\sum_{k=0}^{L-T-1} p_k(T)\exp\left(-\sum_{j=1}^{k} r + w_{j-1}(k)\lambda\sigma\right) = \sum_{k=0}^{L-T-1} p_k(T)\exp\left(-k(r+\tilde{w}\lambda\sigma)\right) \tag{19}$$

Step 1: Assume an asset allocation w and smoothing period N.

Step 2: We then calculate the term on the left-hand side of (19).

Step 3: Equation (19) then enables us to identify the constant asset allocation without smoothing, $\tilde{w}$ that yields the same constant expected pension income stream, as the horizon-dependent asset allocation implied by the smoothing mechanism.

Equation (19) can be derived if we set the expected pension income stream which includes smoothing (where we assume a w) (17) equal to the expected pension income stream with constant asset allocation $\tilde{w}$ (2). Then we need to solve for $\tilde{w}$.

w	0%	35%	66%
$\tilde{w}$ (N=5, r=0.43%, $\lambda\sigma$=4.52%)	0%	28.99%	54.01%
$\tilde{w}$ (N=10, r=0.43%, $\lambda\sigma$=4.52%)	0%	22.93%	42.38%

Table 3: The relation between the asset allocation which includes smoothing (with w and N) and constant asset allocation $\tilde{w}$, such that the expected pension income stream from (17) and (2), respectively, overlaps.

For the example presented in Table 3, an asset allocation strategy of 35% with a smoothing period of ten years implies a similar constant expected consumption stream compared to an asset allocation strategy of 22.93%. Figure 19 presents this graphically. Note that (1), using the asset allocation $\tilde{w}$, defines the first pension payment for these products.

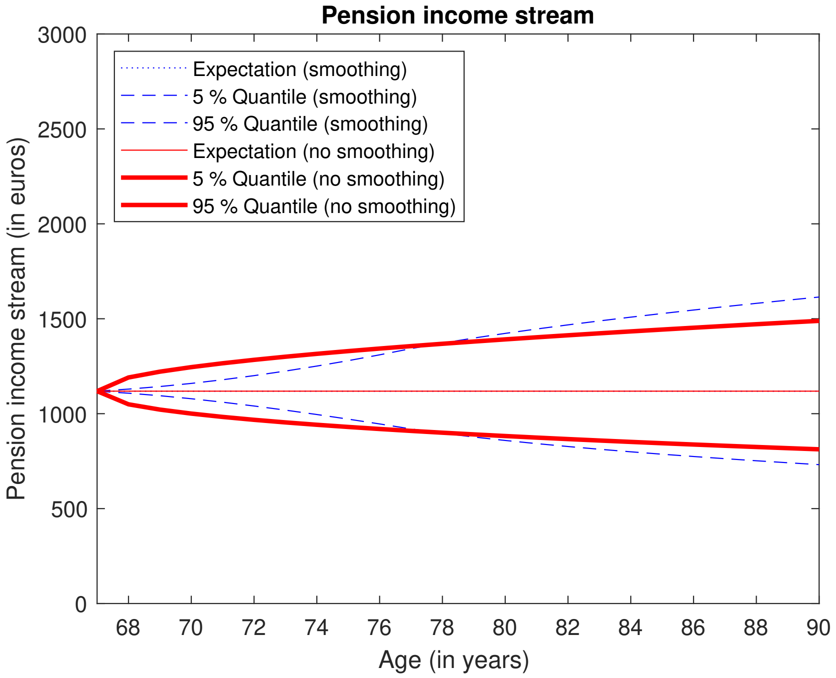

Figure 19: Pension income distribution of a product which includes smoothing, in a Black and Scholes financial market with w=35 %, N=10, AIR is horizon dependent in line with (18) and parameter assumptions in line with Table 1. The pension income distribution of the product without smoothing (=basic variable annuity) is calculated in a Black and Scholes financial market with w=22.93 %, AIR=AIR$_{mean}$=1.45 % and parameter assumptions in line with Table 1.

Figure 19 shows that, with smoothing of financial shocks, the yearly fluctuations in pension income are less compared to a pension product without smoothing of financial shocks. We define the average year-on-year volatility of a pension product as the average yearly change in pension income in absolute terms, in line with the Association of Insurers (2017). We quantify the average year-on-year volatility of a pension product with an asset allocation of 35% and a smoothing period of ten years to be 1.2%. The average year-on-year volatility of a pension product with asset allocation of 22.93% without smoothing is 3.1%. Although these products yield a similar expected pension income, the average year-on-year volatility for a product with smoothing is substantially lower. However, in absolute terms the risk will be higher at later ages in the case which includes smoothing of financial shocks. It is a matter of individual preferences which pension product is preferred by a participant. For example, a participant who exhibits habit formation preferences, a pension product that incorporates a smoothing mechanism can be attractive since it reduces the average year-on-year fluctuations in pension income. However, in the Merton model the average year-on-year fluctuations in pension income do not play a role in optimal product choice.

In principle, we can extend the analysis of non-basic pension products by taking into account time-varying stock returns, interest rate risk, inflation risk, and longevity risk. However, this would not add additional insights to the results presented in earlier sections.

6 Conclusion

We have quantified the risk level of a basic variable annuity that is exposed to stock market fluctuations. We have extended this setting with interest rate risk in line with the KNW model, the underlying model of the scenario set prescribed by the Dutch regulatory authorities. We have shown that, with a full interest rate hedge, the participant faces similar risks as in the Black and Scholes setting which only takes equity risk into account. Also, we have derived the horizon-dependent assumed interest rate that yields a constant expected pension income in nominal terms. Furthermore, we can quantify the pension income stream in real terms.

The additional risk for pension products when taking macro-longevity risk into account depends on the asset allocation in the product. For a fixed annuity the longevity risk can be substantial, although the first-year shock is less than in De Waegenaere et al. (2018). In a 5% quantile, pension income is 2.6% lower fifteen years after retirement when ignoring the insurance premium. For a variable annuity that involves equity exposure, financial risk will dominate the longevity risk. Roughly speaking, the 5% quantile overlaps for a variable annuity with and without longevity insurance. By assuming a higher volatility on future life improvements than a one factor Lee-Carter model would calibrate based on historical data, we show that macro-longevity risk becomes a higher risk factor, even though the additional risk in a 5% quantile is marginal ($<$ 0.4% fifteen years after retirement). Assuming that the Lee-Carter model is the true longevity model and a realistic cost of insuring longevity risk of 4.6% (Gielen and De Waegenaere (2014)), it would be attractive for participants and pension providers to leave the longevity risk in the pool of participants. Steenkamp (2016) comes to a similar conclusion for a fixed annuity with longevity risk. However, as stated before, we cannot guarantee that in the near future no longevity shocks will come about that are beyond the scope of this model as in Balter et al. (2019).

A wide variety of Dutch pension products, several discussed in Balter and Werker (2020) as well, can be written in the methodology used in this paper. Although not explicitly presented, we argue that for these pension products the financial market risk dominates the longevity risk, given that there will be some equity exposure. For pension products that incorporate smoothing of financial shocks, it is possible, depending on the length of the smoothing period, to reduce the average year-on-year volatility of pension income by a factor three compared to a basic variable annuity. This is in line with the results of Balter and Werker (2020) and Bonekamp et al. (2017).

Appendix

In this Appendix we present mathematical derivations. The derivations for each section are presented separately.

Derivations in section 4

Lee-Carter model

Before we can discuss the implications of a macro-longevity shock, we should first discuss the Lee-Carter model. In this model, one-year survival probabilities (in continuous time) can be calculated from the force of mortality $q_{x,t}$ as follows.

$$p_{x,t} = \exp(-q_{x,t}) \tag{20}$$

The (natural logarithm) of the force of mortality can be described as follows, where $\sum_x \beta_x = 1$ and $\sum_t \kappa_t = 0$ ensures uniqueness.

$$\ln(q_{x,t}) = \alpha_x + \beta_x \kappa_t \tag{21}$$

The vectors for α_x, β_x and κ_t will be estimated via (22), where $m_{x,t}$ represents the central death rate between ages x and $x + 1$ at time t with $\zeta_{x,t}$ Gaussian i.i.d.

$$\ln(m_{x,t}) = \alpha_x + \beta_x \kappa_t + \zeta_{x,t} \tag{22}$$

If we denote the first year of the sample with t_0 and the last year of data with $t_{\text{intermediate}}$, we obtain for α_x the following estimate.

$$\alpha_x = \frac{1}{t_{\text{intermediate}} - t_0 + 1} \sum_t \ln(m_{x,t}) \tag{23}$$

Now we perform a singular value decomposition (SVD) on $\ln(m_{x,t}) - \alpha_x \iota$ as follows, where $\iota = (1, 1, \ldots, 1)^T$.

$$\text{SVD}(\ln(m_{x,t}) - \alpha_x \iota) = \lambda_1 U_{x,1} V_{t,1} + \lambda_2 U_{x,2} V_{t,2} + \ldots + \lambda_k U_{x,k} V_{t,k} \tag{24}$$

Then we can estimate β_x, κ_t, where the scaling must be in line with the constraints $\sum_x \beta_x = 1$ and $\sum_t \kappa_t = 0$.

$$\beta_x = \frac{1}{\sum_x U_{x,1}} U_{x,1} \tag{25}$$

$$\kappa_t = \lambda_1 V_{t,1} \sum_x U_{x,1} \tag{26}$$

Next, we should calibrate σ_k and C in the random walk formula for κ_{t+1} in (27), where η_{t+1} has the standard normal distribution.

$$\kappa_{t+1} = \kappa_t + C + \sigma_k \eta_{t+1} \tag{27}$$

Now we are able to present the evolutions of κ_t over time (i.e. the best estimate and the corresponding quantiles). Note that we are extrapolate for h periods.

$$\kappa^{\text{be}}_{t+h} = \kappa_t + Ch \tag{28}$$

$$\kappa^{\text{up}}_{t+h} = \kappa_t + Ch + z_\alpha \sigma_k \sqrt{h} \tag{29}$$

$$\kappa^{\text{down}}_{t+h} = \kappa_t + Ch - z_\alpha \sigma_k \sqrt{h} \tag{30}$$

Substituting (21) in (20) and replacing t by $t+h$, we can write $p_{x,t+h}$ as follows.

$$p_{x,t+h} = \exp(-q_{x,t+h}) = \exp(-\exp(\alpha_x + \beta_x \kappa_{t+h})) \tag{31}$$

We now have the tools to construct the best estimate (be) and the quantiles (up and down) for the future survival probabilities.

$$p^{\text{be}}_{x,t+h} = \exp(-\exp(\alpha_x + \beta_x \kappa^{\text{be}}_{t+h})) \tag{32}$$

$$p^{\text{up}}_{x,t+h} = \exp(-\exp(\alpha_x + \beta_x \kappa^{\text{up}}_{t+h})) \tag{33}$$

$$p^{\text{down}}_{x,t+h} = \exp(-\exp(\alpha_x + \beta_x \kappa^{\text{down}}_{t+h})) \tag{34}$$

Discussing the Lee-Carter model enables us to explain the implications of a macro-longevity shock. Note though that, since we do not take into account the $\zeta_{x,t}$ in the calibration, we underestimate the variance.

An overview of the α_x, β_x and κ_t, based on gender-neutral survival probabilities, is presented below. Note that we make a minor adjustment to the Lee-Carter calibration of α_x to create equivalence with the mortality rates of the Actuarial Association (AG). We solve the following equation for α_x.

$$\alpha_x + \beta_x(\kappa_t + iC) = \log(q^{\text{AG}}_x) \tag{35}$$

In (35) we have to insert for i=3. This is because we use the data from the Human Mortality Database until 2016 and the AG (expected) mortality rates from 2019, in line with the assumption that the annuity is purchased this year.

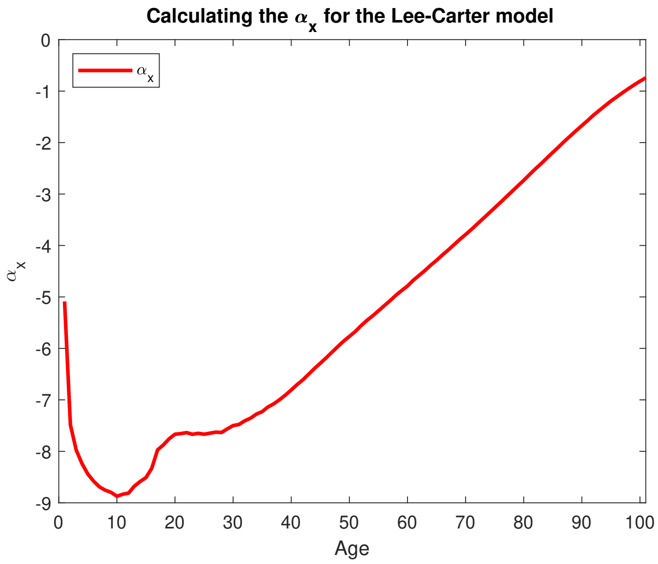

Figure 20: The calibration of α_x in the Lee-Carter model based on gender-neutral data from the Human Mortality Database with sample period 1970-2016. The α_x is marginally adjusted to create equivalence with the survival probabilities of the Dutch Actuarial Association as described in (35).

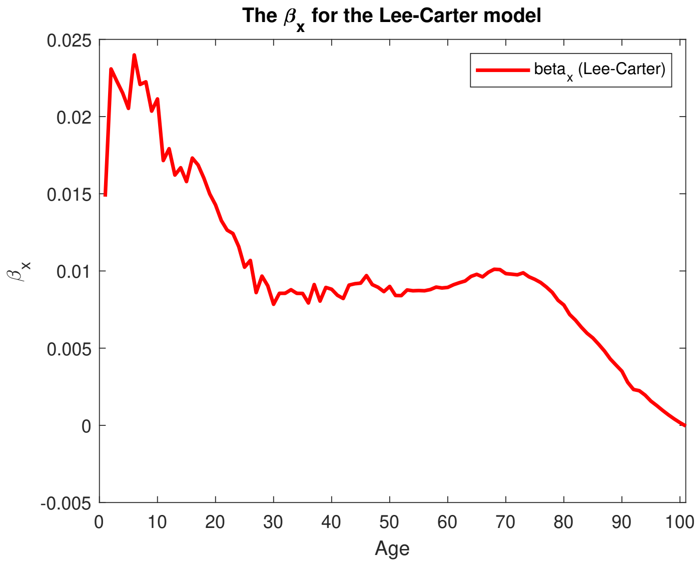

Figure 21: The calibration of β_x in the Lee-Carter model based on gender-neutral data from the Human Mortality Database with sample period 1970-2016.

For σ_k, the volatility of life improvements, we have estimated a value of 2.3198. For C, the expected life improvement over time, we have estimated a value of -1.8979. This is based on gender-neutral data from the Human Mortality database (Netherlands), where the sample period is taken from 1970-2016.

In the specific setting of section 4.2, we must calculate each year the survival probabili-

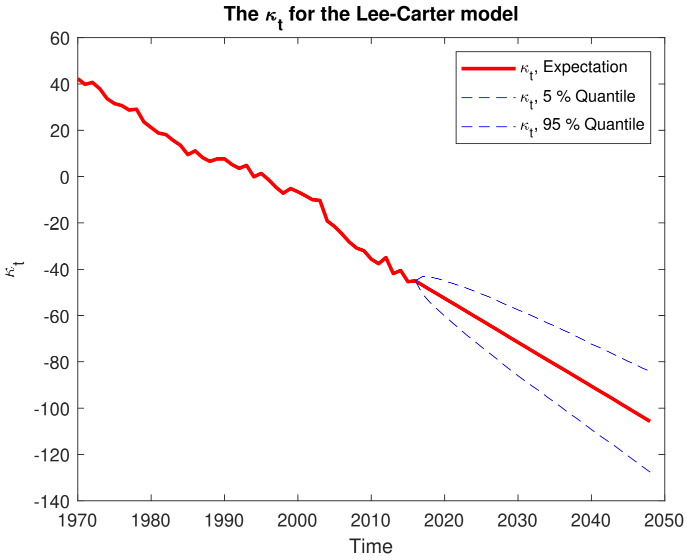

Figure 22: The calibration of κ_t *in the Lee-Carter model based on gender-neutral data from the Human Mortality database with sample period 1970-2016. We have also included simulated values of* κ_t *from (27), with C=-1.8979 and* $\sigma_k = 2.3198$.

ties under the old and new survival tables, as defined below.

$$\begin{aligned} P^{\text{old}}(x) &= \exp(-\exp(\alpha_x + \beta_x\{\kappa_t + iC\})) \\ P^{\text{new}}(x) &= \exp(-\exp(\alpha_x + \beta_x\{\kappa_{t+1} + (i-1)C\})) \end{aligned} \tag{36}$$

For the same reason as in (35), we will use i=3.

Derivations in section 5

The unknown $z_h\mathbb{1}_{low}$ is for simplicity derived in the setting of a fixed annuity. Therefore, the pension income stream, incorporating high-low, is presented as follows.

$$\begin{aligned} E_t(V_h^{\text{high-low, fixed}}(T+h)) &= W_T \frac{p_h(T)\exp(-h(r+z_h\mathbb{1}_{low}))}{\sum_{k=0}^{L-1} p_k(T)\exp(-k(r+z_k\mathbb{1}_{low}))} \cdot \exp(hr) \cdot \left(\frac{1}{p_h(T)}\right) \\ &= W_T \frac{\exp(-h \cdot z_h\mathbb{1}_{low})}{\sum_{k=0}^{L-1} p_k(T)\exp(-k(r+z_k\mathbb{1}_{low}))} \end{aligned} \tag{37}$$

To get a constant pension income stream in the lower period, we need to make this z_h (and we did that already) horizon dependent. This is done as follows.

$$z_h\mathbb{1}_{low} = \frac{1}{h} \cdot Z\mathbb{1}_{low} \tag{38}$$

By inserting 38, we can simplify the expected pension income stream from 37.

$$E_t(V_h^{\text{high-low, fixed}}(T+h)) = W_T \frac{\exp(-Z \cdot \mathbb{1}_{low})}{\sum_{k=0}^{L-1} p_k(T)\exp(-k(r+z_k \cdot \mathbb{1}_{low}))} \tag{39}$$

Note that we can now write the fraction (i.e. difference between highest and lowest pension income) as follows in this setting.

$$\begin{aligned} \text{Difference high-low} &= \exp(-Z \cdot \mathbb{1}_{low}) \\ -\log(\text{Difference high-low}) &= Z \cdot \mathbb{1}_{low} \end{aligned} \tag{40}$$

So we can also write as follows.

$$\begin{aligned} z_h \mathbb{1}_{low} &= \frac{1}{h} Z \mathbb{1}_{low} \\ &= -\frac{1}{h} \log(\text{Difference high-low}) \end{aligned} \tag{41}$$

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