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The impact of uncertainty in risk preferences and risk capacities on lifecycle investment

Anne G. Balter
Rob van den Goorbergh
Nikolaus Schweizer

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Affiliations
Anne G. Balter – Tilburg University
Rob van den Goorbergh – APG
Nikolaus Schweizer – Tilburg University

Summary

We study the impact of suboptimal lifecycle investment as a result of changing risk preferences and unanticipated shocks in income. In particular, we consider the possibility that risk aversion varies with age, and we measure the welfare effect when the risk exposure decided on earlier in life was based on a wrong or outdated assessment of one's risk aversion. Moreover, we explicitly model the lifecycle and allow for wrong expectations about future income and thus about future pension contributions. We find that leverage constraints bound the losses caused by underestimation of risk aversion. A drop in pension accrual due to circumstances such as disability, self-employment, emigration, or part-time work can cause considerable losses, especially when the risk aversion level is underestimated.

Samenvatting

De invloed van onzekerheid in risicopreferentie en risicocapaciteit op levensloopinvesteringen

We bestuderen de invloed van suboptimale levensloopinvesteringen als gevolg van veranderende risicopreferenties en onverwachte inkomensschokken. We houden met name rekening met de mogelijkheid dat risicoaversie varieert met leeftijd en we meten het welvaartseffect wanneer de risicoblootstelling waartoe eerder werd besloten gebaseerd was op een verkeerde of achterhaalde inschatting van iemands risicoaversie. Verder modelleren we de levensloop expliciet en houden we ook rekening met verkeerde verwachtingen over toekomstig inkomen en daarmee over toekomstige pensioenpremies. Onze bevinding is dat leenrestricties de verliezen beperken die veroorzaakt zijn door onderschatting van risicoaversie. Een daling van de pensioenopbouw door bijvoorbeeld arbeidsongeschiktheid, zelfstandig ondernemerschap, emigratie of deeltijdwerk kan grote verliezen veroorzaken, zeker wanneer het niveau van risicoaversie wordt onderschat.

1 Introduction

Under new Dutch pension law, pension funds and insurance companies are required to elicit the risk preferences and risk capacities of individual participants and to adjust (collective) investment strategies accordingly. A considerable amount of recent research (e.g. Alserda et al. (2019), AFM (2023)) has studied how the risk preferences and risk capacities of participants can be measured. Our focus is on the next step, from (possibly noisy) preference measurements to investment strategies. Specific attention is given to the time dimension of the problem and the associated uncertainty, as risk attitudes and risk capacities may change over time. Moreover, there is a large variation in life paths, from the time when pension accrual begins to the pay-out phase. This uncertainty and the possible instability in preferences is a considerable threat to the potential benefits from early personalization of investment strategies.

With evolving risk preferences, an investment strategy that may look optimal to a young participant can turn out to look less promising at later points in time. Even if young participants could see into the future, they might not want to take advice from their older selves because of changing views on what constitutes an acceptable risk. Of course, this problem of evolving preferences does not exist in isolation. Besides a possible uncertainty in future preferences, there is considerable (economic) uncertainty over long horizons when it comes to human capital. Finally, the preferences at an older age should ideally guide the riskiness of investment towards retirement. Yet, these old-age preferences may not be known at the time when the investments are made.

The goal of this paper is to investigate the welfare effect arising from changes in both risk preferences and risk capacity (which we largely identify with human capital). We follow a model-based approach that uses different scenarios for both individual preferences and for the economy. Our sensitivity analyses are based on a simple "moment-of-truth" type model, where a participant realizes his or her true risk preferences or true risk capacity only at some intermediate age. We investigate and quantify how sensitive such a participant's pension outlook is to decisions made earlier in life, when decisions were based on a possibly wrong assessment of risk preferences or of future pension contributions.

Our discussion in this paper starts with the individual participant, studying the importance of tailoring decisions to the participant's specific situation and the costliness of "mistakes" due to changes in risk preferences or risk capacities. Aside from some important exceptions, we find that outcomes are surprisingly robust to deviations from the theoretically optimal strategy. Importantly, this robustness result is largely independent of the precise reason for a difference between the implemented strategy and the theoretical optimum. Besides changes in risk preferences or risk capacities, one can also interpret our results in terms of (1) measurement errors in communicating preferences between the participant and the pension fund, (2) a pension fund grouping slightly different participants in a single risk class, or (3) young participants paying little attention to their pension investments – or a combination of these factors. Perfectly measuring a participant's old-age risk preferences and life-time risk capacity to fully personalize pension investments seems like a daunting task. This is even more the case because financial market conditions are only observed up to statistical error. Our results suggest that such full personalization may not be necessary.

As a first main finding, we see that following a (somewhat) suboptimal lifecycle for up to ten years hardly has an effect on welfare, as this can be counteracted by switching to the optimal lifecycle in time. Of course, the idea here is not to compensate overly risk-averse behavior in earlier periods by overly risky behavior later in life, or the other way around. What rather helps is that the amount invested in risky assets at early ages is limited due to leverage constraints, that a close-to-optimal investment fraction tends to give close-to-optimal results, and that a considerable part of the investment horizon is still left after ten or twenty years.

In fact, leverage constraints are key for ensuring that wealth cannot get (too) negative. Without such constraints, agents who overestimate their human capital (i.e., their future pension contributions) or underestimate their risk aversion may invest too riskily and end up in a situation from which they cannot recover without financial help.[1] Under leverage constraints, the possible welfare losses from working with a wrongly estimated risk aversion or wrongly estimated human capital are limited. Underestimation of risk aversion leads to excessively risky investments – but only to the point allowed by the leverage constraint. Potential losses from overestimation of risk aversion (or underestimation of human capital) are also limited as the investment mix converges to completely risk-free investment. In line with Joseph et al. (2021), we often observe that losses increase more slowly when risk aversion is overestimated rather than underestimated. However, this is not a general result. There are also cases where the absolute loss due to taking too little risk is larger.[2]

Next, we perform a sensitivity analysis with respect to financial market assumption, varying, in particular, the expected return on risky investment. With a higher expected return, the target fraction of risky investment is higher. Thus, in combination with hu-

[1] The Future of Pensions Act (Wet Toekomst Pensioenen) distinguishes between a solidarity scheme and a flexible defined contribution scheme (see Nijman (2022) for an overview). In the solidarity scheme, a leverage position up to 150% will be allowed. When leveraging is allowed and rebalancing happens in discrete time, wealth can become negative. However, pension wealth is not allowed to be negative at any time. The solidarity reserve could in such case ensure that pension wealth remains positive.

[2] For examples, see the left plots in Figures 4b, 5, 6a and 9a.

man capital, there is a more restricted investment trajectory due to leverage constraints being more binding. In this context, we also demonstrate a well-known fact from the literature on quantitative finance: estimating the expected return without access to centuries of data leads to considerable remaining uncertainty about expected returns and thus about the optimal investment fraction. From a quantitative perspective, this type of uncertainty will often be greater than the uncertainty in risk preferences or risk capacity.

Lastly, we show the sensitivity to different shapes of income (and contribution) trajectories over the lifecycle. In our baseline model, we allow for relatively drastic mistakes in estimated human capital – such as a participant wrongly expecting pension contributions to triple at some point. With more realistic amounts of uncertainty about income trajectories, we find much smaller welfare losses. Incorrect estimation of one's risk aversion by a factor two or three seems a more realistic threat compared to similarly drastic mistakes in assessing one's future income.

A key lesson we can draw is that an unexpected drop in pension contributions, such as due to disability, can go together with severe *additional* welfare losses when investment behavior had been too aggressive. Such a drop in pension contributions can also arise from becoming self-employed and thus leaving the mandatory participation in pension saving – or from any other reason that causes a switch from active to "sleeper" status. Trivially these effects are smaller when the unexpected drop in pension contributions is smaller. Such a drop could result from a divorce, a switch to a part-time job, becoming partially self-employed, or loss of a job.

The type of sensitivity analysis we conduct in this paper has some natural limitations. We can examine some sources of suboptimal decisions but never at all of them. Moreover, by settling on one particular relatively simple model, some potential threats will not be covered by our analysis. We mention some of them here. First, our financial market model assumes constant investment opportunities, constant interest rates, and abstracts from inflation. Second, on the individual preference side, we only consider utility functions with different levels of constant relative risk aversion (CRRA). We do not consider other utility functions or preferences outside the expected-utility paradigm such as habit formation, regret, loss aversion, or cumulative prospect theory. Each of these factors can potentially lead to welfare losses that our current analysis does not account for.

This paper lies at the intersection of two larger streams of related work in the pensions literature, namely research on empirical elicitation of preferences and research on optimal investment for individuals with heterogeneous and potentially uncertain risk preferences. See Bokern et al. (2021) and Alserda et al. (2019) among others for references to the former category on preference elicitation methodologies. A particularly related project is recent work by Bokern et al. (2022) on the dynamics of risk attitudes. Our research can be thought of as adding the next steps from dynamic preference trajectories to decisions. In the second category, there are studies by Joseph et al. (2021), Alserda et al. (2019), Balter and Schweizer (2021), and Balter et al. (2022). While these projects focus on heterogeneity in the cross-section of participants at a given point in time, the focus of our research is on heterogeneity over time for a fixed participant. Introduction of another time dimension through the evolution of human capital gives rise to lifecycle theory. We explicitly model the evolution of salaries and human capital in the investment problem we consider. Our paper thus also belongs to the literature on lifecycle investment; see Bodie et al. (1992), Campbell et al. (2001) and Cocco et al. (2005) for seminal contributions in that area.

The paper is organized as follows: Section 2 presents the model, while Section 3 presents the results. Section 4 discusses some practical challenges and Section 5 contains our conclusions.

2 The setting

2.1 Financial Market

There is a risky asset with price process S_t over a time horizon $[0,T]$. The dynamics of $S_{t_{i+1}}$ are given by

$$S_{t_{i+1}} = S_{t_i} e^{\mu\Delta - \frac{1}{2}\sigma^2\Delta + \sigma\Delta W_{t_{i+1}}}, S_{t_0} = 1, \tag{1}$$

where μ and σ are positive constants and $\Delta W_{t_{i+1}}$ is a Brownian motion increment with mean zero and variance Δ. Thus, S_t follows a geometric Brownian motion. Time is discretized in M steps where $t_i = i\Delta, \Delta = \frac{T}{M}$ implying $t_0 = 0$ and $t_M = T$. Our results are all based on a sample of $N = 10,000$ scenarios drawn from this model.

We consider an investor who maximizes expected utility from terminal wealth at time T by trading in the risky asset S and in a riskless asset A. The latter evolves by

$$A_{t_{i+1}} = A_{t_i} e^{r\Delta}. \tag{2}$$

We now revisit the classical portfolio choice problem, i.e., the Merton problem, where V_T is the terminal wealth. Denoting by m_t^V the fraction of wealth invested in the risky asset at time t, the dynamics of V_t are given by

$$V_{t_{i+1}} = (1 - m_{t_i}^V) e^{r\Delta} V_{t_i} + m_{t_i}^V \frac{S_{t_{i+1}}}{S_{t_i}} V_{t_i}. \tag{3}$$

The investor maximizes the objective

$$\max_{(m_{t_i}^V)_i} E[u(V_T)], \tag{4}$$

where we assume that utility u is a CRRA function,

$$u(x) = \begin{cases} \frac{x^{1-\gamma}}{1-\gamma} & \gamma > 1 \\ \ln x & \gamma = 1, \end{cases} \tag{5}$$

and where γ captures the constant relative risk aversion $-x\frac{u''(x)}{u'(x)}$. This is equivalent to solving

$$\max_{(m_{t_i}^V)_i} CE^\gamma(V_T) = \max_{(m_{t_i}^V)_i} u^{-1}(E[u(V_T)]), \tag{6}$$

where $CE^\gamma(V_T)$ denotes the certainty equivalent of terminal wealth V_T. It is well-known that in the continuous time limit, $\Delta \to 0$, the optimal investment fraction is

$$\bar{m}_{t_i}^V = \frac{\mu - r}{\sigma^2 \gamma}. \tag{7}$$

This is also known as the Merton fraction. In the pension context that we consider here, terminal time T denotes the moment of retirement, time is counted in years, and time 0 is the start of the planning horizon. The investor can be thought of as a participant in a pension product offered by a pension fund or insurer. The pension fund or insurer executes the trading (and thus the utility maximization) on behalf of the participant. We thus also call the investor the "participant" or, simply, the "agent". Wealth V can be thought of as the total *pension* wealth. The latter consists of yearly contributions that are proportional to one's salary. Total pension wealth can be subdivided into two categories, financial wealth F_t and human capital H_t:

$$V_{t_i} = F_{t_i} + H_{t_i}. \tag{8}$$

The annualized pension contribution in period t is denoted by h_t. This is equivalent to an actual contribution of $h_t\Delta$ in period t. The fraction of *financial* wealth that is invested in the risky asset S is denoted by m_t. Together this implies the following dynamics of financial wealth

$$F_{t_{i+1}} = (1 - m_{t_i})e^{r\Delta}F_{t_i} + m_{t_i}\frac{S_{t_{i+1}}}{S_{t_i}}F_{t_i} + h_{t_i}\Delta e^{r\Delta}. \tag{9}$$

Thus, in every period of length Δ, the pension account is invested for m_{t_i} in the risky asset, $1 - m_{t_i}$ on the bank account, and the pension contribution $h_{t_i}\Delta$ is added at the beginning of the period and assumed to be invested on the bank account throughout the period. Alternatively, this can be interpreted such that the contribution $h_{t_i}\Delta e^{r\Delta}$ is added to the pension account at the end of the period.

We assume that labor income is independent of developments in financial markets. Moreover, we assume salary to be deterministic. Human capital is defined as the present value of all future premium contributions,

$$H_{t_i} = \sum_{j=i}^{M-1} h_{t_j}e^{-r(j-i)\Delta}\Delta. \tag{10}$$

The amount of human capital affects how much an investor is willing to invest via the magnitude and riskiness of his or her *total* wealth, i.e., the sum of current financial wealth and human capital, $V_{t_i} = F_{t_i} + H_{t_i}$. At the moment of retirement, human capital equals zero

$$H_T = 0 \text{ and thus } V_T = F_T. \tag{11}$$

The dynamics of H_{t_i} can also be expressed by the recursive formulation

$$H_{t_i} = e^{-r\Delta}H_{t_{i+1}} + h_{t_i}\Delta. \tag{12}$$

Finally, note that only F is directly observed in practice. In contrast, H and V can only be best estimates based on future pension contributions.

The dynamics of F_t, A_t and V_t imply that any investment fraction m_t based on F can be translated into an investment fraction m_t^V based on V using the formula

$$m_{t_i} = m_{t_i}^V \frac{F_{t_i} + H_{t_i}}{F_{t_i}}. \tag{13}$$

As we are trading in discrete time, both F and V could become negative in case of leveraging. Mathematically, what we need to guarantee for our model to be well-defined is that terminal wealth $V_T = F_T$ is positive because otherwise $u(V_T)$ is negative infinity. To achieve this, one needs to ensure that the investment fraction $\bar{m}_{t_i}^V$ defined in (7) satisfies

$$0 \leq \bar{m}_{t_i}^V \leq 1. \tag{14}$$

All scenarios studied in this paper are such that (14) holds. Participants may thus want to leverage at the level of financial wealth, $m_{t_i} > 1$, but not at the level of total wealth, leading to possibly negative values of F_{t_i} at intermediate time points which are then compensated by later pension contributions. In line with existing policy regulations that try to limit the probability and extent of negative financial wealth, we assume that there is an upper bound $m_{max} \geq 1$ on the maximum degree of leveraging with regard to financial wealth. We assume throughout that the fraction of financial wealth that is invested in the risky asset is chosen to reflect as closely as possible an investment under the Merton fraction on the level of total wealth,

$$\bar{m}_{t_i} = \min\left(m_{max}, \bar{m}_{t_i}^V \frac{F_{t_i} + H_{t_i}}{F_{t_i}}\right). \tag{15}$$

In our sensitivity analyses below, we consider situations in which investment decisions are based on misspecified values of H and γ (and thus $\bar{m}_{t_i}^V$). In that case, we can still simulate the actual evolution of financial wealth by combining these misspecified investment fractions with the actual process of pension contributions. However, when the investment mix is based on overestimated values of the pension contributions h_{t_i}, it can happen that financial wealth becomes negative and the pension contributions are insufficient for keeping total wealth positive and, importantly, insufficient for a recovery at the end when $F_T = V_T$ with probability 1. The problem is that, in order to check whether (14) is satisfied for a given choice of investment fraction m_{t_i}, one needs to compute the implied investment fraction at the level of total wealth,

$$m_{t_i}^V = m_{t_i} \frac{F_{t_i}}{F_{t_i} + H_{t_i}}. \tag{16}$$

Performing this calculation with an overestimated value for the future pension contribution H_{t_i} can lead to a false belief that $m_{t_i}^V$ is low enough to satisfy (14) and keep total wealth always positive. In principle, only a ban on leveraging, $m_{max} = 1$, can completely eliminate this possibility independently of h, implying that the right hand side of (16) is less than 1 for all $H_{t_i} \geq 0$. In this paper, we take a pragmatic approach to this problem: we fix our set of 10,000 simulated scenarios and note that for all combinations of h and m_{max} that we consider, terminal wealth is positive in all scenarios.[3]

As output measure we calculate the certainty equivalent as a function of $(m_t)_t$, $(h_t)_t$ and γ,

$$CE(m, h, \gamma) = u^{-1}\left(E[u(F_T(m, h))]\right) = \left(E[F_T(m, h)^{1-\gamma}]\right)^{\frac{1}{1-\gamma}}. \tag{17}$$

The certainty equivalent corresponds to the deterministic amount of money received at time T that the agent considers exactly as valuable as the stochastic payoff $F_T(m, h)$. The certainty equivalent under the strategy $\bar{m}_{0,T}(h, \gamma)$ we denote by CE^*,

$$CE^* = CE^*(\bar{m}_{0,T}(h, \gamma), h, \gamma) \tag{18}$$

where

$$\bar{m}_{0,T}(h, \gamma) = \left(\min\left(m_{max}, \frac{\mu - r}{\sigma^2\gamma}\frac{F_{t_i} + H_{t_i}}{F_{t_i}}\right)\right)_{i=0}^{M-1}.$$

In the following, we study the reduction in the certainty equivalent that arises from using strategies $m \neq \bar{m}_{0,T}(h, \gamma)$.

2.2 Suboptimal Decisions

In our analysis, we mainly focus on two sources of suboptimal decision, namely misperceived (or changing) risk preferences and/or misperceived risk capacity, i.e., wrong projections of future pension contributions. We capture this by a simple "moment of truth" model: at some intermediate time point t, such as at age 40 or 50, the agent realizes that his or her investment strategy so far was based on a misperception of risk preferences or expected future earnings. Compared to more complex and thus possibly more realistic models, this model has two major advantages. First, it is simple and easy to interpret and understand. Second, it is relatively extreme and should thus give an upper bound on more continuous processes of adjusting beliefs.

In our baseline model, we assume that the true risk aversion is equal to γ and that the pension contributions are equal to h_0 from time 0 to time t and equal to h_1 from time t to T, reflecting an increase in salary along the career path. Under false beliefs, the risk aversion is equal to $\tilde{\gamma}$ from time 0 to t and correct afterwards. Initially, the computation of overall human capital is based on the true h_0 from time 0 to t and based on false

[3] In fact, as soon as terminal wealth is negative in a single scenario, expected utility jumps to $-\infty$, leading to trivial results.

expectations $\tilde{h}_1$ for time t to T. At time t the agent realizes that his or her career trajectory does not lead to $\tilde{h}_1$ but rather to h_1. From that time onwards, the agent calculates human capital based on h_1. The pension accruals are always based on the true contributions. However, it is the false expectation that causes suboptimal investment strategies.

Note that there is a slight asymmetry in how we model misperceptions about risk preferences and about risk capacity. For risk preferences, it is easy to conceive that an agent thinks for many years that his or her risk aversion is $\gamma = 3$ even though it really is $\gamma = 6$. This is even more so because γ in the present context should be thought of as a best estimate of risk aversion at the moment of retirement at time T, not the current level of risk aversion. In contrast, it seems less realistic that agents would have strongly distorted perceptions of their current pension contributions. Consequently, we only allow for wrong beliefs about the future level of h but not about its current level.

To summarize the notation,

$$\gamma_{t_i} = \gamma \text{ for all } t_i \in [0, T] \tag{19}$$

$$\tilde{\gamma}_{t_i} = \begin{cases} \tilde{\gamma} & \text{if } t_i < t \\ \gamma & \text{if } t_i \geq t \end{cases} \tag{20}$$

$$h_{t_i} = \begin{cases} h_0 & \text{if } t_i < t \\ h_1 & \text{if } t_i \geq t \end{cases} \tag{21}$$

$$\tilde{h}_{t_i} = \begin{cases} h_0 & \text{if } t_i < t \\ \tilde{h}_1 & \text{if } t_i \geq t \end{cases} \tag{22}$$

$$H_{t_i} = \begin{cases} \sum_{j=i}^{t/\Delta-1} h_0 e^{-r(j-i)\Delta}\Delta + \sum_{j=t/\Delta}^{M-1} h_1 e^{-r(j-i)\Delta}\Delta & \text{if } t_i < t \\ \sum_{j=i}^{M-1} h_1 e^{-r(j-i)\Delta}\Delta & \text{if } t_i \geq t \end{cases} \tag{23}$$

$$\tilde{H}_{t_i} = \begin{cases} \sum_{j=i}^{t/\Delta-1} h_0 e^{-r(j-i)\Delta}\Delta + \sum_{j=t/\Delta}^{M-1} \tilde{h}_1 e^{-r(j-i)\Delta}\Delta & \text{if } t_i < t \\ \sum_{j=i}^{M-1} h_1 e^{-r(j-i)\Delta}\Delta & \text{if } t_i \geq t. \end{cases} \tag{24}$$

We denote the resulting suboptimal certainty equivalent by

$$\widetilde{CE} = CE\left(\left\{ \bar{m}_{0,t}(\{h_0, \tilde{h}_1\}, \tilde{\gamma}), \bar{m}_{t,T}(\{h_0, h_1\}, \gamma) \right\}, \{h_0, h_1\}, \gamma \right) \tag{25}$$

and calculate the relative loss by the certainty equivalent ratio, which is the certainty equivalent of the suboptimal investment relative to the optimal certainty equivalent

$$CE\text{-ratio} = \frac{\widetilde{CE}}{CE^*}. \tag{26}$$

This quantity is at most equal to 1 and can be interpreted as follows. When $CE\text{-ratio} = 0.95$ this implies that the certainty equivalent is 5% lower than the certainty equivalent that could have been attained under the optimal investment strategy. To put this number into further perspective, suppose that the optimal certainty equivalent corresponds to an annualized average growth rate ρ^*, $CE^* = V_0 \exp(\rho^* T)$, while the suboptimal certainty equivalent corresponds to a reduced rate $\widetilde{\rho}$, $\widetilde{CE} = V_0 \exp(\widetilde{\rho} T)$. Then, the reduction in rate, $\delta = \rho^* - \widetilde{\rho}$, can be written as

$$\delta = \frac{1}{T} \log(CE\text{-ratio})$$

Consequently, for an investment horizon of forty years, $T = 40$, a $CE\text{-ratio}$ of 0.95 corresponds to a reduction in the yearly growth rate by $\delta = 0.13\%$, while for $T = 20$ we find $\delta = 0.26\%$. Another interpretation of the $CE\text{-ratio}$ is based on reduced pension contributions: $CE\text{-ratio} = 0.95$ implies that $\widetilde{CE}$ is as good as reducing all contributions as well as initial financial wealth by 5% and then investing in the optimal way.[4]

[4]Whether a given level of welfare loss is small or large is highly subjective – and we would not want to prescribe a fixed cutoff value. To simplify the discussion below, we call losses that are less than 1% small and losses that are higher than 20% substantial. We leave it to the reader to decide where the precise cutoff for adverse outcomes should be.

3 Results and discussion

3.1 Outline, Scenarios and Parameters

We are now ready to compute the relative losses due to suboptimality caused by wrong preference estimation, wrong salary expectations, or both. We begin with an overview of the different scenarios that we will study. In Subsection 3.2, we then consider our baseline scenario in detail. In Subsection 3.3, we consider different choices of the true parameters with respect to risk aversion and risk capacity. Next, in Subsection 3.4 we discuss the robustness of our results to financial market conditions. In Subsection 3.5, we vary the timing of the "moment of truth" when the agent realizes the true parameters, and in Subsection 3.6 we consider alternative labor income assumptions that reflect continuous wage growth rather than a one-time jump. Finally, in Subsection 3.7, we look at different bounds on the ability to leverage.

Throughout we assume the following set of parameters: $T = 40$, $M = 120$, $\Delta = \frac{1}{3}$, and $h_0 = 1$. This reflects an individual aged 27 who retires at age 67. As our benchmark, we choose scenario Z_1 as shown in the first row of Table 1. We assume a true risk aversion equal to $\gamma = 3$, which is within the typical $1 - 10$ range found in the literature.[5] The yearly pension contribution is normalized to $h_0 = 1$, which after t years grows with a factor 2 to $h_1 = 2$. In line with the Dutch solidarity pension contribution scheme, we allow for 50% leverage, thus $m_{max} = 1.5$. Moreover, the parameters in the financial market are $\mu = 0.04$, $r = 0.01$ and $\sigma = 0.2$. To avoid a strong demand for excessive leverage at the start of the investment horizon, we set $F_{t_0} = 1$ so that the initial capital is already equal to one year of pension contributions. Moreover, we choose $t = 20$, moving the moment of truth, at which the agent aligns the investment strategy with the true preferences and true income trajectory, to age 47.

In Table 1, we introduce eight alternative scenarios including different values for the true parameters (γ, h_1) in scenarios Z_2-Z_5, a different timing of the moment of truth t in scenarios Z_6 and Z_7, and different bounds on the degree of leveraging (m_{max}) in scenarios Z_8 and Z_9. In the later sections, we assume that one of these scenarios is the truth but that the agent is not aware of this initially. For instance, in Z_5 the agent will suffer from disability and not make any additional pension contributions after time t, $h_1 = 0$. However, until time t the agent is not yet aware of this problem and invests according to a different expectation $\tilde{h}_1$ about future pension contributions. Our analysis then focuses on studying the $CE\text{-ratios}$ introduced before: we ask how much the agent could have gained from an improved financial planning due to having a perfect assessment of his or her future pension contributions. This type of question we ask for all the different

[5] See for instance Conine et al. (2017) and the references therein.

Table 1: Overview of scenarios

	$Z_i,\ i =$	T	t	γ	h_0	h_1	m_{max}	CE^*
Base	1	40	20	3	1	2	1.5	84.3
Risk aversion up	2	40	20	**5**	1	2	1.5	80.0
Human capital up	3	40	20	3	1	**3**	1.5	109.9
Income drop	4	40	20	3	1	**1**	1.5	58.6
Disability	5	40	20	3	1	**0**	1.5	32.6
Early t	6	40	**10**	3	1	2	1.5	99.0
Late t	7	40	**30**	3	1	2	1.5	71.0
No leverage	8	40	20	3	1	2	**1**	83.9
Leverage up	9	40	20	3	1	2	**2**	84.5

scenarios, and we ask it both for contributions (and thus risk capacity) and for risk preferences.

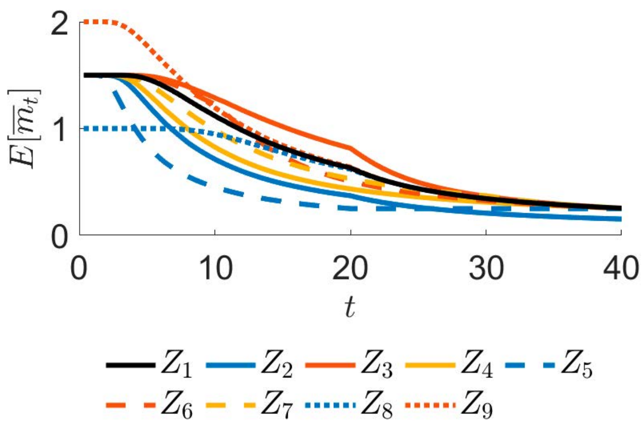
Before we start this *within-scenario* analysis, it may be instructive to compare the scenarios themselves. The final column of Table 1 shows the certainty equivalents CE^* introduced in (18) that result from optimal behavior in each scenario. These numbers thus translate the agent's overall utility in the different scenarios into comparable monetary amounts. Compared to the baseline Z_1, what we see in scenarios Z_2-Z_5 is quite intuitive: the certainty equivalent goes up with higher contributions and down with lower ones. Moreover, it goes down with a higher risk aversion because a more risk-averse agent gets less utility from any lottery. Shifting the timing of t in Z_6 and Z_7 is more meaningful in the later analysis when it corresponds to the end of suboptimal behavior. For the moment, an earlier t means in particular that the event where h doubles is earlier, corresponding to higher human capital and thus a higher certainty equivalent. The last two lines of the table are more interesting: we see that in the economic scenario under consideration, moving from no leveraging (and thus ruling out negative financial wealth) to $m_{max} = 2$ (allowing agents to invest twice their financial wealth in the stock market) only increases the certainty equivalent by less than 1% while introducing a positive probability of negative financial wealth.

Another way to compare the scenarios and illustrate their diversity is by looking at optimal investment behavior. In Figure 1 we show the mean optimal strategies $E[\overline{m}_t]$ over time for all nine scenarios. We take the mean because investment trajectories are stochastic since m_t depends on the state of both financial wealth and human capital.
To give some indication of the volatility, Figure 2 compares the median glide path to the

10%- and 90%-quantiles for scenario Z_1. Clearly, a trajectory that stays at the level m_{max} for a longer period corresponds to a less favorable financial market scenario, because financial wealth is still relatively small compared to human capital. We see that under the 90%-quantile the constraint remains binding for about nine years longer than under the more favorable 10% quantile.

In the base scenario, the true risk aversion level is 3, while the true income level is 1 during the first 20 years and 2 during the last 20 years. This is the black curve in the figure. In the alternative scenario Z_2, the investor's willingness to take risks is smaller, $\gamma = 5$, which leads to a lower investment curve as shown in blue. In the initial periods, however, the leverage constraint $m_{max} = 1.5$ is binding in both scenarios so that the curves are flat and coincide. Later on, human capital diminishes and the difference between total wealth and financial wealth gradually disappears, so that the curves are sloping downward, ultimately converging to the Merton fraction which is 0.15 in scenario Z_2 and 0.25 in all other scenarios.[6] In scenarios with higher human capital, we observe a stronger demand for leverage and thus higher curves. The opposite holds for the disability scenario Z_5 shown in dashed blue. Finally, shifting the leverage constraint in scenarios Z_8 and Z_9 has the expected effect on investment fractions in the initial periods.

Figure 1: Average glide paths in different scenarios



[6] In particular, as long as an agent's perceived risk aversion $\tilde{\gamma}$ lies in the range from 1- 10, the agent will want to invest at most 75% of his or her total wealth in the risky asset so that demand for leveraging is restricted to financial wealth.

Figure 2: Quantiles of glide path for scenario Z_1

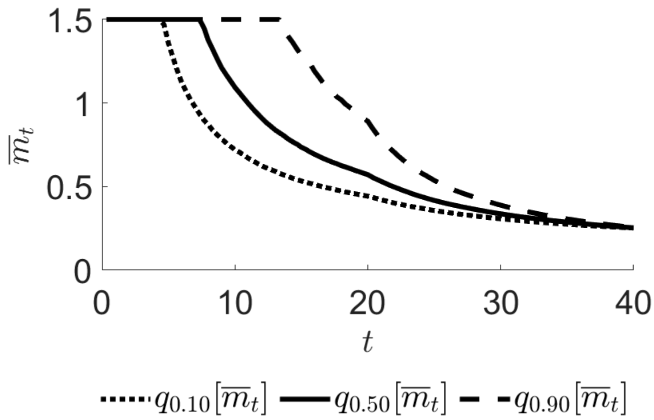
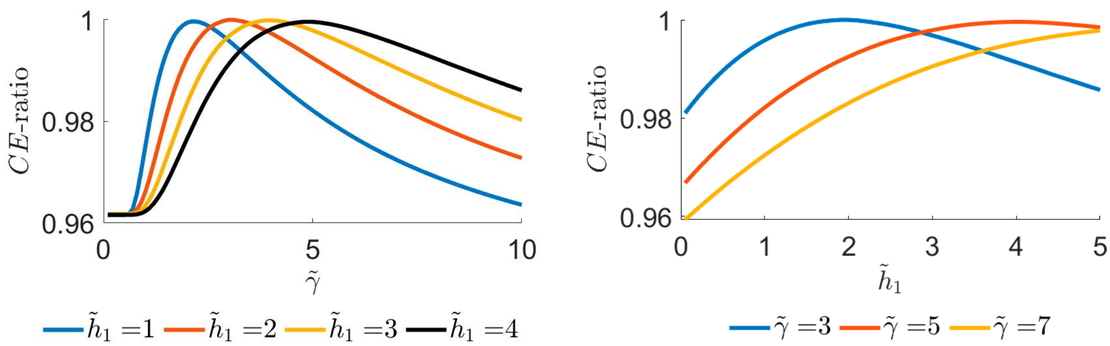


Figure 3: Base scenario Z_1, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 1.5$.



3.2 The baseline scenario

In Figure 3, we show the certainty equivalent ratios

$$CE\text{-ratio} = \frac{\widetilde{CE}}{CE^*}$$

as functions of $\tilde{\gamma}$ for four different estimations of future contributions on the left, and on the right as a function of $\tilde{h}_1$ for three different levels of risk aversion. Thus, in the left panel, the red curve corresponds to the case where beliefs about future contributions are correct, $\tilde{h}_1 = h_1 = 2$, and the belief about risk preferences is on the x-axis. The $CE\text{-ratio}$ is maximal around the true value $\tilde{\gamma} = \gamma = 3$. Moving away in either direction leads to a utility loss. The other curves correspond to different values of $\tilde{h}_1$. Conversely, in the right panel, the blue curve corresponds to correct beliefs about risk aversion, $\tilde{\gamma} = \gamma = 3$, and it is maximal around the point where future pension contributions sion, $\tilde{\gamma} = \gamma = 3$, and it is maximal around the point where future pension contributions are assessed correctly, $\tilde{h}_1 = h_1 = 2$. As a first main take-away from this picture, we see that all curves stay above 0.96 at all points – despite the considerable range of false beliefs under display.

The leverage constraints are a big part of the reason for this robustness. Because leveraging is bounded, the loss due to an underestimation of the true risk aversion parameter is limited. The smaller the perceived risk aversion, the more the investor would mistakenly want to invest in risky assets. However, since this is bounded, the loss is bounded too, and all curves are flat for small $\tilde{\gamma}$ where the constraint is binding. On the other hand, when the agent overestimates the true risk aversion level, then he or she will take less risk than what would be optimal, which lowers the relative utility. In this particular setting, we observe that a perceived risk aversion level that is too low – and following the resulting too risky strategy – leads to a certainty equivalent loss of at most 4%. When the strategy is too conservative, the loss depends on the future income assessment. When the human capital is estimated correctly, the loss is less than 3% for $\tilde{\gamma} = 10$. An overestimation of future income can counterbalance an overestimation of the risk aversion because overestimation of future contributions leads to excessive investment in risky assets, while overestimating the risk level leads to too little exposure.

When the risk aversion is overestimated, the loss is also bounded as in the limit nothing is invested riskily. Thus, when pension wealth is completely invested on the bank account against the risk-free rate, namely, when $\tilde{\gamma} \to \infty$ then $m_{t_i} \to 0$ irrespective of $\tilde{h}_1$. This loss is at its highest when $t = T$, i.e., the suboptimal strategy is followed until the end, thus until the wrong preference estimation is only realized at retirement. In that case the certainty equivalent is simply $\widetilde{CE} = (H_{t_0} + F_{t_0})e^{rT}$ which leads, under the optimal investment decision in scenario Z_1, to a $CE\text{-ratio}$ of 0.87.

For our comparative studies here and later on, we need to fix ranges over which the agent's false beliefs $\tilde{\gamma}$ and $\tilde{h}_1$ vary. For the risk aversion parameter $\tilde{\gamma}$, a natural range is the range from 1 to 10 discussed above. For $\tilde{h}_1$ (and also for the human capital process (h_t)) we deliberately use relatively extreme scenarios regarding the growth of pension contributions and the mistakes that agents can make when assessing their future pension contributions. The goal here is to find the order of magnitude where variations in risk aversion and variations in risk capacity have a comparable impact. In Section 3.6, when looking at more realistic cases for the evolution of pension contributions, we find that, encouragingly, the quantitative impact is much smaller. This leads to the tentative conclusion that wrong assessments of contribution payments have a smaller impact than wrong assessments of risk preferences. Finally, the left panel of Figure 3 illustrates that the interplay between misestimation of both γ and h_1 plays a crucial role: for each of the $\tilde{h}_1$-values under consideration, there is a value of $\tilde{\gamma}$ that gives a near-optimal $CE\text{-ratio}$

close to 1. Yet, similarly, mistakes made in the assessment of the two quantities can also reinforce each other.

3.3 Alternative scenarios for risk aversion and risk capacity

In scenario Z_2, where the true level of risk aversion is not equal to 3 but equal to 5, we obtain Figure 4a. We see now that the lower limit in the left plot of Figure 4a is lower than in the base scenario, but that the losses for high levels of $\tilde{\gamma}$ are less severe. In other words, the loss function shifts to the right together with the true value of γ.

In scenarios Z_3 to Z_5 we consider different values of the true future pension contributions h_1. In Z_3, the true career path involves a tripling in income. Here we see in Figure 4b that underestimation of the risk level causes less severe losses than in Z_1 because the true income is now higher. This implies that, in general, the target investment fraction is higher and thus the leverage constraint becomes more binding.

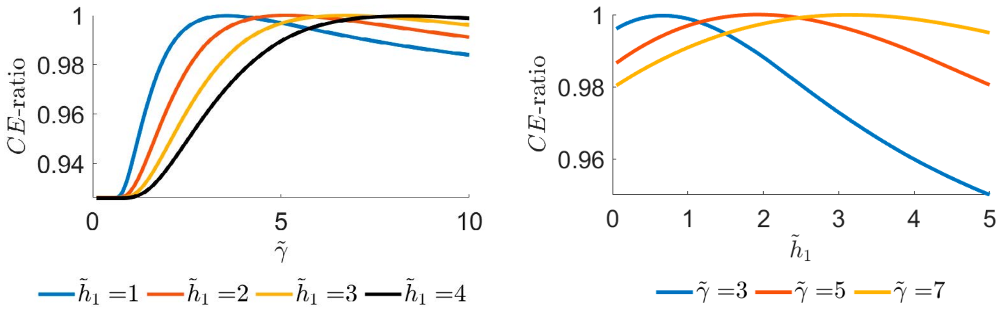
In Figure 4d we show the $CE\text{-ratio}$ when income vanishes after 20 years, scenario Z_5. For example, one might think of a situation in which the agent becomes disabled. If this has not been anticipated while investing pension capital, the loss can be substantial, in particular when $\tilde{\gamma}$ is low or when $\tilde{h}_1$ is high. This means that taking too much risk can come at a high cost when future income disappears. Note that this welfare loss from an ex-post mismatch between realized and optimal investment strategy comes *on top of* the welfare loss from the disability itself, which can be computed by comparing Z_1 and Z_5 in the final column of Table 1.

More generally, the realized income pattern in scenario Z_5 corresponds to individuals leaving the pension systems, i.e., moving from active participant to sleeper. From the perspective of a pension provider, a drop in contribution payments from $h_0 = 1$ during the first 20 years to $h_1 = 0$ in the remaining 20 years can have several, very different but often unobserved causes including disability, but also becoming self-employed, becoming unemployed or, emigration. To react and differentiate optimally, pension providers would ideally have full information on the pension resources. For instance, in situations in which pension is accrued elsewhere this should be reflected in the risk exposure and risk capacity (see AFM (2023)).

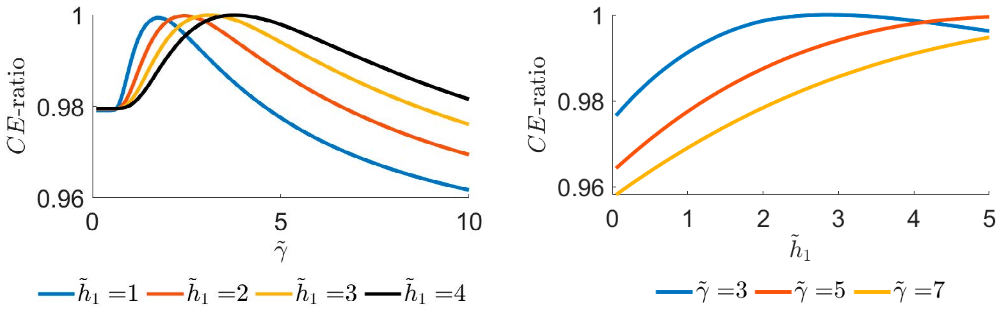
In Figure 4c, we show what happens when $h_1 = 1$, scenario Z_4. This reflects a constant level of income, but compared to $\tilde{h}_1 > 1$ it captures an unexpected decrease in pension contribution relative to what has been anticipated. This implies an interpolation between the previous two figures. Examples of this could be a drop in income because of divorce, partial unemployment, partial disability, or any other unforeseen life event that causes a drop in pension contributions.

Figure 4: Risk aversion and human capital

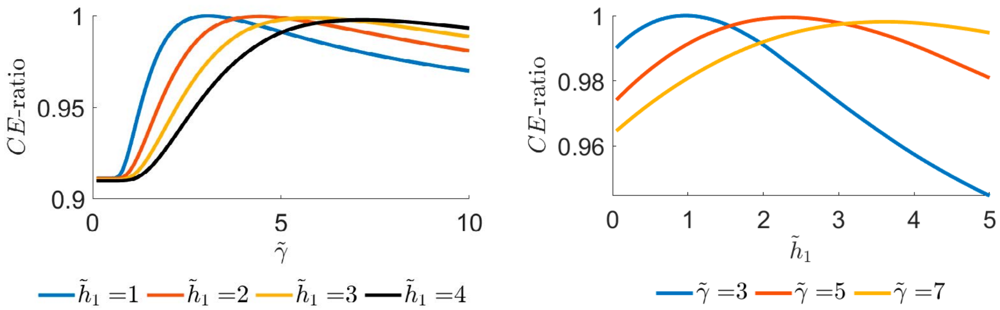
(a) Risk aversion up scenario Z_2, $T = 40$, $t = 20$, $\gamma = 5$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 1.5$.



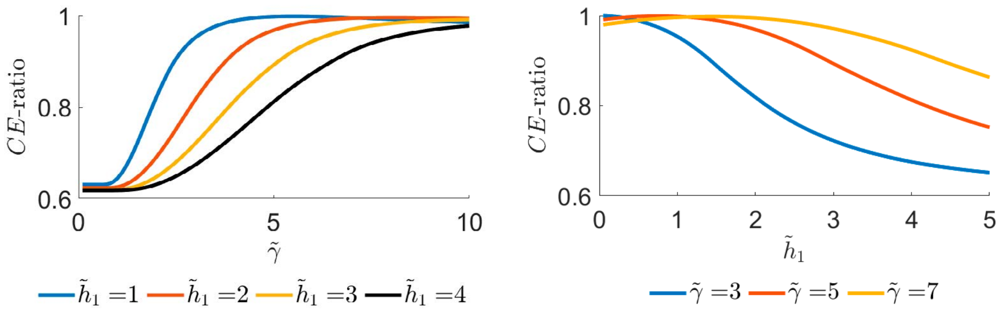
(b) Human capital up scenario Z_3, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 3$, $m_{max} = 1.5$.



(c) Income drop scenario Z_4, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 1$, $m_{max} = 1.5$.



(d) Disability scenario Z_5, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 0$, $m_{max} = 1.5$.



3.4 Financial market conditions

In this section, we briefly discuss how financial market conditions and, in particular, different values for the drift coefficient μ influence our results. Arguably, the strongest assumption we make regarding financial market conditions is that they are perfectly known. We begin by making this point more concrete. From a statistical perspective, μ is notoriously hard to estimate, see, e.g., Section 4.2 of Rogers (2013), who points out that hundreds of years of data might be needed to reliably pin down this parameter. This has some fairly important implications for our analysis as well. The one crucial place where (possibly mismeasured) risk aversion coefficients enter our decision-making process is in the computation of the Merton fraction

$$\widehat{\bar{m}^V} = \frac{\widehat{\mu} - r}{\widehat{\sigma^2}\widehat{\gamma}}.$$

Clearly, this quantity depends on the ratio of our estimated risk aversion $\widehat{\gamma}$ and the notoriously inaccurate estimate of the excess return $\widehat{\mu} - r$. Intuitively, the noise in the ultimate decision $\widehat{\bar{m}^V}$ will reflect the noisiest of the three input quantities $\widehat{\mu}$, $\widehat{\gamma}$ and $\widehat{\sigma^2}$. From this perspective, we cannot expect large gains from aiming at *much* higher precision in the estimation of, e.g., γ than we can expect in the estimation of μ.

To illustrate this difficulty, we simulate 10,000 times 30 years of daily data (260 business days per year) and then estimate μ and σ on each trajectory from the empirical mean and standard deviation of the logarithmic returns using (1). Table 2 gives some descriptive statistics for the resulting estimates of $\mu = 0.04$, $\sigma = 0.2$, and $(\mu - r)/\sigma^2 = 0.75$, which is the optimal investment fraction of an agent with $\gamma = 1$. Here, q_α denotes the α-quantile.

Table 2: Estimating drift and variance

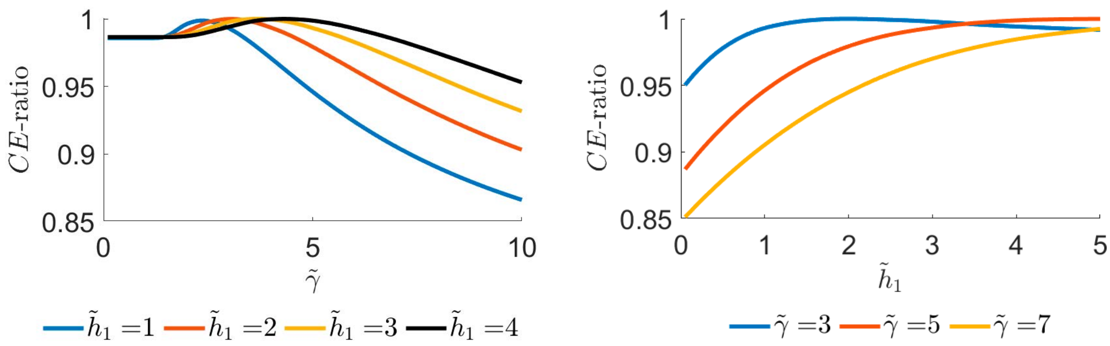
	$\min$	$q_{0.05}$	$q_{0.25}$	$q_{0.5}$	mean	$q_{0.75}$	$q_{0.95}$	$\max$
$\widehat{\mu}$	-0.1285	-0.0189	0.0153	0.0394	0.0397	0.0643	0.0993	0.1703
$\widehat{\sigma}$	0.1944	0.1973	0.1989	0.2000	0.2000	0.2011	0.2026	0.2064
$\frac{\widehat{\mu}-r}{\widehat{\sigma}^2}$	-3.5333	-0.7280	0.1330	0.7342	0.7438	1.3578	2.2264	4.0618

As expected, we see that the estimation of σ is fairly successful while there is considerable variation in the estimates of μ and the resulting investment fractions. For instance, the estimated investment fractions in the 2,500 most conservative cases are more than a factor 10 smaller than the investment fractions in the 2,500 most aggressive cases, covering the entire range from keeping 87% of wealth in the risk-free asset to over-leveraging by 35%. This variation is purely due to the statistical error that is left after thirty years of data. From this perspective, the additional noise that arises in the estimation of γ may have comparatively little impact on the noise in decisions. To end this discussion on a hopeful note, the literature on parameter uncertainty in the Merton problem[7] has shown that the problem is fairly stable in the sense that results stay close to optimal as long as investment fractions are not too far away from the optimum. In fact, also our previous robustness results for working with a misestimated γ can be directly translated into results about misestimating other components of the Merton fraction like the μ – and vice versa.

Next, we consider how sensitive our main results are to changes in financial market conditions themselves. If we increase the expected return on the risky asset from $\mu = 0.04$ to 0.08 while keeping all other things equal to the baseline scenario, then we see in Figure 5 that the losses are quite a bit larger and the leverage constraint is binding more often. One misses out on more, in particular when $\tilde{\gamma}$ is high, now that the expected return is 8% rather than 4%.

Figure 5: Financial market

Return up $\mu = 0.08$ in base scenario $S = 1$, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 1.5$.



3.5 Shifting the "moment of truth"

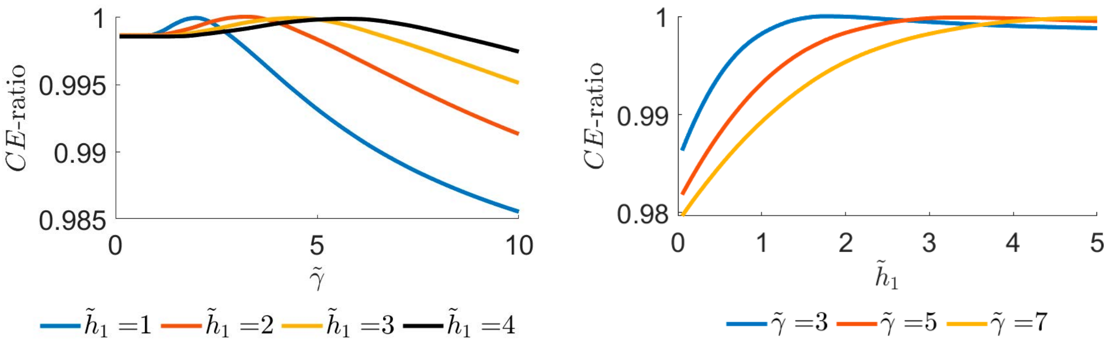
In Figure 6, we show the impact of being wrong about γ and h_1 not until the age of 47 but until the ages of 37 and 57, respectively. As expected, the longer it takes to find out one's true risk aversion and one's true career path, the higher the loss because suboptimal strategies have been implemented for longer. Nevertheless, the figures can give us some quantitative idea on how much can be gained from learning one's true old-age risk

[7] See e.g. again Rogers (2013), Chapter 2.32.

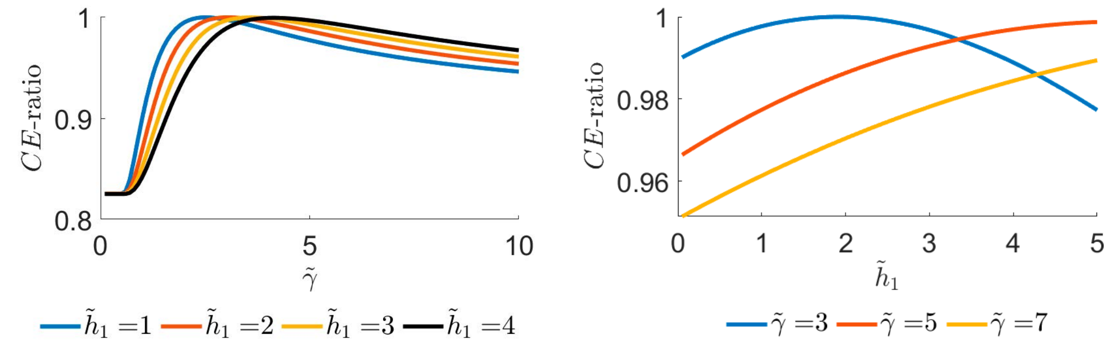
aversion a bit earlier, or from having an accurate estimate of one's overall career path a bit earlier.

Figure 6: Timing the moment of truth

(a) Early t scenario Z_6, $T = 40$, $t = 10$, $\gamma = 3$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 1.5$.



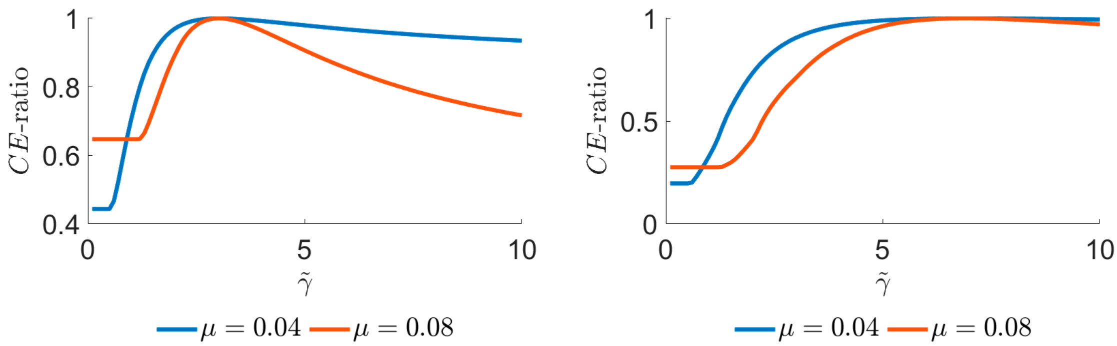
(b) Late t scenario Z_7, $T = 40$, $t = 30$, $\gamma = 3$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 1.5$.



Finally, in Figure 7, we look at the even more extreme case that the moment of truth coincides with the moment of retirement – so that the entire investment strategy was based on parameters that differ from the true ones. In this case, it only makes sense to look at wrong beliefs about risk aversion $\tilde{\gamma}$: there is no time left between t and T so that h_1 drops out of the calculation. A motivation for considering $t = T$ could be the idea that the moment of retirement itself affects risk preferences so that agents can only learn their risk aversion accurately when the build-up phase of their pension wealth is over. Another interpretation would be that $\tilde{\gamma}$ is the implemented risk aversion in a participant's pension account, which differs from the true γ, e.g., because communication between the participant and the pension provider is noisy, or because the pension provider combines participants with similar $\tilde{\gamma}$ in a single risk class with the same investment strategy. In both figures, we see that there is an interval around the true risk aversion level, which guarantees close to optimal results. This interval is wider when μ is smaller. However, substantial welfare losses are possible when there is a stronger mismatch between the optimal and the implemented investment strategy over the entire investment horizon. Some additional discussion in this direction can be found in Sections 4 and 5 of Balter and Schweizer (2021), who investigate the welfare effects of offering only a limited number of investment fractions to a population of agents with heterogeneous risk preferences. Their results include bounds on how close a menu with a finite number of products comes to the full personalization optimum and heuristics for how to choose a menu of γ-levels.

Figure 7: The case $t = T$

The case $t = T = 40$ for $\mu = 0.04$ (blue curves) and $\mu = 0.08$ (red curves) under a true risk aversion of $\gamma = 3$ (left panel) and $\gamma = 7$ (right panel) with $h_0 = 1$, $m_{max} = 1.5$.



3.6 Patterns of wage growth

So far, we have looked at relatively extreme scenarios for wage growth where pension contributions would double, triple or even vanish at some point in time (Z_3-Z_5). The motivation behind this was to study how much we need to shock the contribution process to get sizable effects. In this section, we round up this analysis by verifying that for more realistic patterns of wage growth the quantitative impacts are much smaller.

In order to build more realistic wage (and contribution) profiles, we use a stylized scheme which is known as the "$3 - 2 - 1 - 0$" scheme. This is a simple age-dependent pattern, where wage growth is 3% up until age 35, then 2% in the ten years until age 45, then 1% in the ten years until age 55, and 0% thereafter. Let g_{t_i} be the yearly rate at which contributions grow: per time step Δ, contributions grow with rate $(1+g_{t_i})^{\Delta}$. Under false beliefs, the human capital is based on the true contribution path h_{t_i} until time t and based on false contributions $\tilde{h}_{t_i}$ after time t. The present value of the "wrong" human capital is based on these discounted contributions until time t, after which the agent realizes that the contributions are different and adapts his or her false expectation to the true h_{t_i} after t. Overall, human capital is described by the following equations, where $\tilde{g}_{t_i}$ denotes the false growth rate in income:

$$h_{t_0} = 1 \quad (27)$$

$$h_{t_i} = h_{t_{i-1}} \cdot (1 + g_{t_{i-1}})^{\Delta} \quad (28)$$

$$\tilde{h}_{t_i} = \begin{cases} h_{t_i} & \text{if } t_i \leq t \\ \tilde{h}_{t_{i-1}} \cdot (1 + \tilde{g}_{t_{i-1}})^{\Delta} & \text{if } t_i > t \end{cases} \quad (29)$$

$$H_{t_i} = e^{-r\Delta} H_{t_{i+1}} + h_{t_i}\Delta \quad (30)$$

$$\tilde{H}_{t_i} = \begin{cases} e^{-r\Delta} \tilde{H}_{t_{i+1}} + \tilde{h}_{t_i}\Delta & \text{if } t_i < t \\ H_{t_i} & \text{if } t_i \geq t \end{cases} \quad (31)$$

and where

$$g_{t_i} = \begin{cases} g_0 & \text{if } 27 + t_i \leq 35 \\ g_1 & \text{if } 35 < 27 + t_i \leq 45 \\ g_2 & \text{if } 45 < 27 + t_i \leq 55 \\ g_3 & \text{if } 27 + t_i > 55 \end{cases} \quad (32)$$

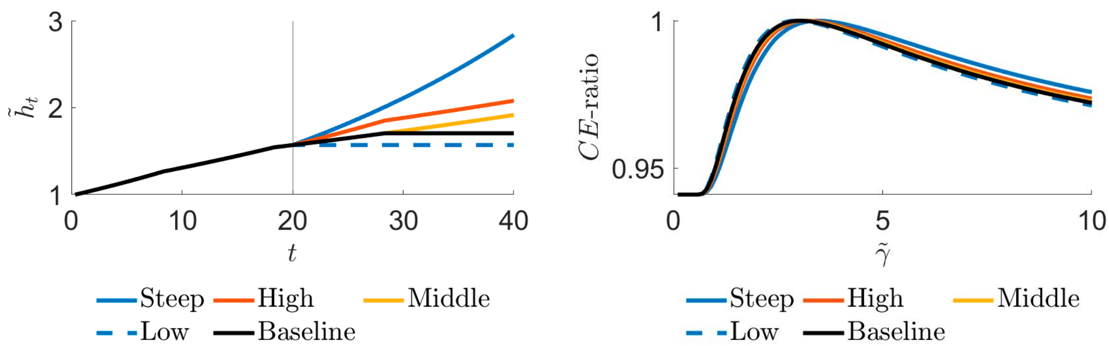
For $T = 40, t = 20, \gamma = 3, h_0 = 1, m_{max} = 1.5$ we consider the profile $3 - 2 - 1 - 0$ as the new baseline scenario Z_{10}. As alternatives, we consider steeper and flatter wage profiles as described in Table 3 and the left plot in Figure 8, with the resulting $CE\text{-ratios}$ shown on the right. In all these scenarios, the true growth curve of pension contributions is the same and identical to the baseline Z_{10}. The only difference is that until time t the agents behave as if they were on one of the other curves.

The blue line reflects expectations in line with a typical career path in the highest-achieving group (Lever et al. (2013)). Due to unforeseen circumstances, the anticipated increase in income is not achieved and the agent drops to the baseline curve. Examples might be failing to become medical specialist or a judge, occupations with long periods of education and development. In contrast, the dashed blue line reflects the wrong expectation that no career development will occur, reflecting, for example, an employee is promoted to a management position despite lower personal expectations. These differences in career paths seem to lead to only minor effects. More dispersion in income is needed to cause sizable impact, as we have seen in the previous sections.

Table 3: Wage profiles

Income growth	$Z_i,\ i=$	$\tilde{g}_0$	$\tilde{g}_1$	$\tilde{g}_2$	$\tilde{g}_3$
Baseline	10	0.03	0.02	0.01	0.00
Steep	$10a$			0.03	0.03
High	$10b$			0.02	0.01
Middle	$10c$			0.01	0.01
Low	$10d$			0.00	0.00

Figure 8: Income growth $3-2-1-0$ based on scenario Z_{10} and alternatives as depicted in Table 3



3.7 Leverage

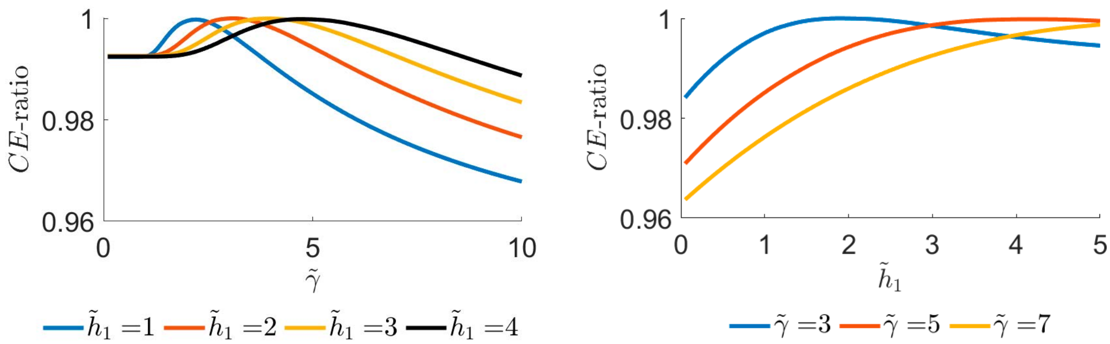
We finally have a look at scenarios Z_8 and Z_9, which vary the leverage constraint m_{max} compared to the baseline value of $m_{max} = 1.5$ from scenario Z_1.[8] One important observation was already made earlier in the context of Table 1, namely that the welfare gains from leveraging in terms of CE^* are fairly modest in our setting, as the move from no leveraging in Z_8 ($m_{max} = 1$) to a considerable degree of leveraging in Z_9 ($m_{max} = 2$) only leads to a gain of less than 1%. A main reason for this is that the Merton fraction of our baseline agent is 0.25 so that, ideally, 25% of total wealth is invested in the risky asset. Thus leverage constraints on financial wealth will typically only be binding in a

[8]Note that we do not include a scenario without leverage constraints. At the beginning of the investment horizon, the demand for leveraging is so high that without a constraint we would see many scenarios with negative financial wealth at intermediate points in time. In combination with optimistic beliefs about human capital, $\tilde{h}_1 > h_1$, we would then see scenarios with a realized utility of negative infinity, implying an expected utility that is flat at negative infinity.

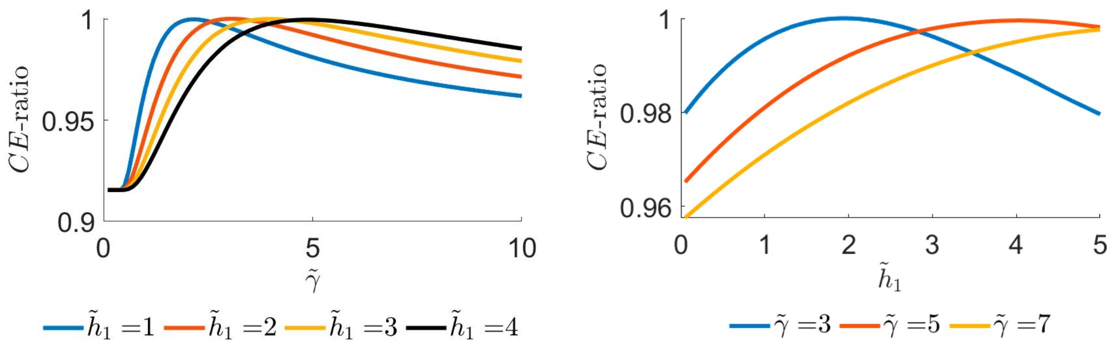
relatively short period early in the investment horizon, when total wealth is dominated by human capital. In Figure 9a we see that losses are limited when leverage positions are not allowed, as is the case in the “flexible pension scheme” proposed in the current Dutch reform where there is no intergenerational risk sharing via a solidarity buffer[9]. In particular, the constraint becomes binding when $\tilde{\gamma}$ is small. Agents with a smaller $\tilde{\gamma}$ wants to take higher risks due to underestimation of their own risk aversion. The leverage constraint keeps the agent from making this mistake, leading to a flat curve for small $\tilde{\gamma}$ and, importantly, a lower bound on the possible losses from underestimation of one’s own risk aversion. By decreasing m_{max}, we increase the level of $\tilde{\gamma}$ at which this effect kicks in. The price we pay for this lower bound is that it limits participants’ ability to borrow against their human capital when they are young. While the resulting welfare loss is small in the present example, it can be expected to be larger when the target investment fraction is higher, for example because true risk aversion γ is lower or expected returns μ are higher.

Figure 9: Leverage

(a) No leverage scenario Z_8, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 1$.



(b) Leverage up scenario Z_9, $T = 40$, $t = 20$, $\gamma = 3$, $h_0 = 1$, $h_1 = 2$, $m_{max} = 2$.



[9] In flexible contracts, there is the possibility of a so-called risk sharing buffer, however, its distribution rule cannot depend on realized returns.

4 Practical challenges

A major problem in the implementation of (collective) investment strategies based on risk preferences and risk capacities is to quantify and measure the two. In most of this paper, we looked at the outcomes that arise when there is a discrepancy between the true risk preferences and capacities and the risk preferences and capacities that form the basis of an investment strategy, trying to understand how sensitive the problem is to different types of discrepancies. Of course, this type of research should go hand in hand with attempts to measure and control the magnitudes of these discrepancies. Importantly, when we also account for statistical error in the assessment of market conditions, there are so many competing sources of uncertainty that a fully personalized, individually optimal investment solution clearly remains an illusion. This makes it even more important to aim at investment strategies that are robust to misspecifications.

When it comes to the measurement of risk capacities, there are practical dimensions to the problem that deserve attention. To come up with a fair assessment of risk capacity, both financial pension wealth and human capital need to be computed. These two numbers reflect the size of the pension pot so far and how much will still be contributed in the form of pension premiums. In an ideal setting, these computations would account for the full picture, including financial and housing wealth, the family situation, and different pension accounts. For instance, individuals can have pension accounts at different pension funds or insurance companies because they might have accrued pension rights with various jobs and employers, possibly even in different countries. Typically, this private information is not shared between pension providers (AFM, 2023).

On top of that, even with full information about the present situation, future income and thus contributions are uncertain. Many factors contribute here, including career stage, age, life events and the overall state of the economy. If there is a correlation between the stock market and salary, human capital is partly exposed to the same risks as financial wealth. Thus, in order to keep the risk exposure of total wealth constant, the risk exposure in financial wealth needs to be decreased if human capital is not risk-free. Finally, there are also non-market risks such as the risk of a health shock or a divorce, that add uncertainty to human capital in practice and can have a considerable impact as we discussed in the context of scenarios Z_4 and Z_5. Relaxing the assumption of risk-free human capital is thus an interesting direction for further research.

Incorporating a state pension (such as the Dutch AOW) increases the human capital component of pension wealth, but leaves the financial capital unchanged.[10] Conse-

[10]In particular, the discounted sum of state pension payments can be collected in the terminal value H_T of the human capital process which then satisfies $H_T > 0$. One may debate whether “human capital” is the best name for this non-liquid part of pension wealth when the state pension is included.

quently, a higher risk exposure in financial wealth would be optimal. However, one can also argue that participants' true utility functions include a subsistence level, i.e., a positive minimal amount of wealth that is needed. This would lead to a HARA (i.e. shifted CRRA) rather than a standard CRRA utility function. If one then assumes that the subsistence level is equal to the level of the state pension, we return to a setting like our baseline model where the CRRA function is applied to the second pillar savings only. In this way, our results can be extended to cover the state pension in two different ways, either by including them in human capital or by assuming that they are equal to a subsistence level that is also included in preferences. A further investigation is beyond the scope of this paper.

5 Conclusion

Risk preferences, risk capacity, and financial market assumptions together determine the optimal investment decision. Mistakes in their assessment, estimation, or perception lead to suboptimal lifecycle investing. We investigate the impact that unanticipated changes have on the expected utility from pension wealth at retirement. If suboptimal lifecycles are implemented for some period of time – until the "moment of truth" at which it is realized what the true preferences and capacities are – there is a loss compared to what could have been achieved. We find that leverage constraints bound the loss due to underestimating the risk aversion. Alleviating this constraint can cause pension wealth to become negative – a feature that is not allowed within the new pension design. On the other hand, the loss due to overestimating risk aversion is also bounded since in the limit risk exposure is zero. The impact of wrong beliefs about future income seems to be even smaller compared to wrong beliefs about risk preferences, at least within most parameter ranges considered. Moreover, an overestimation of future income can counterbalance overestimation of the risk aversion because overestimation of future contributions leads to excessive investment in risky assets while overestimating the risk level leads to too little exposure, and vice versa. Of course, in the same way, different mistakes can also reinforce each other, for example when an overestimation of future income goes together with an underestimation of one's risk aversion and an overly optimistic assessment of financial market conditions.

If a sizable drop in income is not foreseen, the impact can be substantial. Situations in which pension contributions disappear include disability or unemployment but also emigration or becoming self-employed. However, the latter two situations could entail that pension is accrued elsewhere. Factors like these should also be taken into account when assessing the risk capacity.

Interpreting our observations from another direction, we find that a perfect match between individual preferences and portfolio strategies, i.e., a full personalization, is not needed for close to optimal results. Instead, it seems key to look for strategies that are robust in the sense that they still work well under slightly different preferences and slightly different personal situations and market environments. Once we account for more sources of uncertainty besides the market itself, product features such as leverage constraints or built-in disability insurance may contribute much more to welfare than the illusion of a perfect match between the individually optimal investment fraction and the implemented one. Finally, a certain degree of aggregation across similar agents may help to avoid extreme choices that can sometimes arise as the result of extreme preferences or extreme personal circumstances – but also as the result of misperceptions or mistakes.

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