THE IMPACT OF PRODUCT-DEPENDENT POLICYHOLDER RISK SENSITIVITIES IN LIFE INSURANCE: INSIGHTS FROM EXPERIMENTS AND MODEL-BASED SIMULATION ANALYSES

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ABSTRACT

In contrast to previous work, this paper studies *product-dependent* risk sensitivities of policyholders towards reported safety levels of a life insurer in a *long-term* multi-period setting. Toward this end, we first conduct two choice-based conjoint analyses using a German survey panel to investigate the effect of an insurer's reported default probability on individuals' willingness to pay for annuities and term life insurances. Our experimental results suggest that individuals (sharply) reduce their willingness to pay for probabilistic life insurance products, with (strong) product-specific differences. In light of these observations, the paper then revisits their impact on portfolio effects (regarding the sold product mix) in a simulation study based on an asset-liability model with a specific focus on a life insurer offering annuities and term life insurances. The results reveal a potentially strong impact of such product-dependent risk sensitivities on risk-reducing portfolio compositions. One main driver is the deviation between risk sensitivities depending on the respective product (annuities vs. term life).

Keywords: Life insurance; asset-liability model; risk-reducing portfolio; willingness to pay

JEL Classification: G22; G23; G32; D81

1. INTRODUCTION

The event of an insurer's insolvency can result in serious financial consequences for its customers. To protect policyholders against this risk, the first pillar of the European insurance regulatory framework Solvency II imposes solvency capital requirements for insurance companies to ensure a one-year default probability of at most 0.5 percent. However, there is empirical

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evidence that even for a very low default probability of e.g. 0.3 percent, if transparently communicated, policyholders could decrease their willingness to pay for certain insurance products by up to 14 percent (see Zimmer et al., 2009).

The transparency towards policyholders has steadily increased over the last years, driven by multiple developments. First, pillar three of Solvency II aims for higher transparency and market discipline in the insurance industry based on public disclosure requirements like the Solvency and Financial Condition Reports.[1] Second, specialized rating agencies increasingly provide financial strength indices for insurance companies that are explicitly addressed to policyholders and intermediaries.[2] Third, the digital transformation and emergence of insurtechs results in more accessible information for policyholders by e.g. social media platforms or comparison sites (see Eling and Lehmann, 2018).[3] Therefore, when reporting shortfall probabilities, from an insurer's perspective not only regulatory requirements need to be considered but also the potential effect on the customer's willingness to pay for insurance products, which could result in a strong income reduction for the insurer. While many experiments in non-life insurance showed that policyholders react to reported shortfall probabilities by reducing their willingness to pay for probabilistic insurance (e.g. Zimmer et al., 2009; Zimmer et al., 2018), experimental evidence in the life insurance sector is – to the best of our knowledge – still missing. Further, while there exists literature that takes into account policyholders' willingness to pay within an asset-liability model-based analysis (e.g. Eckert and Gatzert, 2018; Gründl et al., 2006; Klein and Schmeiser, 2019a), previous work has not yet specifically focused on how the policyholders' (*product-dependent*) sensitivity to default risk may impact a life insurer's risk situation in a long run setting with multiple product lines. Against this background, we first conduct an experiment to investigate the effect of a reported default probability on the policyholders' willingness to pay in life insurance with a focus on product-specific differences. Further, we aim to gain additional insights by analyzing the impact of policyholders' willingness to pay depending on reported shortfall probabilities on a life insurer with different product lines (term life and annuities) using a simulation analysis, which we calibrate based on our experimental findings. The main focus of our analysis is on portfolio effects, in the sense of the impact of a change in the sold product mix on the insurer's risk situation.

1 Gatzert and Heidinger (2020) observed significant cumulative abnormal returns as a response to the publication of the first Solvency and Financial Condition Reports in 2017, which might reflect investors' expectation of a forthcoming policyholders' behavioral change.

2 For example, the national German financial rating agency Assekurata, which was founded in 1996, is specialized in assessing insurance companies from the customers' point of view (see Theis and Wolgast, 2012).

3 While the main purpose of comparison sites is to compare insurance prices, some of them already provide additional information about customer service and insurer's financial security (see, e.g., www.insure.com).

To date many experimental studies demonstrated that policyholders strongly reduce their willingness to pay if their contract can potentially default (Biener et al., 2019; Wakker et al., 1997; Zimmer et al., 2009; Zimmer et al., 2018). These studies further find that the ratio of policyholders' willingness to pay and the actuarially fair insurance premium decreases with increasing default risk. Additional experiments by Klein and Schmeiser (2019b) and Hillebrandt (2021) demonstrate that this holds true for small default probabilities like 0.1 percent, and thus far below regulatory solvency levels. As a result, there appears to be a need to include the mechanism of policyholders' willingness to pay with respect to reported shortfall probabilities into risk- and value-based analysis, which we believe to be especially important for the management in long-term life insurances. This is also supported by the literature on the existence of market discipline in the insurance sector based on real market data (Eling and Schmit, 2012; Epermanis and Harrington, 2006; Gatzert and Heidinger, 2020; Park and Tokutsune, 2013; Phillips et al., 1998; Sommer, 1996). Consistent with the experimental studies, this branch of research shows that communicating the insurer's financial situation, or a change of it, directly influences its future premium income. Furthermore, empirical research on real market data allows comparing the impact for different lines of business. Phillips et al. (1998) use an option pricing framework for multiline insurance companies, which they fit on US real market data to show that the impact of a company's shortfall risk on its insurance prices varies between different lines of business, and that this effect is particularly pronounced for business with a longer payout tail. Epermanis and Harrington (2006) analyzed the US property and casualty insurance market and observed that changes in insurers' financial strength ratings influence its premium growth in the subsequent years, where the degree of influence differed between commercial and personal insurance lines. Similar results were obtained for the German insurance market by Eling and Schmit (2012), who, in general, found varying impacts between different lines of business, where effects in life insurance appeared stronger than in property/liability insurance. The more comprehensive literature about market discipline in the banking sector affirms these observations, as an overview article by Eling (2012) emphasizes. These findings motivate further research about the effects of policyholders' willingness to pay with respect to reported shortfall probabilities on an insurer's risk situation. Especially the situation of a life insurer with multiple product types, where policyholders' risk sensitivities may differ between these types, seems to be an important and realistic, but still unresearched scenario.

In the literature, different approaches to model policyholders' willingness to pay with respect to reported shortfall probabilities have been used in risk- and value-based (simulation) analyses. Among the first, Gründl et al. (2006) model insolvency-averse insurance buyers within a shareholder value maximization framework. For this, they linearly reduced the premium income of actuarially priced life insurance products depending on customers' risk sensitivity and reported shortfall probability. However, in order to run a discrete optimization algorithm to solve their shareholder value maximization problem, they made use of a single-step asset-liability model, and in contrast to the setting in the present paper, they do not analyze the impact of product-dependent risk sensitivities. Gatzert and Kellner (2013) used a similar linear reduction mechanism to model policyholders' willingness to pay, but in a non-life insurance context. Instead of reducing the insurance price, Yow and Sherris (2008) reduced the demand of insurance in a linear way depending on the company's default risk. While they model a non-life insurer with multiple business lines, they also focus on a one-period model and assume equal risk sensitivities across business lines. Instead of a linear reduction of premiums depending on reported shortfall probabilities, Lorson et al. (2012) use a logarithmic relation, to measure the benefits of higher solvency levels. To estimate the policyholders' risk sensitivities, they run a regression analysis based on the empirical findings by Zimmer et al. (2009), whereby the same formula as in Lorson et al. (2012) is used in Eckert and Gatzert (2018) to study optimal decisions in the risk- and value-based management of a non-life insurer. In contrast to this, Klein and Schmeiser (2019a) argue that an exponential regression would better fit the empirical findings by Zimmer et al. (2018), and embedded this relation within a one-period model for non-life insurance companies. In the context of life insurance, Nirmalendran et al. (2013) use a similar exponential relation to model the demand of life annuities depending on the price and the reported default probability, within a value-maximization framework. While they investigate the impact of varying customers' risk sensitivities and reported shortfall probabilities, they focus on the situation of a single line life insurer after a single year.

In this paper, we expand the existing literature by first conducting two surveys using a German sample with 196 and 191 participants to experimentally determine the decrease in (*product-dependent*) policyholders' willingness to pay for annuities and term life insurances for an increasing reported shortfall probability of an insurer. Embedding the experimentally derived results into a simulation analysis of a life insurer in a *long run* setting with these two product lines, we investigate the impact of product-dependent risk sensitivities (as indicated by empirical research as laid out above and confirmed by our experiment) as well as different portfolio compositions of sold annuities and term life insurances on a life insurer's risk situation. By doing this, we intend to gain a better understanding of how the policyholders' willingness to pay with respect to reported shortfall probabilities may impact an insurer's risk situation under more complex long-term cash flow structures, which we believe will become even more important in the future with an increasing transparency regarding shortfall risk.

For our survey-based experiment, we apply choice-based conjoint (CBC) analysis, which has been used previously in the literature to investigate consumers' preferences for life insurance products. For example, Braun et al. (2016) run a CBC analysis on a large sample of 2,017 German consumers to analyze their preferences and willingness to pay for specific product designs in term life insurance. Similarly, Fuino et al. (2020) performed a CBC analysis to investigate the importance of guarantees in participating life insurance, and Shu et al. (2016) investigate the relevance of monthly income, guarantees and company's financial strength in immediate life annuities. For our simulation analysis, we build on a general asset-liability model for a life insurer used in Bohnert et al. (2015), which we adjust in several ways to suit our setting. This multi-period model contains many real world mechanisms like actuarially priced life insurance products, fair compensation of shareholders by dividend payments and surplus distribution for policyholders. We further extend this model by explicitly taking into account the policyholders' willingness to pay. For this, the insurer reports a one-year default probability, as it is done e.g. in case of Solvency II. As a consequence, the premium income is affected depending on the customers' risk sensitivity, which we calibrate based on our experimental results. To obtain numerical results for the asset-liability model, we use Monte Carlo simulation, thereby varying the level of reported default probabilities and the degree of customers' risk sensitivity. For different portfolio compositions of term life insurances and annuities, we then estimate risk measures that are relevant for the insurer as well as the policyholders. Our results suggest that policyholders indeed exhibit product-dependent reactions to reported safety levels and that these can have a considerable impact on risk-reducing portfolio compositions (of term life products and annuities), which should be taken into account in risk assessment.

The remainder of this paper is structured as follows. In Section 2, the methodology for the CBC analysis is presented, followed by the experimental design and the corresponding findings. In Section 3, the life insurer's asset-liability model is described along with the mechanisms of risk reporting and the resulting policyholders' willingness to pay. Numerical results of the simulation analysis using the model and the calibration based on the experiment are discussed in Section 4. Section 5 summarizes the main findings.

2. Experiment

In order to study product-dependent risk sensitivities, we first conduct an experiment and use choice-based conjoint analysis to derive the product-dependent willingness to pay for annuities and term life insurance products. By doing this, we investigate whether - and to what extent - the experimental results in non-life insurance, which already showed that policyholders strictly decrease their willingness to pay in case of a positive reported shortfall probability (e.g. Zimmer et al., 2009; Zimmer et al., 2018), carry over from the non-life to the life insurance sector. To address the empirical findings that policyholders' risk sensitivities could vary between different business lines (e.g. Eling and Schmit, 2012; Phillips et al., 1998), we conduct two separate (and product-specific) survey-based experiments with German respondents as laid out below.

2.1 Methodology: Choice-based conjoint (CBC) analysis

To estimate the consumers' willingness to pay, we perform choice-based conjoint (CBC) analyses, where the survey participant is set into a realistic purchase situation and has to choose the most preferred product profile from a set of alternatives multiple times. In each set of alternatives, the product profiles differ in a fixed number of attributes *K*, where each attribute *k* can take one of M_k levels (see Louviere and Woodworth, 1983). Assuming that the survey participant *i* has a linear utility function in the observed attributes, the participant's *i* deterministic utility of alternative *a* is given as

$$v_{ia} = \sum_{k=1}^{K} \sum_{m=1}^{M_k} \beta_{ikm} \cdot x_{akm} = \langle \beta_i ; x_a \rangle , \tag{1}$$

where the vector of dummy variables x_a describes the active attribute levels of alternative *a* and the vector β_i describes the unknown part-worth utilities for individual *i* (see Louviere and Woodworth, 1983).[4] Extending the deterministic utilities v_{ia} by adding independent Gumble distributed error terms ε_i , i.e. $V_{ia} = v_{ia} + \varepsilon_i$, the fundamental equation of a CBC analysis can be derived by random utility theory, which is known as the multinomial logit model (see, e.g., McFadden, 1974). It is given as

$$P(y_i = a \mid A) = \frac{\exp(\langle \beta_i ; x_a \rangle)}{\sum_{j \in A} \exp(\langle \beta_i ; x_j \rangle)} , \tag{2}$$

[4] Note that in the original work by Louviere and Woodworth (1983), the part-worth utility vector depends on the set of alternatives rather than the individual.

where $P\left(y_i = a \mid A\right)$ denotes the probability of individual *i* choosing alternative *a* from a set of alternatives *A* (see Louviere and Woodworth, 1983).

When estimating the part-worth utilities β_i on an aggregate level, i.e. all individuals *i* share the same vector $\beta_i = \beta$, classical regression methods can be used, where the left side of Equation (2) is replaced by the observed frequency of respondents choosing alternative *a* from the set of alternatives *A* (see Louviere and Woodworth, 1983). However, Markov chain Monte Carlo hierarchical Bayes methods make it possible to estimate the part-worth utilities β_i on an individual level, which is superior as it allows to model heterogeneity within the population of the survey participants (see, e.g., Lenk et al., 1996). Given Equation (1), the estimated single entries β_{ikm} of the vector β_i then describe the utility for individual *i*, when the product's feature *k* equals level *m*. Therefore, the part-worth utilities directly provide insights into the customers' product preferences. Further, if the attribute $k=1$ represents the product's price levels $p_1, \dots, p_{M_1}$, the part-worth utilities can be used to calculate more sophisticated metrics, like the marginal willingness to pay for changing the level of a non-price attribute, as it is done e.g. in Braun et al. (2016). In this case, to compute the marginal willingness to pay $MWTP_{ik}\left(h,l\right)$ of an individual *i* for changing a non-price attribute $k \neq 1$ from some level *l* to level *h*, the utility gain $\beta_{ikh} - \beta_{ikl}$ is divided by a price coefficient V_p, i.e.

$$MWTP_{ik}\left(h,l\right) = \frac{\beta_{ikh} - \beta_{ikl}}{V_p}, \tag{3}$$

where the price coefficient

$$V_p = \frac{\max\limits_{m=1,\dots,M_1}\left\{\beta_{i1m}\right\} - \min\limits_{m=1,\dots,M_1}\left\{\beta_{i1m}\right\}}{\max\limits_{m=1,\dots,M_1}\left\{p_m\right\} - \min\limits_{m=1,\dots,M_1}\left\{p_m\right\}} \tag{4}$$

defines the increase in utility when decreasing the product's price by one unit (see Braun et al., 2016). The idea behind using Equation (3) and Equation (4) to compute the marginal willingness to pay is that the change in price should be equal to the change in utility divided by the utility per price.

The main advantage of using CBC analysis to indirectly compute the customers' willingness to pay over direct approaches, where the survey participants must directly state their willingness to pay for certain product profiles, is that in a CBC analysis a more realistic purchase situation is provided based on intuitive and simple selection tasks (see DeSarbo et al., 1995).[5] Further, a

[5] Note that such selection tasks provide a very realistic purchase situation, e.g. in case life insurance products are bought on comparison sites like www.check24.de, which also contains a financial strength information on the insurer.

CBC analysis is very suitable for life insurance products in general, as research by Miller et al. (2011) showed its advantages over other approaches in case of higher-priced and less frequently purchased product categories with existing market competition.

Therefore, while incentive-compatible experiments, where the respondents' decisions have an actual effect in the real world[6], are known to provide more accurate results (see e.g. Miller et al., 2011; Zimmer et al., 2018), the CBC analysis is sufficiently suitable for our purposes. First, a market research company ensures high-quality survey responses of a large and balanced survey-panel by confirming personal information in the recruiting process, by incentives such as monetary payouts, and by an ongoing monitoring process regarding the quality of their panel responses. Second, while we estimate the marginal willingness to pay with hierarchical Bayes methods on an individual level (see Equation (3)), we use the median of the single values to calibrate the functional relationship between the communicated default probability and the policyholders' willingness to pay in the model, which we then use in our simulation analysis. This makes the approach relatively robust against outliers, e.g. single respondents who may not state their true preferences. Last but not least, we do not have to solely rely on an "accuracy" of the experimental results, but run various sensitivity analyses in the simulation analysis based on the experimentally observed values.

2.2 Experimental design

To investigate the impact of a reported shortfall probability on policyholders' willingness to pay and whether they are product-specific, we design two experiments for CBC analyses for annuities and term life insurances, respectively. To ensure that the survey participants understand the insurance products, we consider immediate annuities without bequest, which are sold against single premiums. In case of the term life insurance, we follow the setting in Braun et al. (2016) where a monthly premium is considered.

At the beginning of both surveys, a specific situation in life is described, which sets the survey participant in a realistic purchase situation for the given type of contract. For example, in case of the immediate annuity, the following text guides the participant into the questionnaire, which is similar to the setting in Fuino et al. (2020):[7]

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[6] While incentive-compatible experiments have been used previously in the non-life insurance context (e.g. Zimmer et al., 2018), such experiments would face various challenges in case of life insurance products due to their long term nature and high volumes.

[7] The original wording in German as well as the purchase description for the term life insurance product is provided in the Appendix.

"*Imagine that you are 65 years old, you are about to retire and you would like to invest 100,000 € in an immediate annuity, which from now on pays you a monthly annuity payment for a certain period of time. The period of time and the amount of the monthly annuity payment depend on the specific product design. In each of the following 12 scenarios, please select the product you prefer the most.*"

The age of 65 years is motivated by the average retirement age of Germans, which normally lies slightly below the statutory retirement age of 67 years, and the amount of 100,000 € was previously used in a CBC analysis for immediate annuities in Shu et al. (2016). For the description of a realistic purchase situation for a term life insurance, we build on the empirical findings by Swiss Re (2013) as well as the descriptions in Schreiber (2017), i.e. a 40 year old, married person with children, making the more money in a stable relationship as their partner. Further, in case of the term life insurance, we used the same amount of 100,000 € for the sum insured as it done in Braun et al. (2016).

The survey participants had to complete twelve selection tasks, where each time three different product profiles are randomly shown based on a fractional factorial choice design in order to optimize the balance and overlap of the shown attribute levels. We thereby followed the recommendations in Johnson and Orme (2003) to keep the number of attributes and levels in the CBC selection tasks as small as possible, i.e. we use three attributes with at most five levels as shown in Table 1.

Table 1: Attributes and levels for the CBC analyses

Attribute	**Levels**	
Contract term	• Annuity:	20, 25 or 30 years
	• Term life insurance:	10, 15 or 20 years
One-year default probability	0%, 1%, 2%, 3% or 4%	
Price of the insurance	Five equally distanced price steps in EUR based on the actuarially fair values with 10% price steps.	

First, we include the contract term as a key component for the two insurance products in our analysis, where we use the same three levels of 10, 15 and 20 years for the term life insurance as in Braun et al. (2016). To allow comparability between the two contract types, we use the same number of three levels and the distance of 5 years between the levels for the contract terms of the annuity, but postponed by 10 years to better fit the described purchase situation, i.e. for the annuity we use the contract terms of 20, 25 and 30 years[8].

As our experimental research aims to investigate the impact of an insurer's reported default probability on its customers' willingness to pay, we include the one-year default probability as a second attribute. Here we use five equally distanced levels with a relatively wide range from 0% to 4%. While we are aware that one-year default probabilities of more than 1% are an unrealistic scenario in practice, we aim to provide clearly separated levels, so that the survey participants can better differentiate between the displayed choices. Further, in reality it is more likely that policyholders access the insurers' financial safety level by verbal ratings instead of a numerical expression (e.g. by comparison sites like www.check24.de for Germany or financial advisors), and experimental research by Zimmer et al. (2018) showed that individuals strongly overestimate default probabilities in the case of verbal ratings.

For the third attribute we include the price of insurance, taking into account the communicated setting in the survey. The price for the term life insurance for a 40 year-old policyholder is given by the monthly premiums based on the sum insured of 100,000 € and the respective contract term. In case of the immediate annuity, the communicated initial single premium of 100,000 € for a 65 year-old person and the specified contract term determines the monthly annuity payments. To obtain comparability between the two different contract types and to derive the marginal willingness to pay, we compute the insurance prices based on the actuarially fair values with five equally distanced price steps within the two product lines, where the formulas of the actuarially fair values are shown in Section 3.

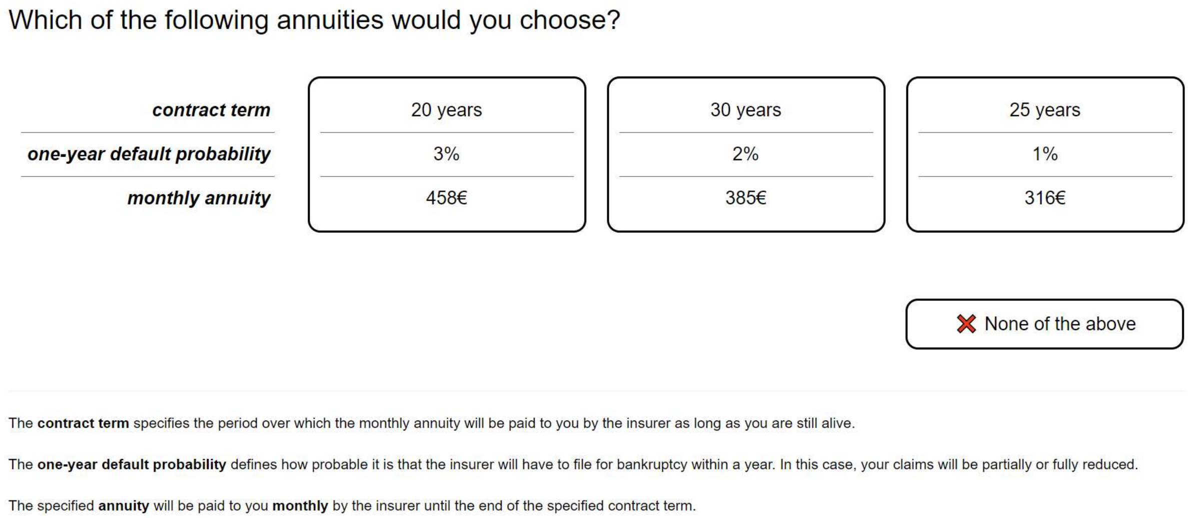
For both contract types, price steps of 10% are used, where the actuarially fair premium for term life insurances is increased and the actuarially fair annuity is decreased, i.e. the prices are given by 100%, 110%, 120%, 130% or 140% of the actuarially fair premium for term life insurances and 100%, 90%, 80%, 70% or 60% of the actuarially fair annuity. For the computation of the actuarially fair values (without considering the default risk), the actuarial interest rate is set to 0.25%. The death probabilities are based on the first-order mortality tables "DAV 2008 T" and "DAV 2004 R" of the German Actuarial Association, where we use different death probabilities for men and women in order to present more individual prices. For this, the survey participants' gender is asked right before the description of the purchase situation and the gen-

[8] While the situation of a whole life annuity represent a relevant product, we did not include this level in our analysis in order to retain comparability with the contract duration of the term life insurance.

der-specific prices are used for the CBC selection tasks. Similarly, in the case of term life insurance we further differentiate between prices for smokers and non-smokers, as it is done in practice and in Braun et al. (2016).

For all three attributes (contract term, one-year default probability, price), a short explanation is provided at the bottom of each of the twelve selection tasks in order to ensure that all respondents understand the mechanics of the respective life insurance product (see Figure 1 for an illustration).[9] Further, in each of the twelve selection tasks we include a "no-buy-option", allowing the respondents to refrain from selecting one of the three given alternatives. The twelve selection tasks are followed by two control questions, asking on a scale of 1 to 7 how realistic the introductory described purchase situation was perceived as well as how understandable the selection tasks were. This allows us to further increase the data quality. After the selection tasks, demographic questions about the respondents' age, size (as a control question), education, job, wage and previous experience with life insurance products are asked, where we used the wordings from Unger et al. (2022).

Figure 1: Example of a single CBC task (translated from German)



[9] The original wordings in German for the short explanations of the three attributes used in the annuity survey as well as the term life insurance survey are provided in the Appendix.

2.3 Sample description and results

For both CBC analyses we used the all-in-one survey research platform Conjoint.ly[10] to create and evaluate the surveys. Further, we used the paid service of Conjoint.ly to recruit the survey participants in order to access a balanced and high quality survey panel in Germany, where 218 (220) participants completed the survey about annuities (term life insurances). We excluded 5 (6) respondents because of a fraudulent behavior[11] and 6 (4) because of the same IP address. Last, we restricted our analysis to those respondents who answered both control questions with at least 3 out of 7, which led to the exclusion of an additional 11 (22) participants. As a result $n_R = 196$ (51% female, average age 47.2 years) participants are included in the analysis of annuities and $n_S = 191$ participants (40.8% female, average age 49.3 years) in the analysis of term life insurances. In both surveys, about 50% of the survey participants stated that they either own one or more related life insurance products or think about buying one. In the survey about annuities the "no-buy-option" was selected in 12% and in case of the term life insurances in 19% of the selection tasks.

Based on the respondents' choices, two separate multinomial logit models as described by Equation (2) were fitted, whereby Conjoint.ly uses a Markov chain Monte Carlo hierarchical Bayes method to estimate the part-worth utility vectors β_i on an individual level. For both surveys, the multinomial logit models yielded a strong fit with McFadden's pseudo R^2 of 65.4%.

As a result, Figure 2 shows the average part-worth utilities $\bar{\beta}_{km} = \sum_{i=1}^{n} \beta_{ikm}$ for annuities and term life contracts for the different attribute levels, which were transformed to zero-centered for each attribute and standardized such that the single utility ranges for the three different attributes sum up to 100%. One can see that longer contract terms yield lower average utilities for both products, i.e. the average customer is not willing to pay the actuarially fair price increase for longer contract terms of 20/30 years, especially in case of the term life insurance. One reason for this might be that policyholders do not understand why the monthly premium for the term life insurance increases for longer contract terms, as they do not associate a longer contract term with their increasing age and therefore increasing death probabilities. Regarding the reported one-year default probability and the product's price, Figure 2 shows the expected

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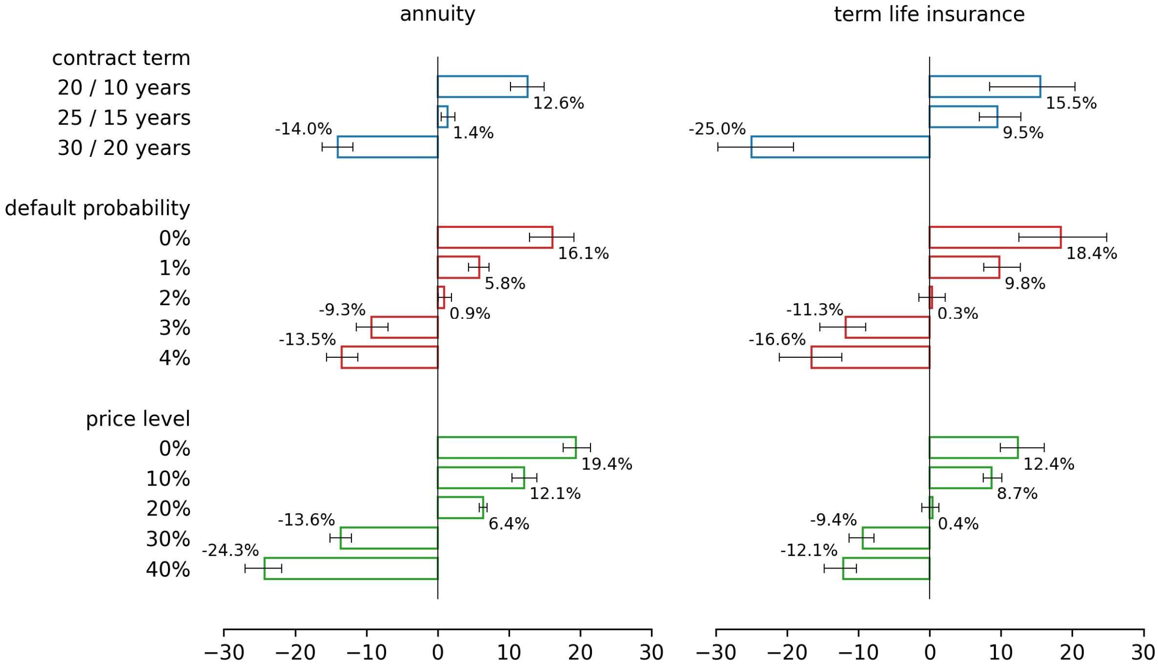
[10] Conjoint.ly provides a comprehensive online platform to create, perform and evaluate surveys for product and pricing research with a focus on conjoint analysis (see www.conjointly.com).

[11] The system automatically excluded respondents with fraudulent behavior, like answering the questions too fast, insufficiently moving the mouse or missing scroll behavior, which would be required to see all alternatives and attribute explanations.

ordering, as the part-worth utilities decrease for an increasing reported one-year default probability as well as the increasing price levels.

Figure 2: Average part-worth utilities for the different attribute levels (Table 1) for annuities and term life insurances based on the CBC analyses



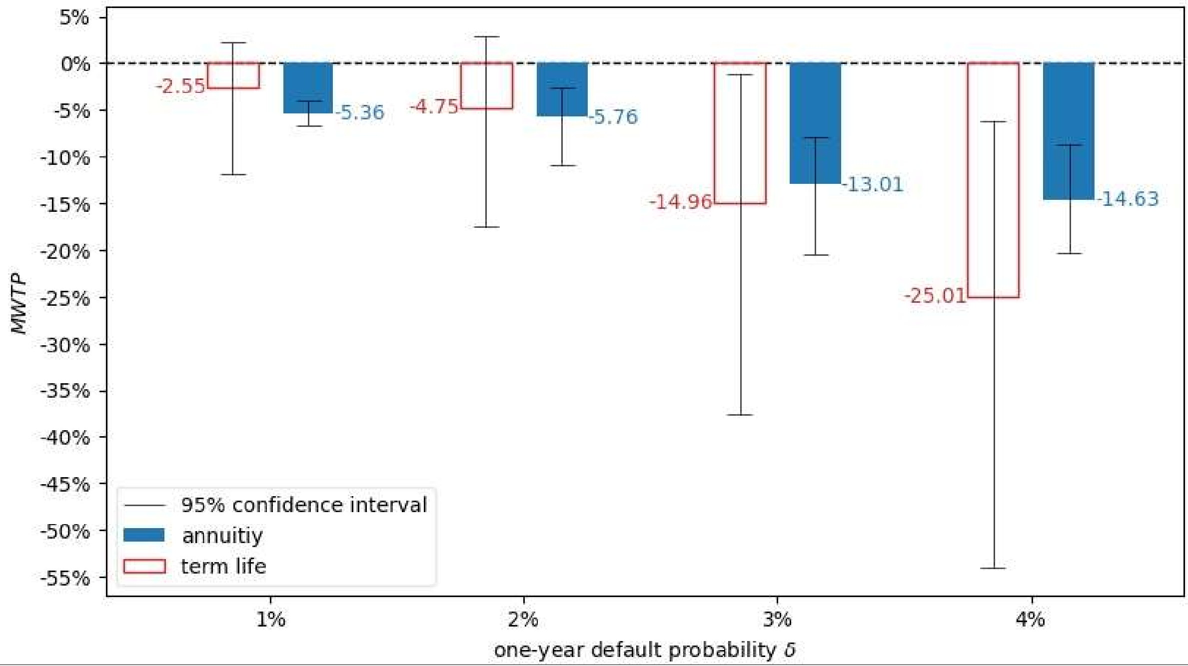
Notes: Displayed are the average part-worth utilities $\bar{\beta}_{km} = \sum_{i=1}^{n} \beta_{ikm}$*, which are transformed to zero-centered by subtracting the average attribute utility* $\bar{\beta}_k = \sum_{m=1}^{M_k} \bar{\beta}_{km}$ *and standardized by division by the maximum utility gain* $G_{\max} = \sum_{k=1}^{K} \left(\max\left\{\bar{\beta}_k\right\} - \min\left\{\bar{\beta}_k\right\} \right)$ *(with 95% confidence intervals, see whiskers).*

Besides the part-worth utilities, we evaluate the marginal willingness to pay when increasing the reported one-year default probability δ from 0% to the higher levels ranging from 1% to 4%, using the median of the individual values given in Equation (3).[12] As our experimental design defines the price for insurance indirectly, where the actuarially fair values are changed in 10% increments, the marginal willingness to pay can be directly expressed as the percentage change compared to the actuarially fair premium in case of term life, whereby the values for the annuities are also transformed accordingly.

[12] Note that the values for the marginal willingness to pay are provided by Conjoint.ly, where the price coefficient V_p in Equation (4) is estimated by means of fitting a separate hierarchical Bayes logistic regression model, where the price coefficient is treated as a continuous variable to ensure linearity in the price.

The results for the marginal willingness to pay depending on the increase of the reported one-year default probability δ are displayed in Figure 3. For example, in case of the term life insurance, the value of -2.55 means that the customers would (in terms of median) decrease their willingness to pay by 2.55%, if the insurer increases the reported one-year default probability from 0% to 1%. One can see that for both types of insurance, the customer's willingness to pay strictly decreases for an increasing reported one-year default probability, which is in line with the previous experiments in non-life insurance (e.g. Zimmer et al., 2009; 2018).

Figure 3: Median marginal willingness to pay for annuities and term life insurances depending on the reported one-year default probability δ based on the CBC analyses (reduction in median *MWTP* as compared to $\delta = 0\%$)



Further, it can be seen that the median marginal willingness to pay is indeed product-dependent, as already indicated by empirical research in different contexts (e.g. Eling and Schmit, 2012; Phillips et al., 1998). For reported one-year default probabilities of 1% and 2%, the decrease in policyholders' willingness to pay is more pronounced for the annuity than for the term life insurance. This could be caused by the customers' age, i.e. an immediate annuity is bought in older ages and a term life insurance is bought in younger ages. While at an older age, it is impossible to compensate a default by working harder or working more, it is typically still possible to react to a default in younger ages. However, for a default probability of 3% and 4%, this effect is reversed, i.e. the decrease in policyholders' willingness to pay is more pronounced for the term life insurance than for the annuity. One explanation for this behavior could be that policyholders are more sensitized towards a potential reduction or default of their pension as publicly often discussed in many countries, which might carry over to the private sector, and thus react earlier even for (comparably) lower default probabilities. For term life insurances, this sensitization might not be given to the same extent, and thus customers' react later and rather for higher default probabilities. The reaction might then be stronger compared to the annuity, as a default in case of a term life insurance not only harms one's own financial situation but also the financial situation of relatives such as children or spouses. However, the results of our CBC analysis only provide information about *how* policyholders react (as a central input and starting point for the following model and simulation study with sensitivity analyses) and not *why*. For this, further research is required, where our findings could serve as a starting point.

3. MODEL FRAMEWORK

In light of the experimental results, we use a model to further investigate the impact of product-dependent risk sensitivities on a life insurer's risk situation in more detail. We first describe a multi-period asset-liability model for a life insurer that is closely related to the setting in Bohnert et al. (2015), but makes some adjustments. For example, to study portfolio effects, we do not consider endowment contracts but term life insurances, as they are better suited to act as a counterpart to annuities also in the sense of natural hedging (Gatzert and Wesker, 2012; Gründl et al., 2006).

3.1 The product mix and corresponding liabilities

We consider a fixed time horizon of T years, where cash flows only arise at the beginning or ending of each year. For any year $t \in \{1,\ldots,T\}$ we denote with t^- the ending of the previous year and for $t \in \{0,\ldots,T\}$ the beginning of the current year with t^+. At time $t = 0^+$ a total of N insurance contracts are taken out, consisting of N^R temporary annuities and N^S temporary term life insurances, i.e. $N = N^R + N^S$.

Both products are sold against single premiums P^R and P^S at time $t = 0^+$ and have a contract term of T years. While monthly premiums would be more common in case of the term life product as also used in the experimental setting (Section 2), comparability between the two products is improved and portfolio effects can be better identified if we assume single premiums for both. The annual annuity payment is denoted with R_t and in the case of term life insurance, the sum insured paid out if the policyholder dies in year t is denoted with S_t. Both payments can vary over time because of surplus distribution, as explained later, whereby we also study the case without surplus participation as in the experimental setting within a sensitivity analysis.

The single premiums are further decomposed into the actuarially fair premium without default risk and a loading. The respective actuarial premiums are given by

$$P_a^R = R_1 \cdot a_{x_R:\overline{T}|} \text{ and } P_a^S = S_1 \cdot {}_{|T} A_{x_S},$$

with $a_{x:\overline{T}|} = \sum_{t=1}^{T} v^t {}_t p_x$ and ${}_{|T}A_x = \sum_{t=0}^{T-1} v^{t+1} \cdot {}_t p_x \cdot q_{x+t}$, where $v = (1+r^G)^{-1}$ denotes the discount factor with an actuarial interest rate r^G, ${}_t p_x$ represents the probability of an x-year old surviving t years, and q_{x+t} is the probability of dying within one year for a person of age $x+t$. Adding a loading λ, which accounts for administrative and acquisition costs, the single premiums are given by

$$P^R = P_a^R \cdot \left(1+\lambda^R\right) \text{ and } P^S = P_a^S \cdot \left(1+\lambda^S\right). \tag{5}$$

At a later point, these single premiums will be further adjusted to account for the policyholders' willingness to pay.

The book value of liabilities at the end of each year is given by the actuarial reserves. The actuarial reserve for the pool of N^R sold annuities at time t^- is given by

$$PR_{t^-}^R = \left(N^R - \sum_{i=1}^{t} d_i^R\right) \cdot {}_tV_x^R,$$

where d_i^R denotes the number of deaths in year i from policyholders with annuities and ${}_tV_x^R = R_{t+1} \cdot a_{x+t:\overline{T-t}|}$ (see Bohnert et al., 2015). Analogously, the actuarial reserves for the pool of N^S sold term life insurances at time t^- is given by

$$PR_{t^-}^S = \left(N^S - \sum_{i=1}^{t} d_i^S\right) \cdot {}_tV_x^S,$$

where d_i^S denotes the number of deaths in year i from policyholders with term life insurances and ${}_tV_x^S = S_{t+1} \cdot {}_{|T-t} A_{x+t}$. Therefore, as the overall actuarial reserve we get

$$PR_{t^-} = PR_{t^-}^R + PR_{t^-}^S.$$

3.2 Development of assets and liabilities

At the beginning of the contract term, shareholders make an initial contribution E_0, which together with the premiums results in an initial investment in assets of

$$A_{0^+} = E_0 + N^R \cdot P^R + N^S \cdot P^S .$$

We assume that assets follow a geometric Brownian motion, i.e.

$$\mathrm{d}I_t = \mu \cdot I_t \mathrm{dt} + \sigma \cdot I_t \mathrm{dW_t} \tag{6}$$

with constant drift μ, volatility σ and (W_t) a standard Brownian motion. The solution to this equation is given by

$$I_t = I_0 \cdot \exp\left(\left(\mu - \frac{\sigma^2}{2}\right) \cdot t + \sigma \cdot W_t\right) = I_{t-1} \cdot \exp(r_t)$$

for some initial value I_0, and with r_t denoting the continuous one-period return. The asset development can thus be described by

$$A_{t^-} = A_{(t-1)^+} \cdot \exp(r_t) - R_t \cdot \left(N^R - \sum_{i=1}^{t} d_i^R\right) - S_t \cdot d_t^S, \quad t = 1, ..., T .$$

The liabilities are given by the actuarial policy reserves PR_t^-. The generated surplus is first transferred to a buffer account defined by $B_{t^-} = A_{t^-} - PR_{t^-} - E_t$, $t = 1, \ldots, T$, where equity capital (E_t) is assumed to be constant over time. For the transition from time t^- to t^+ three different cases can be distinguished (see Bohnert et al., 2015). First, if the buffer account is large enough to pay out a constant fraction ξ of the shareholders' initial contribution, dividends are paid out, i.e. $D_t = \xi \cdot E_0$ if $B_{t^-} \geq \xi \cdot E_0$, $t = 1, \ldots, T$. In this case, the buffer account is adjusted by $B_{t^+} = B_{t^-} - D_t$, $t = 1, \ldots, T$ and the assets at the beginning of year t+1 are given by $A_{t^+} = A_{t^-} - D_t$, $t = 1, \ldots, T$. Second, if the buffer account is positive, but not large enough to pay the fraction ξE_0 as a dividend, then the amount of buffer account is paid as a partial dividend, set to zero, and assets are adjusted, i.e. $D_t = B_{t^-}$, $B_{t^+} = 0$ and $A_{t^+} = A_{t^-} - D_t$, $t = 1, \ldots, T$. Further, if the buffer account is negative, but equity capital can cover the losses, i.e. $B_{t^-} < 0$ and $B_{t^-} + E_t \geq 0$, then no dividends are paid, the buffer account is set to zero and assets stay unchanged. Formally this is described by $D_t = 0$, $B_{t^+} = 0$ and $A_{t^+} = A_{t^-}$, $t = 1, \ldots, T$. Third, if the buffer account is negative and equity capital is not sufficiently high enough to cover the losses, i.e. $B_{t^-} + E_t < 0$, the insurer is insolvent and is liquidated prematurely. In this case, the current assets are reduced by a bankruptcy/liquidation costs coefficient c and the remaining capital $(1-c)\cdot A_{(t-1)}\cdot \exp\left(r_t\right)$ is distributed to the policyholders with open contracts based on their reserves.

3.3 Surplus distribution scheme

In addition to their guaranteed sums insured, policyholders receive a share in the insurer's surplus. For this purpose, the policy interest rate r_t^P that includes the guaranteed interest rate as well as surplus is calculated as

$$r_t^P = \max\left\{ r^G,\ \alpha\cdot\left(\frac{B_{(t-1)^+}}{PR_{(t-1)^-}} - \gamma\right)\right\},$$

with a target buffer ratio γ, surplus distribution ratio α and an initial buffer account B_{0^+} (see Bohnert et al., 2015; Grosen and Jørgensen, 2000). We assume that the policy interest rate that exceeds the guaranteed interest rate r^G is paid on the contract's book values and that it is annuitized over the remaining contract term, thus increasing the guaranteed annuity payment and death benefit payment to

$$R_{t+1} = R_t + \frac{PR^R_{(t-1)^-}\cdot\left(r_t^P - r^G\right)\Big/\left(N^R - \sum_{i=1}^{t} d_i^R\right)}{a_{x+t:\overline{T-t|}}},\quad t = 1,\ldots,T-1$$

and

$$S_{t+1} = S_t + \frac{PR^S_{(t-1)^-}\cdot\left(r_t^P - r^G\right)\Big/\left(N^S - \sum_{i=1}^{t} d_i^S\right)}{{}_{|T-t}A_{x+t}},\quad t = 1,\ldots,T-1\,.$$

3.4 Policyholders' willingness to pay

To integrate the policyholders' willingness to pay in our model, at the beginning of the contract term the insurer reports an upper bound $\delta\in[0,1)$ for its one-year default probability that for simplicity reasons is assumed to be constant over the entire time horizon.[13] As this reported default probability will generally influence the paid amount of single premiums at time

[13] Note that in reality, the insurer's reported one-year default probability can vary over time, but the policyholders have only limited possibilities to react to this since all premiums are paid at time $t = 0^+$. Therefore, policyholders could only cancel their insurance, which, however, would result in cancellation fees.

$t = 0^+$, the premiums P^R and P^S in Equation (5) are multiplied by a factor $\rho(\delta;\, z)$ that depends on the communicated one-year default probability δ and a scaling factor *z*. Here we use the same formula as in Eckert and Gatzert (2018), i.e.

$$\rho(\delta; z) = \max\{1 - z \cdot PR(\delta);\, 0\}, \tag{7}$$

where *PR* denotes the premium reduction, which will be calibrated based on the experimental results, as will be explained later. The scaling factor *z* takes the customers' search costs into account, as the default probability may not be directly given to the policyholder, and also allows to run sensitivity analyses with respect to the policyholders' risk sensitivity. To model the experimental observation that customers' risk sensitivity to the reported one-year default probability can vary between different product lines, we assume different functional forms for the premium reduction PR^R of annuities and PR^S of term life insurances as well as scaling factors z_R and z_S, yielding two potentially different factors $\rho^R(\delta;\, z_R) = \max\{1 - z_R \cdot PR^R(\delta); 0\}$ and $\rho^S(\delta; z_S) = \max\{1 - z_S \cdot PR^S(\delta)\}$. Assuming that $PR^R(0) = PR^S(0) = 0$, the loadings $(1+\lambda^R)$ and $(1+\lambda^S)$ in Equation (5) can now be interpreted as the maximum loading that policyholders would accept in the case without default risk, as is also argued in Gatzert and Kellner (2013).

3.5 Fair valuation from the policyholders' and the shareholders' perspective

During the contract term, the true shortfall probability should not exceed the reported one-year default probability. The underlying shortfall probability over the entire contract term is thereby defined as

$$SP^{overall} = P(T_s \le T), \tag{8}$$

where $T_s = \inf\{t = 1, \ldots T : A_{t^-} < PR_{t^-}\}$ denotes the stopping time for the first occurrence of default. To account for the fact that the insurer typically only reports one-year default probabilities as e.g. the case with Solvency II, the overall shortfall probability must be decomposed. For this purpose, we define the conditional annual shortfall probability as

$$SP_t^{annual} = P\left(A_{t^-} < PR_{t^-} \mid A_{\tau^-} \ge PR_{\tau^-}\ \forall\, \tau < t\right) = \frac{P(T_s = t)}{P(T_s > t - 1)},\ t = 1, \ldots, T,$$

describing the situation that the insurer becomes insolvent in year *t*, given that the insurer stayed solvent until year $t-1$.

To ensure that the reported one-year default probability δ is not exceeded for each contract year, the maximum one-year default probability

$$SP_{\max}^{annual} = \max\left\{SP_t^{annual} : t = 1, ..., T\right\} \tag{9}$$

must satisfy the inequality

$$SP_{\max}^{annual} \leq \delta . \tag{10}$$

For example, this could be achieved by calibrating the initial contribution E_0 by

$$E_0 = \underset{E_0 \in \mathbb{R}^+}{\arg\min}\left\{SP_{\max}^{annual}\left(E_0\right) \leq \delta\right\}.$$

This approach is closely related to the estimation of the multistep value at risk measure in Wong et al. (2017). Other possibilities for the insurer are, for example, to choose a risk reducing product composition of term life insurances and annuities or to invest in less risky assets (see Gründl et al., 2006).

To ensure a fair situation for the shareholders, the dividend rate ξ is calibrated by means of risk-neutral valuation such that the initial contribution of the shareholders equals the discounted (with the risk-free interest rate r_f) expected value of dividends and the final payment under the risk-neutral pricing measure Q, i.e.

$$\begin{aligned} E_0 &= E^Q\left(e^{-r_f \cdot T} E_T + \sum_{t=1}^{T} e^{-r_f \cdot t} D_t\right) \\ &= E^Q\left(e^{-r_f \cdot T} \cdot \min\left\{E_0, E_0 + B_{T^-}\right\} \cdot 1\left\{T_s > T\right\} + \sum_{t=1}^{T} e^{-r_f \cdot t} \cdot \xi \cdot E_0 \cdot 1\left\{T_s > t\right\}\right) \end{aligned} \tag{11}$$

(see Bohnert et al., 2015), where under the risk-neutral pricing measure Q the drift μ in Equation (6) is replaced with the risk-free interest rate r_f and the standard Brownian motion (W_t) by a Q-standard Brownian motion (W_t^Q). Since actuarial premiums are computed based on mortality tables with safety loadings, mortality risk is already taken into account and is thus neglected here.

4. Numerical Analysis

In this section, we present the numerical simulation results regarding risk measures and portfolio effects for different policyholders' willingness to pay. For this purpose, we vary the reported one-year default probability δ for different functional forms of the premium reduction *PR* and different product mix compositions. We thereby fix the initial contribution of shareholders E_0 and for each parameter combination derive the respective fair dividend parameter ξ according to Equation (11). All Monte Carlo simulations are done based on the same 100,000 Latin hypercube sample paths. Each sample path is of size *3T*, where the first *T* realizations are used to simulate the asset returns and the second and third *T* realizations are used to simulate the number of annual deaths from policyholders with annuity and term life insurance contracts, respectively.

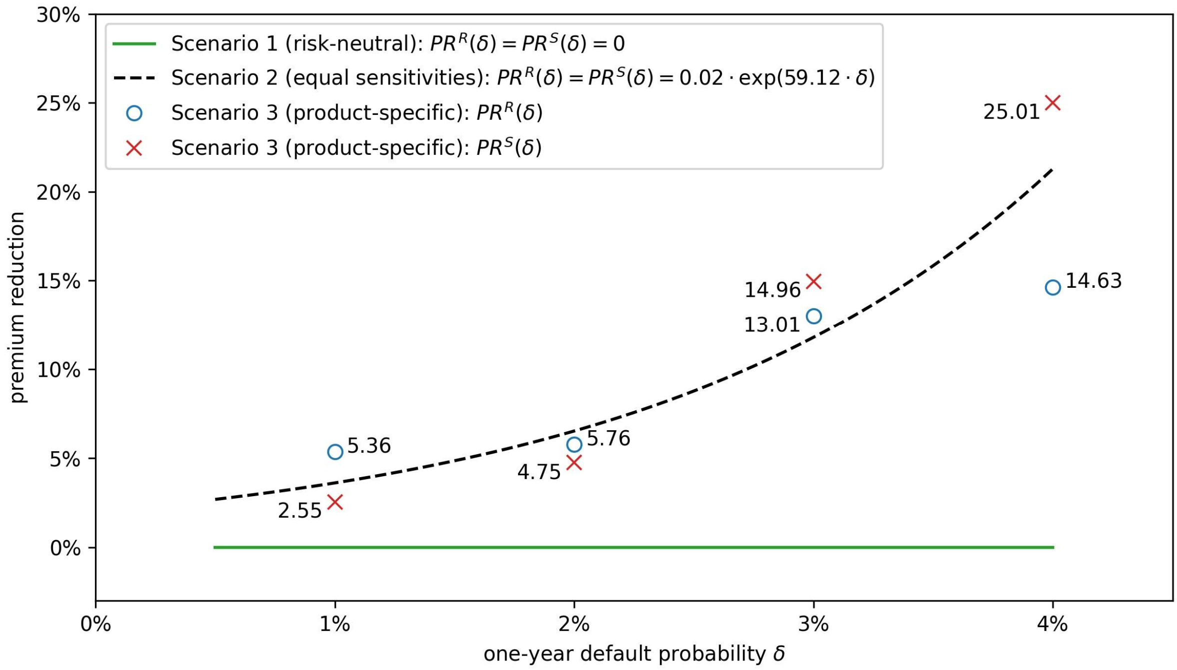
4.1 Input parameters

We assume a time horizon of $T = 30$ years, where at the beginning a total of N = 100,000 contracts are taken out. All annuities are calibrated for $x_R = 65$ year old males and term life insurances for $x_S = 40$ year old males. The actuarially fair premiums are computed based on first-order mortality tables "DAV 2008 T" and "DAV 2004 R" of the German Actuarial Association, respectively where for annuities a static life table is used. The actuarial interest rate r^G is set to 0.25%. We assume an initial annuity payout of $R_1 = 1$, which results in an actuarially fair single premium of $P_a^R = 15.10$. To obtain better comparability between different product mixes, the initial sum insured is calibrated to $S_1 = 108.81$, which results in the same price $P_a^R = P_a^S = 15.10$. The equityholders' initial contribution E_0 is set to 8% of the total initial premiums without loadings, yielding $E_0 = 131,304$. The cost loadings are set to $\lambda^R = \lambda^S = 10\%$. Regarding the target buffer ratio, surplus distribution ratio and liquidation costs, the same parameters as in Bohnert et al. (2015) were used, i.e. $\gamma = 10\%$, $\alpha = 70\%$ and $c = 20\%$. With respect to the assets, we use a drift $\mu = 6\%$ and a volatility $\sigma = 8\%$, which can be interpreted as the result of a portfolio weighting of low and high risk investments, resulting in a continuous expected one-year return of $E(r_t) = 5.68\%$. The risk free interest rate r_f is set to 0.5%. The relevant parameters were all subject to a sensitivity analysis, since we are interested in general interaction effects. The dividend rate ξ is calibrated such that Equation (11) is satisfied and can be found in the Appendix.

For risk measurement purposes, when simulating the actual ("real-world") number of deaths d_t^R and d_t^S, in contrast to pricing, we use the corresponding second-order mortality tables without safety loadings. Regarding the functional forms of the premium reduction functions PR^R and PR^S, which depend on the reported one-year default probability δ, we consider the three scenarios in Figure 4 to gain insight in the impact of a product-dependent willingness to pay in life insurance on risk measures. In scenario 1, we assume that policyholders are "risk neutral" and indifferent towards default risk, i.e. $PR^R(\delta) = PR^S(\delta) = 0$, indicated by the horizontal solid line in Figure 4. In scenario 2, we assume that the premium income is strictly reduced for an increasing reported one-year default probability δ due to a decreasing willingness to pay, but without product-dependent risk sensitivities, where we assume that the reduction is equal for both product lines. For this scenario, we fit an exponential function through the combined results of our two separate surveys, as shown by the dashed line in Figure 4, which results in $PR^R(\delta) = PR^S(\delta) = 0.02 \cdot \exp(59.12 \cdot \delta)$. Finally, in scenario 3 we assume that policyholders exhibit product-specific risk sensitivities in line with the observations in our experiment, i.e. (see Figure 3 for the values and the circles / crosses in Figure 4):

$$PR^R(\delta) = \begin{cases} 0.0536 & \text{for} \quad \delta = 0.01 \\ 0.0576 & \text{for} \quad \delta = 0.02 \\ 0.1301 & \text{for} \quad \delta = 0.03 \\ 0.1463 & \text{for} \quad \delta = 0.04 \end{cases} \quad \text{and} \quad PR^S(\delta) = \begin{cases} 0.0255 & \text{for} \quad \delta = 0.01 \\ 0.0475 & \text{for} \quad \delta = 0.02 \\ 0.1496 & \text{for} \quad \delta = 0.03 \\ 0.2501 & \text{for} \quad \delta = 0.04 \end{cases}$$

Figure 4: Considered scenarios regarding the premium reduction function for annuities PR^R and term life contracts PR^S depending on the one-year default probability



To take into account that in the experiment the default probabilities were stated directly, which is generally not the case in reality, we first use a scaling factor of $z_R = z_S = 0.5$ in the following simulation analysis to adjust the premium reduction values (see Equation (7)), which we then vary in different settings.

4.2 The impact of policyholders' willingness to pay on a life insurer's risk situation

Figure 5 displays the impact of different levels of the reported one-year default probability δ (1% and 4%) in the previously defined three scenarios on the insurer's actual shortfall probability under various portfolio compositions.[14] The upper graphs show the overall shortfall probability over the entire contract term, and the bottom graphs the maximum annual shortfall probability (which should not exceed δ).

Comparing scenarios 1 and 2, as a first result one can see that taking into account the policyholders' willingness to pay increases the overall shortfall probability over the entire contract term (upper graphs) for all portfolio compositions by about 0.5 (9.5) percentage points for a reported δ of 1% (4%). In contrast to this, the increase in $SP_{\max}^{annual}$ (lower graphs) strongly depends on the portfolio composition. Here, portfolios with a higher fraction of annuities are more affected by taking into account the policyholders' willingness to pay, which can be explained by the product-specific cash flow structures (see also Gatzert and Wesker, 2012). While the payouts for term life insurances increase over time, they decline for annuities. As a result, the risk of default is highest and rather occurs at the beginning of the contract term in case of annuities, and at the end in case of term life insurances. Since a reduction in the policyholders' willingness to pay reduces the initial premium income, and thus mainly affects the shortfall probabilities in the first years, portfolio compositions with higher fractions of annuities are more affected.

In contrast to previous findings (see e.g., Gatzert and Wesker, 2012; Wong et al., 2017; both however with somewhat different model set-ups), we do not observe a mixed portfolio composition with a minimum default risk value in scenarios 1 and 2, which can arise for mixed portfolios due to smoother cash flow structures. In scenario 1 as well as scenario 2, both $SP^{overall}$

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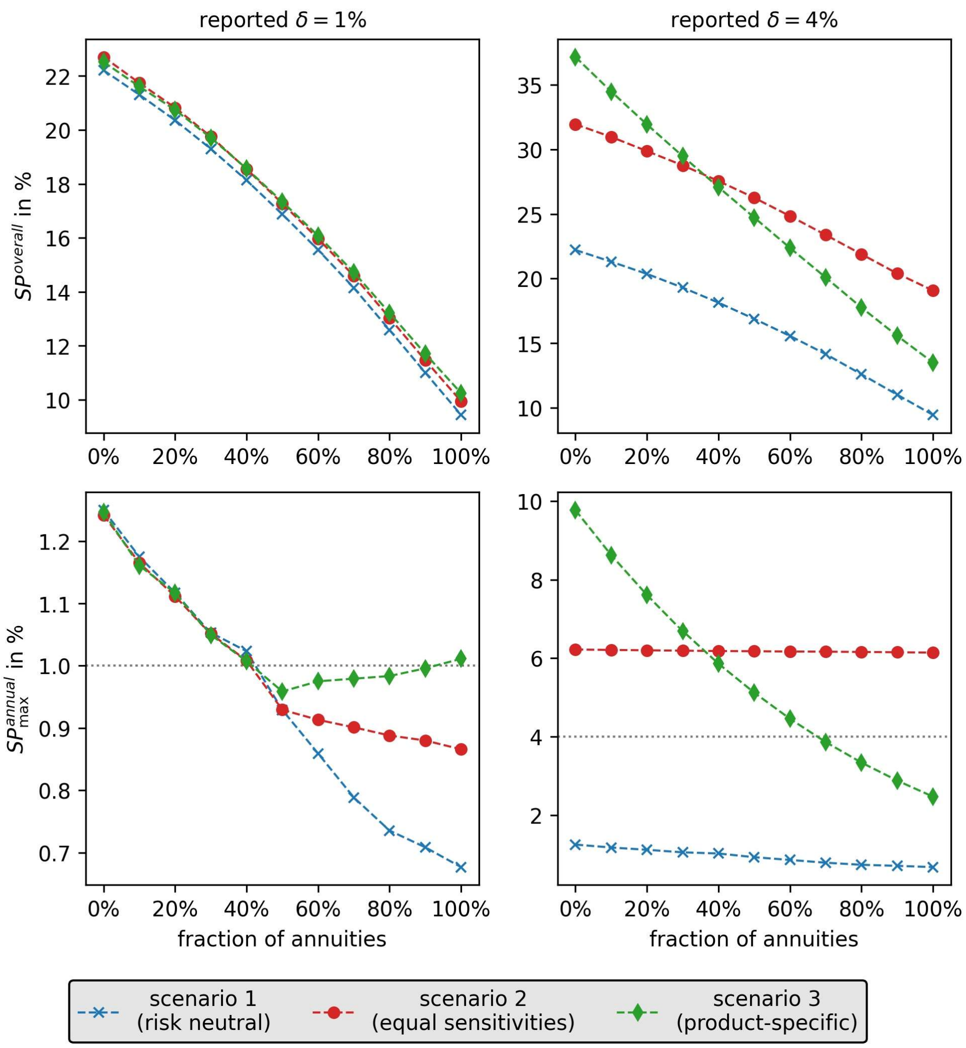
[14] For illustration purposes, we focus on the situations with $\delta = 1\%$ and $\delta = 4\%$, where the deviations between the premium reductions of annuities compared to term life insurances are most pronounced and reversed in the two cases in scenario 3 (see Figure 4).

and $SP_{\max}^{annual}$ are strictly decreasing for an increasing portion of annuities, as Figure 5 shows.[15] One reason for this might be the policyholders' surplus distribution, as the bonus system exponentially increases the annuities as well as the sums insured over time due to cliquet-style interest rate effects (see Bohnert et al., 2015). Thus, later payments are more affected, which are more pronounced in case of term life insurances. However, the calibrated fair dividends in Figure A.1 suggest that there are still some portfolio effects, as fair dividends are minimal for a portfolio composition consisting of only 90 or 80 percent annuities.

Figure 5: The impact of different levels of the reported default probability δ in the three scenarios (see Figure 4) on the insurer's actual overall and maximum annual shortfall probability (see Equations (8) and (9)) under various portfolio compositions with scaling factors $z_R = z_S = 0.5$



[15] Only in case of the higher reported one-year default probability of $\delta = 4\%$, $SP_{\max}^{annual}$ slightly increases for an increasing portion of annuities, because of the product-specific cash flows and the higher premium reduction as compared to $\delta = 1\%$.

While in Figure 5 specific portfolio effects in regard to (e.g. risk-minimizing) shortfall probabilities cannot be seen for the first two scenarios, such an effect is clearly visible in the third and - for our research purpose most relevant and new - scenario, where based on our experimental findings for the lower reported one-year default probability $\delta = 1\%$, the policyholders' risk sensitivities are higher for customers purchasing an annuity than for term life contracts, whereby for the higher $\delta = 4\%$, this effect is reversed (see Figure 4). As a result, for $\delta = 1\%$ the initial premium income for portfolios with a higher fraction of annuities is reduced, and for $\delta = 4\%$ it is increased. In case of the lower reported one-year default probability ($\delta = 1\%$), risk-minimizing portfolio effects arise for $SP_{\max}^{annual}$, as can be seen in the lower left graph in Figure 5: Increasing the fraction of annuities first strictly reduces $SP_{\max}^{annual}$ until a minimum of about 0.95% is reached, before rising again. While $SP_{\max}^{annual}$ is slightly increasing for higher fractions of annuities in scenario 2, in case of the higher reported one-year default probability ($\delta = 4\%$) in scenario 3 it is strictly decreasing, because of the lower premium reduction for annuities as compared to term life contracts. Regarding the overall shortfall probability, the upper two graphs of Figure 5 show that in scenario 3, $SP^{overall}$ still only decreases for an increasing fraction of annuities, but for $\delta = 1\%$ with a smaller slope and for $\delta = 4\%$ with a higher slope as compared to scenario 2.

Furthermore, the numerical results indicate that in all three scenarios both $SP^{overall}$ and $SP_{\max}^{annual}$ can be substantially lowered by the "right" portfolio composition. Additionally, the lower left part of Figure 5 illustrates that product portfolio management is an important tool for life insurers to ensure that the maximum one-year default probability does not exceed the reported one. In the example, only portfolio compositions which lie below the dotted line satisfy Equation (10) and are thus valid.[16]

4.3 The impact of larger deviations between product-dependent risk sensitivities

In this section, we build on the previous observation in scenario 3, where portfolio effects with a minimum shortfall probability could only be observed in case of a larger premium reduction for annuities compared to term life insurance, i.e. we investigate the situation of the lower reported one-year default probability ($\delta = 1\%$) in scenario 3. Therefore, for additional sensitivity analysis we first set the scaling factors from previously $z_R = z_S = 0.5$ to $z_R = z_S = 1$, i.e. we use the (higher) premium reductions as observed in our experiment. In a second analysis, we

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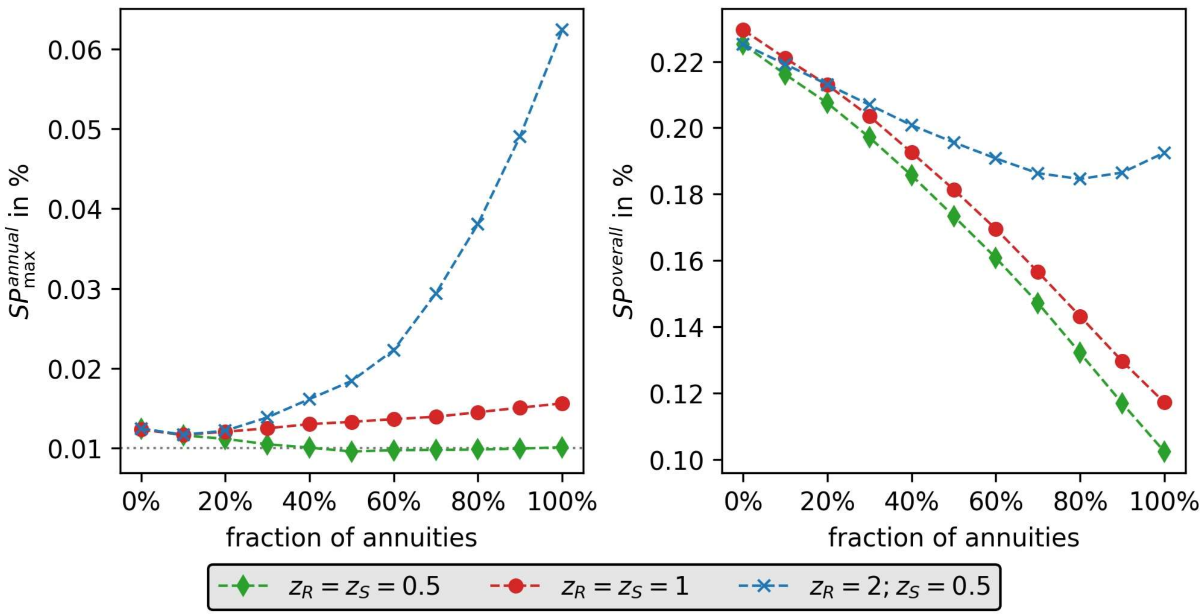
[16] Note that a more granular reaction in the insurer's risk management could be implemented to ensure that the reported one-year default probability is not exceeded, e.g. increasing the initial contribution E_0 or adjusting the asset allocation, as already described in Section 3.5.

artificially increase the differences between the premium reductions for annuities and term life insurances by setting the scaling factors to $z_R = 2$ and $z_S = 0.5$, where the experimentally observed premium reduction for annuities PR^R is multiplied by two and the premium reduction PR^S for term life insurances is divided by two.

Figure 6 shows that increasing the differences between the premium reductions in scenario 3 (with $\delta = 1\%$) strongly influences the risk-reducing portfolio composition, where in case of the highest difference ($z_R = 2$; $z_S = 0.5$) additional portfolio effects arise on the level of the overall shortfall probability $SP^{overall}$. Thus, product-dependent risk sensitivities can imply new or at least strengthen portfolio effects in a life insurer's product portfolio, depending on the respective differences.

Figure 6: The impact of different deviations between product-dependent risk sensitivities given by the respective scaling factors z_R and z_S on the insurer's actual overall and maximum annual shortfall probability (see Equations (8) and (9)) under various portfolio compositions in scenario 3 with a reported one-year default probability $\delta = 1\%$



Notes: The product-dependent premium reduction value (see scenario 3 in Figure 4) for annuities is multiplied with z_R and for term life with z_S.

The left graph of Figure 6 shows that the risk-reducing portfolios regarding $SP_{\max}^{annual}$ contain a decreasing fraction of annuities when the deviation between the product-dependent risk sensitivities is increased. While in case of the lowest deviation ($z_R = z_S = 0.5$) the risk-reducing portfolio consists of about 50% annuities, it consists of only about 10% in the other two cases. Furthermore, the right graph of Figure 6 shows that in case of higher deviations between risk sensitivities $(z_R = 2;\ z_S = 0.5)$, different portfolio effects arise, as it would be optimal to sell a portfolio consisting of 80% annuities in order to reduce the overall shortfall probability $SP^{overall}$. Therefore, minimizing the overall shortfall probability does not automatically imply that the annual maximum shortfall probability is minimized as well. This indicates that solely aiming to satisfy one-year regulatory requirements may not necessarily provide suitable incentives for a long run risk management perspective.

4.4 Further sensitivity analyses

To investigate the robustness of our numerical results, we perform various sensitivity analyses using different model parameters in the setting of Figure 6 with the following results. First, portfolio compositions with higher fractions of term life insurances are more affected by an increasing asset volatility σ in the present setting (with a stronger emphasis on later payouts, where volatility plays a particularly important role). Therefore, in case of the highest deviation between the premium reductions ($z_R = 2;\ z_S = 0.5$), the $SP^{overall}$-reducing portfolio consists of a higher fraction of annuities when volatility is increased. Similarly, the maximum one-year default probability $SP_{\max}^{annual}$ is substantially higher for an increased volatility, but with similar risk-reducing portfolio compositions for $SP_{\max}^{annual}$ for all volatilities.

In contrast to this, a decreasing initial contribution E_0 by the equityholders implies an upward shift of the overall shortfall probability $SP^{overall}$ for all portfolio compositions. But the increase in the maximum one-year default probability $SP_{\max}^{annual}$ is more pronounced for portfolios with higher fractions of annuities, as here a default mainly occurs during the first years, being more affected by a decreasing initial contribution.

A strong influence can also be found when varying the surplus distribution rate α, where we especially investigate the situation without surplus in line with our experiment. An increasing surplus distribution rate α thereby leads to higher (cliquet-style) interest rate guarantees for policyholders and thus generally results in higher shortfall probabilities. Since later payments are more affected, varying α has a stronger impact on portfolios with higher fractions of term life insurances with higher payouts in later contract years. As a result, we observe similar (but more pronounced) effects as in case of the asset volatility σ. Overall, the surplus distribution mechanism increases the differences between the product-specific cash flow structures and is thus important for portfolio effects in the present setting in the sense of the possibility to smooth cash flows of mixed portfolios, but possibly (due to higher guarantees) at higher shortfall levels.

5. SUMMARY AND IMPLICATIONS

This paper examines the impact of policyholders' willingness to pay with respect to reported shortfall probabilities on a life insurer's risk situation. To the best of our knowledge, this paper is the first to study *product-dependent* policyholders' willingness to pay. We conduct the first experiment and run a model-based simulation analysis to study the impact of a reported shortfall probability on the policyholders' willingness to pay for annuities and term life insurances, where we especially investigate the existence of product-specific differences. In contrast to previous literature, we further investigate a longer-term setting with cash flows over 30 years instead of a single-period model, and we analyze the impact of product-dependent risk sensitivities, where the risk sensitivity for purchasing annuities differs from term life insurances. The asset-liability model, which we use for our simulation analysis, incorporates actuarially priced annuities and term life insurances with cost loadings, fairly calibrated dividend rates for shareholders, and (cliquet-style) guarantees as well as surplus distribution for policyholders. We further take into account the mechanism of a product-dependent policyholders' willingness to pay (calibrated based on an experiment), where the insurer reports its one-year default probability and, as a result, premium income is reduced depending on the reported shortfall probability as well as depending on the product (annuities vs. term life).

The results of our experiment reveal that policyholders sharply reduce their willingness to pay for life insurance products in case of a reported default probability, which is in line with previous experiments in the non-life insurance sector. Furthermore, we find evidence that policyholders' risk sensitivities are indeed product-dependent and differ between annuities and term life insurances, which was already indicated on the general level of business lines by empirical research on real market data.

Our simulation results strongly emphasize that depending on the reported default probability and customers' risk sensitivity, the mechanism of policyholders' willingness to pay can considerably affect a life insurer's risk situation. We further confirm that the "right" portfolio composition (with respect to the portion of term life contracts and annuities) from the insurer's perspective can significantly reduce its shortfall probability and thus help to satisfy reported safety levels. The main finding of this paper in terms of economic implications for insurers is that different portfolio effects arise if policyholders' risk sensitivities are indeed *product-dependent* as shown in our experiment, and that these effects are strongly influenced by the *extent* of the deviation of risk sensitivities, the asset volatility, the equityholders' initial contribution and the surplus distribution rate.

In summary, our results suggest that the policyholders' willingness to pay depending on reported safety levels should be considered in a life insurer's risk- and value-based management to better assess the effect of portfolios on the risk situation and to identify risk-reducing or risk-minimizing portfolio compositions, where especially the degree of customers' (product-dependent) risk sensitivities should be taken into account in some way. As the present paper was intended to provide first insight on this topic, we conclude that there is a general need for further theoretical, numerical and empirical research about the mechanisms and implications of policyholders' willingness to pay on the level of (complex) long-term products in life insurance.

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APPENDIX

Table A.1: Described purchase situation in the annuity survey

Original wording in German	English translation
Stellen Sie sich vor, Sie sind 65 Jahre alt, stehen kurz vor dem Ruhestand und wollen 100.000 € in eine Sofortrente investieren, bei der Ihnen ab sofort jeden Monat für einen festgelegten Zeitraum eine gewisse Rente gezahlt wird, solange Sie noch am Leben sind. Der Zeitraum und die Höhe der monatlichen Rentenzahlung hängen vom konkreten Produkt ab. Wählen Sie bitte in den folgenden 12 Szenarien jeweils dasjenige Produkt aus, welches Ihnen am ehesten zusagen würde.	Imagine that you are 65 years old, you are about to retire and you would like to invest 100,000 € into an immediate annuity, which from now on pays you a monthly annuity payment for a certain period of time. The period of time and the amount of the monthly annuity payment depend on the specific product design. In each of the following 12 scenarios, please select the product you prefer the most.

Table A.2: Described purchase situation in the term life insurance survey

Original wording in German	English translation
Stellen Sie sich vor, Sie sind 40 Jahre alt und der/die Hauptverdienende in einer festen Partnerschaft mit Kindern. Um Ihre Familie finanziell abzusichern, möchten Sie eine Risikolebensversicherung mit einer Versicherungssumme von 100.000 € abschließen, welche Ihren Hinterbliebenen ausgezahlt wird, wenn Sie innerhalb des vertraglich festgelegten Zeitraums versterben. Hierfür müssen Sie eine monatliche Prämie zahlen. Die Höhe der Prämie und die Vertragslaufzeit hängen vom konkreten Produkt ab. Wählen Sie bitte in den nachfolgenden 12 Szenarien jeweils dasjenige Produkt aus, welches Ihnen am ehesten zusagen würde.	Imagine you are 40 years old and live in a stable partnership with children, where you are the person with the highest wage. In order to financially protect your family, you would like to buy a term life insurance with a sum insured of 100,000 €, which will be paid out to your surviving relatives if you die within the contractually defined period. For this you have to pay a monthly premium. The amount of the premium and the period of time depend on the specific product design. In each of the following 12 scenarios, please select the product you prefer the most.

Table A.3: Description of the attributes used in the annuity survey

Original wording in German	English translation
Die *Vertragslaufzeit* gibt an, über welchen Zeitraum die monatlichen Renten vom Versicherer an Sie gezahlt werden, solange Sie noch am Leben sind.	The *contract term* specifies the period over which the monthly annuity will be paid to you by the insurer as long as you are still alive.
Die *jährliche Ausfallwah*rscheinlichkeit gibt an, wie wahrscheinlich es ist, dass der Versicherer innerhalb eines Jahres Insolvenz anmelden muss. Die Versicherungsleistung wird in diesem Fall teilweise oder ganz gekürzt.	The *one-year default probability* defines how probable it is that the insurer will have to file for bankruptcy within a year. In this case, your claims will be partially or fully reduced.
Die angegebene *Rente* wird *monatlich* bis zum Ende der vorgegebenen Vertragslaufzeit vom Versicherer an Sie ausgezahlt.	The specified *annuity* will be paid to you *monthly* by the insurer until the end of the specified contract term.

Table A.4: Description of the attributes used in the term life insurance survey

Original wording in German	English translation
Die *Vertragslaufzeit* gibt an, über welchen Zeitraum der Todesfall des Versicherten abgesichert ist.	The contract term specifies the period over which the insured‘s death is covered.
Die *jährliche Ausfallwahrscheinlichkeit* gibt an, wie wahrscheinlich es ist, dass der Versicherer innerhalb eines Jahres Insolvenz anmelden muss. Die Versicherungsleistung wird in diesem Fall teilweise oder ganz gekürzt.	The *one-year default probability* defines how probable it is that the insurer will have to file for bankruptcy within a year. In this case, your claims will be partially or fully reduced.
Die *monatliche Prämie* gibt die Höhe der Zahlung an, die Sie jeden Monat über die vorgegebene Vertragslaufzeit an den Versicherer zahlen müssen.	The *monthly premium* defines the amount of payment you must pay to the insurer each month over the specified contract term.

Figure A.1: Fair dividend rates for portfolio compositions displayed in Figure 5

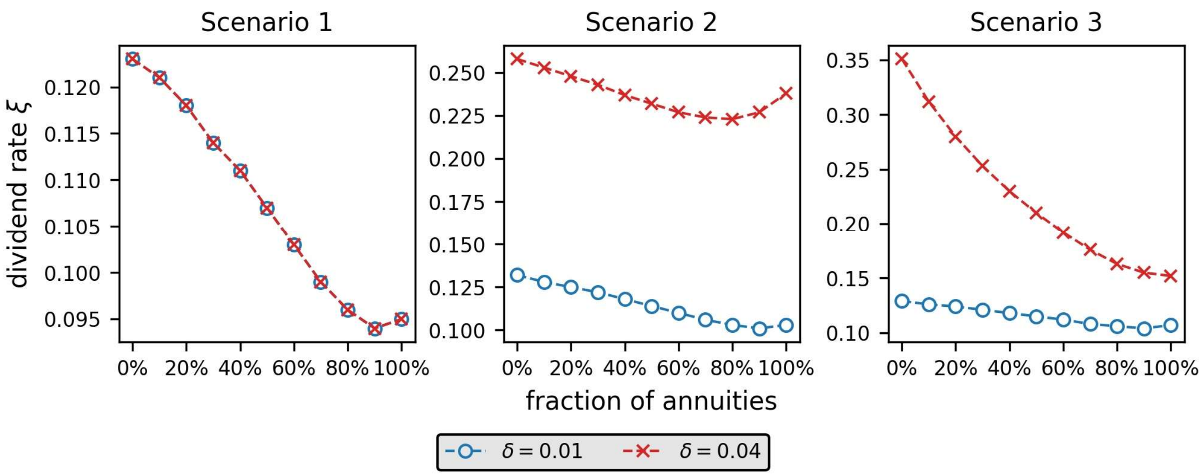

Figure A.2: Fair dividend rates for portfolio compositions displayed in Figure 6