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The impact of risk-based regulation on European insurers' investment strategy

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Abstract This paper examines the impact of Solvency II on the attainability of target returns, the attainability of portfolio efficiency and the asset allocation of European insurers. I start with a brief introduction to the Solvency II Directive, focusing on the rules for calculating solvency capital requirements (SCR) according to the Solvency II standard formula. The subsequent numerical analysis includes several portfolio optimizations focusing on six relevant asset classes for the 1993–2017 time period. I derive optimal portfolios with respect to the Solvency II capital requirements, with respect to conventional risk measures, and I combine both optimization problems. My results show that the capital requirements according to Solvency II are not adequately calibrated. Nevertheless, due to a solid equity base, the majority of European insurers are still able to attain high target returns and mean-variance-efficiency. However, undercapitalized insurers are not able to hold risk-optimal allocations of equities, real estate and hedge funds any longer. In an environment of very low interest rates, these insurers may also face difficulties obtaining their target returns. To the best of my knowledge, this is the first paper to explicitly incorporate the solvency capital requirement as a numerical constraint into the insurers' portfolio optimization problem. As a result, my approach first provides insights about the attainable target return and the asset weights as a direct function of insurers' equity.

Auswirkungen risikobasierter Regulierung auf die Anlagestrategie europäischer Versicherer

Zusammenfassung Der vorliegende Artikel untersucht die Auswirkungen von Solvency II auf die Asset Allocation europäischer Versicherungsunternehmen, insbeson-

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dere im Hinblick auf die Erreichbarkeit von Zielrenditen und Portfolioeffizienz. Ich beginne mit einer kurzen Einführung in das Solvency II Framework mit Fokus auf das Marktrisikomodul der Solvency II Standardformel. In der darauffolgenden numerischen Analyse wird die Asset Allocation über die sechs relevantesten Assetklassen für den Zeitraum von 1993 bis 2017 optimiert. Die Portfolien werden hinsichtlich der Solvenzkapitalanforderungen nach Solvency II und hinsichtlich konventioneller Risikomaße optimiert. In einem weiteren Analyseschritt werden die Portfolien im Hinblick auf beide Zielgrößen simultan optimiert. Meine Ergebnisse zeigen, dass die Solvenzkapital-anforderungen nach Solvency II gegenüber konventionellen Risikomaßen fehlparametrisiert sind. Die Mehrzahl der europäischen Versicherer ist aufgrund hoher Eigenkapitalquoten dennoch in der Lage, hohe Zielrenditen und Portfolioeffizienz zu erreichen. Unterkapitalisierte Versicherer sind nach Solvency II hingegen nicht mehr in der Lage, risikooptimale Anteile an Aktien, Immobilien und Hedge Fonds zu halten. Bedingt durch das Niedrigzinsumfeld geraten unterkapitalisierte Versicherer zudem in Gefahr, ihre Zielrenditen nicht mehr zu erreichen. Nach meinem besten Wissen ist dies der erste Artikel, der die Solvenzkapitalanforderungen nach Solvency II explizit als Nebenbedingung in der Portfoliooptimierung berücksichtigt. Hierdurch zeigt sich erstmals die Sensitivität der erreichbaren Zielrendite und der Gewichte der verschiedenen Assetklassen in Abhängigkeit vom Eigenkapital der Versicherer.

1 Introduction

Short-term and long-term interest rates are currently close to their historical lows, as are yields on top-rated government bonds. For example, the annual yield on new issue 10-year German government bonds was just 0.467% in July 2017, with no sustainable interest rate turnaround foreseeable anytime soon. According to a recent publication by the European Central Bank (ECB), more than half the investments of insurance companies in Europe are in fixed-interest securities. Hence, this politically motivated low-interest phase poses a major challenge to the largest institutional investors in Europe, which together hold almost EUR 7.8 trillion of assets.[1] More precisely, the combination of low bond yields and high interest rate guarantees on existing life insurance policies can result in severe undercoverage for insurers.[2] The pressure on insurance companies to take action is growing even stronger because the high yielding bonds from the pre-low-interest phase that insurers still hold in their portfolios will mature sooner than the "high rate" insurance policies. Insurers will therefore be forced to move their investments out of top-rated government bonds into asset classes offering higher returns, such as corporate bonds, equities or alternative investments like real estate or hedge funds.

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[1] See ECB (2017).

[2] According to an analysis by Assekurata (2016), for example, the average guaranteed interest rate on existing policies among German life insurance companies amounted to 2.97% in 2016.

Several practitioner studies report that European insurers have already expanded their quotas for alternative investments in recent years.[3] However, the introduction of a new risk-based regulatory framework in 2016 (Solvency II) could have significant implications on insurers' investment strategy and could even counteract this trend in the months and years ahead. In order to limit their insolvency risk, insurers must now underpin all risky balance sheet items (including investments) pro rata with equity capital. The required amount of equity – the solvency capital requirement or SCR – varies considerably depending on the respective asset class. From an economic perspective, the regulator has introduced a new constraint into the portfolio optimization problem: The aggregate of the SCR for all risk positions must be less than the insurer's amount of equity capital (the basic own funds or BOF). If this constraint is binding, a shift in the portfolio weights is foreseeable. Since the optimized portfolios without the constraint are efficient, the constrained portfolios must exhibit either more risk or less return. Both effects are highly undesirable, considering that the original purpose of the regulation is the mitigation of risk, and that insurers are already facing undercoverage in terms of return.[4]

Most of the existing literature on the effects of Solvency II on insurers' investment policy only deals with specific details of the framework, such as the calibration of the SCR for certain asset classes, for example.[5] There are, however, two very comprehensive and seminal contributions by Hoering (2013) and Braun et al. (2015), entitled "Will Solvency II Market Risk Requirements Bite? The Impact of Solvency II on Insurers' Asset Allocation" and "Portfolio Optimization Under Solvency II: Implicit Constraints Imposed by the Market Risk Standard Formula", respectively. Hoering (2013) states that the aforementioned constraint imposed by the Solvency II standard formula's market risk module is not binding for many European insurers. He notes that the widely-used Standard & Poor's (S&P) rating model requires even more equity capital than Solvency II for most S&P rating classes. He concludes that insurers with a credit rating of BBB or better will most likely not alter their asset allocation after the introduction of Solvency II. However, Hoering is not examining efficient portfolios in an environment of extremely low interest rates, but rather the investment portfolio of a representative European-based life insurer in 2012. Braun et al. (2015), on the other hand, consider the issue of optimizing an insurance company's asset allocation when the firm needs to adhere to the capital requirements of Solvency II in the context of modern portfolio theory. They run a quadratic portfolio optimization program, and subsequently compute the capital charges for the respective portfolios according to Solvency II. They find that most of the efficient portfolios are not admissible if the insurer's amount of equity capital is limited to the industry average of 12%. In contrast to Hoering, Braun et al. therefore conclude that Solvency II might cause severe asset management biases in the European insurance sector.

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[3] Blackrock (2013), Preqin (2013), Preqin (2015), Insurance Europe and Oliver Wyman (2013), Towers Watson (2013), EY (2016), EY (2017).

[4] Besides the effects on portfolio efficiency, a reallocation of insurers' assets could lead to fundamental shifts in demand and pricing for several asset classes, as Fitch Ratings (2011) has already pointed out.

[5] See, for example, Braun et al. (2014), Gatzert and Kosub (2013), Gatzert and Martin (2012), Severinson and Yermo (2012), Fischer and Schlüter (2012), Rudschuck et al. (2010) and Van Bragt et al. (2010).

This paper fills the gap between the two aforementioned studies: Depending on insurers' equity capital and investment objectives, Solvency II might render certain target returns unattainable, cause portfolio inefficiency or lead to no restrictions on insurers' asset allocation at all. To the best of my knowledge, there exists no previous study that has explicitly incorporated the solvency capital requirement as a numerical constraint into the insurers' portfolio optimization problem. As a result, my approach first provides insights about the attainability of different target returns as a direct function of insurers' basic own funds.[6] Furthermore, I calculate the critical threshold for the basic own funds needed to attain portfolio efficiency at the respective target returns. Ultimately, my analysis provides an in-depth look at how the optimal portfolio weights for individual asset classes will respond to a restriction on insurers' equity capital.

The paper is structured as follows. Sect. 2 presents the market risk standard formula of Solvency II. Sect. 3 introduces the dataset used within the portfolio optimization, as well as the specific calibration of the Solvency II standard formula according to the dataset. In Sect. 4, I run different portfolio optimization programs with the solvency capital requirement as an explicit constraint, and present the results. Finally, Sect. 5 concludes.

2 The Solvency II standard formula

Solvency II codifies and harmonizes the insurance regulation inside the European Union (EU). Its primary concern is the amount of equity capital that insurance companies must hold to reduce their risk of insolvency. For this purpose, Solvency II introduced risk-based capital requirements across all EU Member States for the first time. The solvency capital requirement (the SCR) for an individual insurer can be determined either by using a standard formula imposed by the regulator, or by implementing an insurance internal model. The focus of this paper will be on the Solvency II standard formula, which serves as a reference point for any further analysis.

The Solvency II standard formula refers to basic actuarial principles, and it is calibrated according to historical data. The standard formula consists of separate risk modules (i. e., risk categories), including market risk, counterparty default risk, life underwriting risk, non-life underwriting risk, health underwriting risk and intangible asset risk. Each of these modules consists of further sub-modules (see EIOPA 2012). In order to determine a company's overall capital requirement, the capital requirements for all risk modules (and sub-modules) are determined first, and aggregated subsequently by taking into account diversification effects.

The further analysis is focused on the market risk module, which is of particular importance as its capital requirements depend directly on the insurers' asset allocation. In addition, according to the "EIOPA Report on the fifth Quantitative Impact Study (QIS5) for Solvency II" (see EIOPA 2011), and according to a study by Fitch

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[6] Note that the attainability of a certain target return is necessary to fulfill the interest rate guarantees on existing life insurance policies, as already pointed out.

Ratings ([2011](#)), the market risk module plays the predominant role in determining a company's overall SCR.

The market risk module (SCR_{mkt}) consists of seven sub-modules: interest rate risk, equity risk, property risk, spread risk, concentration risk, illiquidity risk and exchange rate risk. In line with previous studies (see Gatzert and Martin [2012](#) or Braun et al. [2015](#), for example), the further analysis is limited to the most important sub-modules, which are interest rate risk, equity risk, property risk and spread risk. Generally, the SCR for each sub-module refers to the change in the basic own funds (ΔBOF) that results due to a shock or stress in the financial markets, related to the module's risk category (e. g., a real estate crisis, a shift in the term structure of interest rates, etc.). BOF is defined as the difference between the market values of assets and liabilities. Without loss of generality, BOF is assumed to equal the equity capital position on the insurer's balance sheet. All specifications presented next are taken from the "Revised Technical Specifications for the Solvency II valuation and Solvency Capital Requirements calculations" released by EIOPA ([2012](#)).[7] This document defines the Solvency II standard formula.

The interest rate risk sub-module (Mkt_{int}) accounts for the fact that both assets and liabilities react to changes in the term structure of interest rates. As the assets' and the liabilities' interest rate sensitivities are typically not perfectly matched, both upward and downward shocks to the yield curve could theoretically have a negative effect on the BOF. Hence, the capital requirement for interest rate risk depends on two possible states,

$$Mkt_{int}^{up} = \Delta BOF|_{up} \tag{1}$$
$$Mkt_{int}^{down} = \Delta BOF|_{down} \tag{2}$$

where $\Delta BOF|_{up}$ and $\Delta BOF|_{down}$ are the changes in the market value of assets minus liabilities caused by an upward or downward change in the interest rate, respectively. The altered interest rate structures for the two stress scenarios ("up" and "down") are derived by multiplying the current interest rate for any given maturity (r_t) by predefined upward and downward stress factors (s_t^{up} and s_t^{down}), which are specified and tabulated by the regulator (see EIOPA [2012](#)):

$$r_{t\_stressed}^{up} = r_t * (1 + s_t^{up}) \tag{3}$$
$$r_{t\_stressed}^{down} = r_t * (1 + s_t^{down}) \tag{4}$$

In any case, the absolute change in the interest rate for a stress scenario must be at least 1 percentage point, according to EIOPA. In practice, the downward stress scenario is of much greater relevance, especially for life insurance companies. This is due to the typically higher duration of insurers' liabilities compared to assets, causing the market values of liabilities to rise more than those of assets in case of a downward interest rate shock. Moreover, the absolute value of liabilities usually exceeds the absolute value of interest rate-sensitive assets. Hence, only a downward

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[7] The European Insurance and Occupational Pensions Authority (EIOPA) is part of a European System of Financial Supervisors that comprises three European Supervisory Authorities.

shift of the yield curve has a negative impact on the BOF in the vast majority of cases.

The equity risk sub-module refers to volatility in the market value of equities and its impact on the BOF. Generally, EIOPA distinguishes between two types of equities: The "type 1" equities include all equities listed in countries of the EEA or OECD, while the "type 2" equities include all those listed in other countries. Moreover, all non-listed equity investments, such as private equity, hedge funds, commodities and other alternative investments, are also considered "type 2" equities. The capital requirement for the equity risk sub-module is determined in two steps. First, the individual capital requirement ($\text{Mkt}_{eq,i}$) for each type of equities (i) is determined by the predefined stress factors:

$$\text{Mkt}_{eq,i} = \max\left(\Delta\text{BOF}|\text{equity shock}_i; 0\right) \tag{5}$$

The stress factors for "type 1" and "type 2" equities are 39% and 49%, respectively. These figures are based on historical total return data, and refer to the value at risk (VaR) with a confidence level of 99.5% on an annual basis. Second, the resulting overall equity risk SCR is calculated using a preset correlation matrix imposed by the EIOPA,

$$\text{Mkt}_{eq} = \sqrt{\sum_i \sum_j \text{CorrIndex}_{ij} * \text{Mkt}_{eq,i} * \text{Mkt}_{eq,j}} \tag{6}$$

where CorrIndex_{ij} is the predefined correlation coefficient of 0.75 between "type 1" and "type 2" equities.

Similarly, the property risk sub-module accounts for risks arising from volatility in the real estate markets. This sub-module applies to direct investments (land, buildings and immovable property rights) and to real estate funds, if it is possible to assess and evaluate the risk of the funds' underlying assets (look-through approach). The capital requirement for property risk (Mkt_{prop}) is again determined by the 99.5% VaR on historical total return data, and amounts to 25%:

$$\text{Mkt}_{\text{prop}} = \max(\Delta\text{BOF}|\text{property shock}; 0) \tag{7}$$

The spread risk sub-module accounts for risks that occur due to changes in the level or in the volatility of credit spreads over the risk-free interest rate structure. In particular, it applies to traditional fixed-income products (e. g., corporate bonds), asset-backed securities and other structured credit products, as well as credit derivatives. Depending on the type of product, the individual spread shock on bonds is determined as follows:

$$\text{spread shock on bonds} = \sum_i MV_i * F(\text{rating}_i; \text{duration}_i) \tag{8}$$

where MV_i is the market value of the credit risk exposure of bond i and $F(\text{rating}_i; \text{duration}_i)$ is a function of the individual credit quality and duration of each bond or loan. The actual factors $F(.)$ can be found in a table published by the regulator (see EIOPA 2012). In this paper, I limit my analysis to traditional corporate bonds. Hence, the capital requirement for credit spread ($\text{Mkt}_{\text{spread}}$) simply refers to the spread shock on bonds as calculated according to Eq. 8.

$$\text{Mkt}_{\text{spread}} = \max(\Delta\text{BOF}|\text{spread shock on bonds}; 0) \tag{9}$$

Finally, the total capital requirement for the insurer's market risk exposure (SCR_{mkt}) is an aggregation of all sub-risks using the predefined regulatory correlation matrix (see EIOPA 2012 or Sect. 3) as follows:

$$\text{SCR}_{\text{mkt}} = \max \left\{ \begin{array}{l} \sqrt{\sum_i \sum_j \text{CorrMkt}_{ij}^{\text{up}} * \text{Mkt}_i^{\text{up}} * \text{Mkt}_j^{\text{up}}}; \\ \sqrt{\sum_i \sum_j \text{CorrMkt}_{ij}^{\text{down}} * \text{Mkt}_i^{\text{down}} * \text{Mkt}_j^{\text{down}}} \end{array} \right\} \tag{10}$$

where $i, j \in$ {interest risk, equity risk, property risk, spread risk} and "up" and "down" indicate whether the upward or downward stress scenario for interest rate risk is applied. The correlation coefficients differ slightly depending on the "up" or "down" scenario. The exact calibration of the standard formula and the descriptive statistics according to the dataset will be presented in Sect. 3.

3 Data and calibration

3.1 Data

In this section, I introduce the dataset used for the portfolio optimization and for the exact calibration of the Solvency II standard formula. Common benchmark indices are used as proxies for the respective asset classes. I therefore assume that each asset class's sub-portfolio has already been diversified prior to the overall asset allocation process. The dataset includes the six most common asset classes: government bonds, corporate bonds, stocks, real estate, hedge funds and money market instruments. I use quarterly total return data for the last 25 years (Q1 1993 to Q2 2017).[8]

European government bonds are represented by the Citigroup European World Government Bond Index with mixed maturities. The index covers government bonds from 16 European countries and is frequently used as a benchmark index. Corporate bonds are represented by the Barclays U.S. Corporate Bonds Market Index, since there is no European benchmark index with a sufficiently long time series

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[8] All data is obtained from Thomson Reuters Datastream.

for corporate bonds.[9] This index consists of various investment-grade bonds with different maturities, which is in line with the actual bond portfolios held by European insurers. Stocks are represented by the MSCI Europe Total Return Index. Short-term money market investments are represented by the JP Morgan Euro 1M Cash Total Return Index. Direct real estate is represented by the IPD U.K. Property Total Return Index, which is also used by EIOPA for the overall calibration of the standard formula's property risk sub-module (see EIOPA 2012). Since the index is based on valuations rather than on the actual transaction prices of properties, the capital return component is subject to the so-called appraisal smoothing bias. Hence, I follow Rehring (2012) and correct the capital returns by using the unsmoothing approach of Barkham and Geltner (1994). In addition, direct real estate investments entail high transaction costs. Therefore, I correct the total returns for overall transaction costs of 7%, as proposed by Collet et al. (2003), Marcato and Key (2005) and Rehring (2012). Finally, hedge fund investments are represented by the HFRI Fund Weighted Composite Index, which is a commonly used industry-level performance benchmark.

3.2 Calibration of the Solvency II standard formula

To calculate the individual SCR for each of the six asset classes, as well as the aggregated SCR for the resulting portfolio (i.e., SCR_{mkt}), I apply the EIOPA specifications as presented in Sect. 2, taking into consideration the characteristics of the aforementioned benchmark indices. For direct real estate, a 25% SCR must be applied. While the MSCI Europe Index is classified as "type 1" equities with a 39% SCR, the HFRI Fund Weighted Composite Index is classified as "type 2" equities, and thus requires a 49% SCR. The capital charges for both types of equities are aggregated, using the regulatory prescribed correlation of 0.75 as described in Eq. 6. Government bonds and money market instruments are not subject to capital charges, and therefore do not enter the SCR calculations directly. However, the overall portfolio's SCR also depends on the allocation of government bonds, as the allocation of government bonds affects the duration of the portfolio and therefore the SCR for interest rate risk. The interest rate sensitivity of government bonds is given by the modified duration of the Citigroup European World Government Bond Index (5.03 as of 02/2017).

To determine the SCR for the spread risk module, Eq. 8 from Sect. 2 is applied. The respective duration and rating of the corporate bond portfolio determines the exact SCR. I use the modified duration of the Barclays U.S. Corporate Bond Market Index as of 02/2017, which is 7.16. Since the index represents a bucket of investment-grade fixed-income securities, I average the spread shocks across several credit quality buckets for the aforementioned duration of 7.16, using the prescribed formulas taken from the EIOPA specifications for the Solvency II standard formula (see EIOPA 2012). As a result, I obtain an 8.9% SCR for the spread risk module.

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[9] The BofA Merrill Lynch (Code: MLEX-PEE) European corporate bond index only dates back to 1996. The index shows a very similar risk-return profile and correlation patterns. Therefore, my results are unlikely to be affected by the choice of this index.

For the interest rate risk module, I use a simplified approach suggested by Hoering (2013), who determines the capital requirement based on the total duration gap between assets and liabilities. The duration gap is calculated as the difference between the duration of the asset side and the duration of the liability side of the balance sheet, and hence indicates the interest rate sensitivity of the basic own funds (BOF) of the insurer. The duration of the asset side is determined by the actual portfolio allocation, or, more precisely, by the relative weights of the government bonds and corporate bonds and by their respective durations. In contrast, the duration of the liability side is given exogenously. I use the information provided by the "CEIOP's Report on its fourth Quantitative Impact Study (QIS4) for Solvency II" (CEIOPS 2008), according to which the median duration of the liabilities of life insurers in Europe is 8.9. Moreover, Braun et al. (2014) set the duration of representative life insurers' liabilities to 10.0, based on several practitioner studies for the German life insurance market. I use the average, and set the duration of the liability side to 9.5 in this study.

Following Braun et al. (2014) and Hoering (2013), the interest rate shock is approximated by parallel upward and downward shifts of the interest rate structure curve. As a result of the low interest rate environment, the respective upward and downward shock factors are currently extremely small (see Eqs. 3 and 4). However, as per the EIOPA framework, I consider the minimum shock factor of 1 percentage point for the further analysis. In addition, given the presented calibration, the duration of liabilities exceeds the duration of assets for every possible portfolio composition, so I limit the further analysis to the downward shock scenario. To summarize, I model the risk of interest rate changes as a −1 percentage point parallel shift in the interest rate structure curve. The actual SCR for interest rate risk is therefore determined by multiplying the downward interest rate shock of −1 percentage point by the duration gap, which in turn is determined by the respective portfolio allocation. For example, a duration gap of 6.0 would require capital charges for the interest rate risk of 6.0%.

3.3 Descriptive statistics

Table 1 depicts the empirical risk and return profiles for the benchmark indices, as well as the empirical and regulatory correlation matrices and the SCR. The upper figures in the first section of the table show the empirical correlations between the returns of the benchmark indices. The figures in parentheses below show the regulatory correlations as imposed by EIOPA (2012). The second section of the table provides information on the mean quarterly returns, the standard deviations, the empirical VaR (on an annual basis) as well as the corresponding SCR, as already outlined in Sect. 3.2.

The descriptive statistics show the expected risk-return relationship for the benchmark indices: Short-term money market instruments yield the lowest returns and also exhibit the lowest risk in terms of standard deviation. At the other extreme are stocks with a mean quarterly return of 2.45% and a standard deviation of 9.51%, thus representing the riskiest and best-yielding asset class, except for hedge funds. The rather high capital requirements for high yielding assets (stocks, hedge funds and real estate) indicate that certain target returns may no longer be attainable for insurers

Table 1 Descriptive Statistics and Solvency II Standard Formula Calibration

	Direct Real Estate	Hedge Funds	Money Market	Corp. Bonds	Stocks (Europe)	Govt. Bonds	Interest Rate Risk
Direct Real Estate	1.00 (1.00)	–	–	–	–	–	–
Hedge Funds	0.14 (0.75)	1.00 (1.00)	–	–	–	–	–
Money Market	0.03 –	0.05 –	1.00 –	–	–	–	–
Corp. Bonds	0.19 (0.50)	–0.04 (0.75)	0.52 –	1.00 (1.00)	–	–	–
Stocks (Europe)	0.47 (0.75)	0.18 (0.75/1.00)	0.06 –	0.14 (0.75)	1.00 (1.00)	–	–
Govt. Bonds	–0.13 –	0.37 –	0.29 –	0.07 –	–0.02 –	1.00 –	–
Interest Rate Risk	– (0.50)	– (0.50)	– –	– (0.50)	– (0.50)	– –	– (1.00)
Mean	1.90%	2.62%	0.75%	1.83%	2.45%	1.33%	–
STD (σ)	5.08%	5.32%	0.62%	3.17%	9.51%	1.89%	–
SCR	25.00%	49.00%	–	8.86%	39.00%	–	1% × DG
99.5% VaR	18.38%	16.50%	0.15%	8.82%	38.84%	4.31%	–
Duration	–	–	–	7.16	–	5.03	–

Notes: The upper division of the table shows the empirical correlation coefficients and the regulatory correlation coefficients (in parentheses below). All correlations refer to the downward interest rate shock scenario. Stocks and hedge funds are aggregated first with a 0.75 correlation. The lower division of the table shows the mean quarterly returns of the assets and the corresponding standard deviations (σ). Moreover, the capital requirements (SCR) and the values at risk (VaR) as their empirical counterparts are presented. The interest rate risk's SCR must be calculated depending on the actual duration gap (DG). The respective durations for the assets are outlined in the last row.

with a low equity base, as already conjectured in the introduction. Moreover, the SCR calculated by EIOPA in 2012 does not seem to be in line with its empirical counterpart any longer. The indices I use show a value at risk of only 18.38% for real estate and only 16.50% for hedge funds, as opposed to 25% SCR and 49% SCR, respectively.[10] Similarly, the correlation figures imposed by the Solvency II standard formula severely overestimate the empirical correlations, which undermines the incentive for a thorough portfolio diversification. The parameterization of the standard formula may therefore not only render certain target returns unattainable, but may also lead to inefficient portfolio allocations and increase investment risk, instead of mitigating risk.

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[10] In accordance with the EIOPA framework, the value at risk was calculated on an annual basis for the 99.5% level.

In the next section, I further analyze the effects of the potentially incorrectly parameterized capital requirements of the Solvency II standard formula in a dynamic portfolio optimization context.

4 Portfolio optimization

4.1 Attainability of target returns and portfolio efficiency

The attainable target return as a function of insurers' basic own funds is obtained by solving the well-known quadratic portfolio optimization program, as first introduced by Markowitz (1952). The covariance matrix ($\Sigma_{\mathbf{reg}}$) is comprised of capital requirements (SCR) and regulatory-imposed correlations, instead of empirical standard deviations (σ) and empirical correlations.[11] The optimization program can be stated as follows:

$$\min_{\mathbf{w}} : \text{SCR}_{\text{mkt}} = \sqrt{\mathbf{w}' \Sigma_{\mathbf{reg}} \mathbf{w}}, \tag{11}$$

Subject to

$$\mathbf{w}' M = \mu_{\text{target}} \tag{12}$$
$$w_i \geq 0, \tag{13}$$
$$\mathbf{w}' 1 = 1, \tag{14}$$

and

$$\mathbf{w}_i \leq u_i \quad i \in \{1, 2, ..., 6\}, \tag{15}$$

where:

- w_i weight of asset class i,
- $\mathbf{w}$ column vector of portfolio weights,

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[11] The Solvency II covariance matrix is calculated as the outer product of the regulatory correlation matrix ($R_{\mathbf{reg}}$) and the column vector of capital requirements ($\mathbf{SCR}$), both as shown in Table 1 ($\Sigma_{\mathbf{reg}} = \mathbf{SCR} \otimes R_{\mathbf{reg}} \otimes \mathbf{SCR}'$). The resulting matrix is not positive semi-definite, which may cause a discontinuity in the quadratic objective function (Eq. 11). I therefore apply the algorithm of Higham (2002) in order to obtain the nearest positive semi-definite matrix. Furthermore, there are circularity issues: Both the equity SCR and the interest rate SCR are a function of the portfolio weights themselves (i.e., a function of the solution vector of the optimization program). While the equity SCR accounts for diversification within the equity sub-module, the interest rate SCR is determined by the duration gap, which in turn depends on the weights of corporate bonds and government bonds. To overcome these issues, all N permissible combinations of hedge funds, stocks, corporate bonds and government bonds are enumerated up to the fourth decimal place. For any given target return, the original problem is now solved N times. Each of the N optimizations uses the corresponding preset asset weights as additional constraints (i.e., the weights of the four asset classes with circularity issues are held constant). Hence, the covariance matrix no longer exhibits circular references. Finally, the portfolio allocation with the lowest SCR of all the *N* optimization results is chosen as the global optimum for the respective target return.

- **M** column vector of mean returns,
- u_i upper limit for the weight of asset class i.

The optimization objective is to minimize the portfolio's SCR with respect to a given target return (Eqs. 11 and 12). Equation 13 excludes short positions, and Eq. 14 constrains the budget. In addition, Eq. 15 introduces investment limits to ensure that only realistic portfolios are obtained. The limits are derived from previous European regulatory standards, which are still reflected in the actual portfolios of European insurers.[12] Specifically, real estate weights are capped at 25%, hedge fund weights at 5%, stocks at 35% and equities (hedge funds and stocks together) are not allowed to exceed 35% of total assets.

The optimization program is solved for all achievable target returns.[13] The resulting portfolios exhibit the lowest possible capital charges for any given target return. The results likewise show the maximum attainable target return for any given SCR (i.e., any exogenously given amount of basic own funds). The attainability of portfolio efficiency depending on the insurers' basic own funds is derived in a straightforward way. I run the portfolio optimization program as described by Eqs. 11 to 15, replacing the regulatory covariance matrix (Σ_{reg}) with the empirical covariance matrix (Σ_{emp}) in order to obtain the set of mean-variance-efficient portfolios. Subsequently, I calculate the SCR induced by the mean-variance-efficient portfolios, using Eq. 10.

Fig. 1 illustrates the results of both optimization programs in the μ-SCR-space. The SCR-optimal frontier is plotted as a solid line, while the mean-variance-efficient portfolios are plotted as a dashed line. It is obvious that the SCR-optimal portfolios lead to much lower capital requirements than the mean-variance-efficient portfolios. In other words, almost any target return is attainable with a much lower amount of basic own funds if the insurer strictly adheres to the Solvency II standard formula instead of minimizing investment risk. This first result already shows the incompatibility between actual investment risk and the market risk capital requirements according to Solvency II. Moreover, the asset allocations and the investment risk differ decisively between the results of both optimization programs. The SCR-optimal frontier is characterized by four points, which are depicted in Fig. 1: The Min-SCR-portfolio at the lower left end of the curve consists of 100% government bonds. This is not surprising, since government bonds have no SCR as such, but they have a duration of 5.03, which enables them to hedge insurers' liabilities against interest rate shocks. The portfolio at point 2 consists of 100% corporate bonds. Corporate bonds have comparably low capital requirements, but also have very good abilities to hedge liabilities against interest rate shocks (a duration of 7.16). At point 3, the portfolio consists of 65% corporate bonds, 30% stocks and 5% hedge funds. This

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[12] The investment limits I use are particularly inspired by the German "Regulation on the Investment of Restricted Assets of Insurance Undertakings" (Investment Regulation; German: Anlageverordnung).

[13] The lowest portfolio target return is determined by the asset class with the lowest expected return, i.e., money market. At the other extreme, the highest portfolio target return is achieved by sequentially increasing the weights of the assets with higher expected returns, until the individual investment limits are reached.
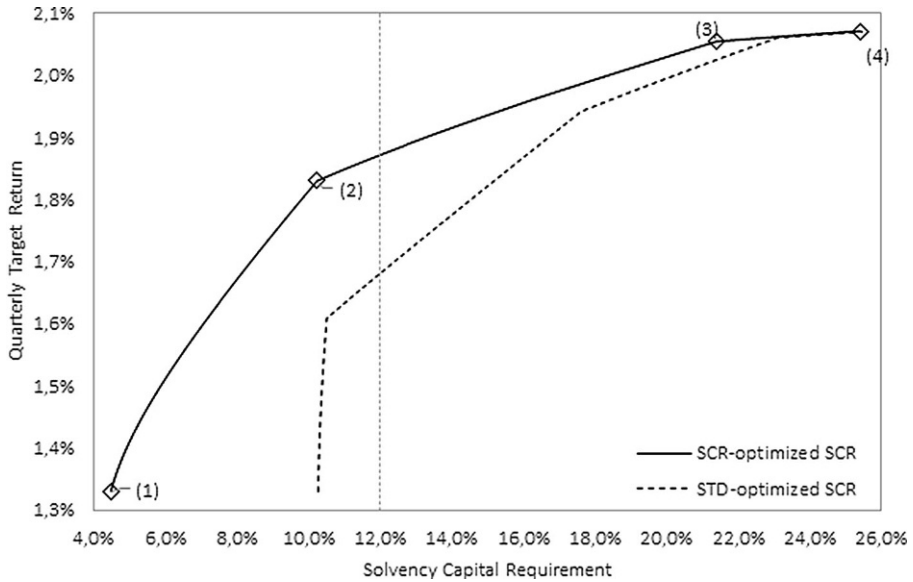
Fig. 1 Optimized Portfolios in the μ-SCR-Space. Notes: See text for explanations

portfolio at point 4 has the maximum achievable target return given the investment limits ($\mu = 2.07\%$, $\mathrm{SCR} = 25.42$). The portfolio consists of 40% corporate bonds, 30% stocks, 5% hedge funds and 25% direct real estate. The concave curvature between the four knit points indicates that the Solvency II standard formula accounts for some diversification in terms of capital charges. However, compared to the common Markowitz optimization, the diversification effect is negligible, and clearly does not govern the allocation process. The allocation is clearly driven by the asset classes' capital charges and durations. The asset classes are allocated sequentially without noteworthy diversification. Asset classes with high capital requirements are allocated only when required by the target return.

The mean-variance-efficient portfolios also consist of government bonds and corporate bonds to a large extent, as the returns of these asset classes exhibit low volatility. However, stocks, hedge funds and real estate are now allocated across the entire spectrum of target returns. In contrast to the SCR-optimal portfolios, the asset classes are now allocated simultaneously, not sequentially. The allocation is governed by the diversification effect instead of the duration gap. Appendix 1 (Fig. 4) shows the asset allocations for both optimization programs' results in detail. Fig. 2 illustrates the results of both optimization programs in the μ-σ-Space and manifests the deadweight loss caused by the Solvency II standard formula: Given a target return of 1.75%, the standard deviation of the mean-variance-efficient portfolio is 75 basis points below the corresponding standard deviation of the SCR-optimal portfolio. Using two standard deviations as the relevant measure for quantifying risk, the shortfall risk of the portfolio would increase decisively by 150 basis points per
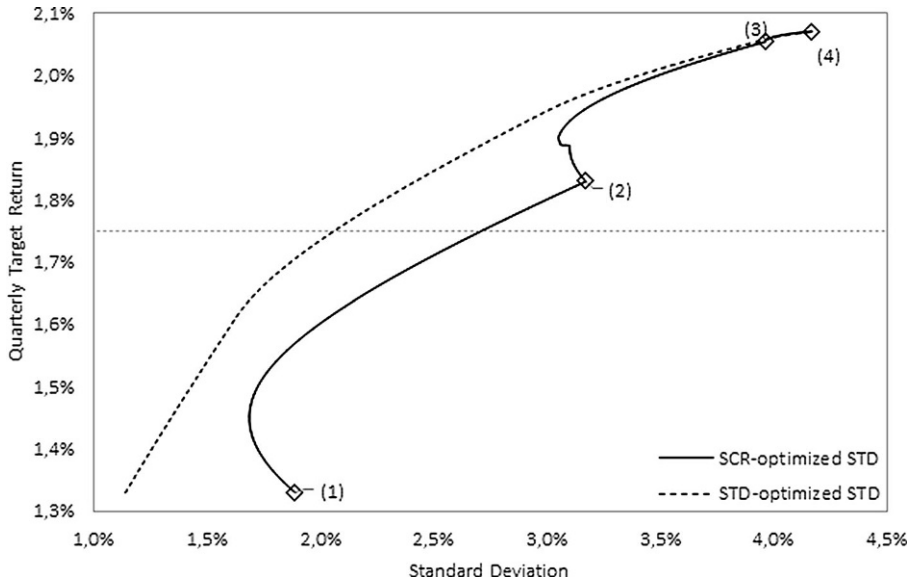
Fig. 2 Optimized Portfolios in the μ-σ-Space. Notes: See text for explanations

quarter.[14] As Fig. 2 shows, the dead weight loss becomes even larger for higher target returns.

According to the information provided by the German Federal Financial Supervisory Authority (BaFin) and the results of QIS5 released by EIOPA (2011), the average European insurer's basic own funds amount to approximately 10–12%. In the spirit of Braun et al. (2015) and Hoering (2013), I use 12% as a reference point for the further analysis. Considering the average European insurer's asset allocation in the past (see, e. g., Fitch Ratings 2011; Insurance Europe and Oliver Wyman 2013), as well as the past performance of the asset classes, the quarterly target return used to be approximately 1.75% (or 7% p. a.). This is sufficient to cover the high interest rate guarantees on existing insurance policies and additional overhead costs.

As the vertical gridline in Fig. 1 shows, quarterly returns of up to 1.88% are attainable with basic own funds of 12%. However, only 1.68% are efficiently attainable. The efficient portfolio with a 1.75% quarterly return induces an SCR of 13.45%. This result shows that average and overcapitalized European insurers are well equipped to fulfill the capital requirements according to the Solvency II standard formula and minimize their portfolios' investment risk at the same time. However, the situation turns out differently for undercapitalized market participants. According to the QIS5 results of EIOPA (2011), one-quarter of all European insurers are at risk of not meeting the capital requirements imposed by Solvency II. Putting aside operational risks (e. g., insufficient reinsurance or high concentration risk), it is likely that these insurers' basic own funds amount to less than 12%. As Fig. 1 shows, the

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[14] This corresponds to a value at risk of approximately 95%, assuming returns are normally, identically and independently distributed.

attainable target return decreases sharply for insurers with basic own funds below 10%. The efficiently attainable target return decreases even more rapidly. Portfolio efficiency is not attainable at all for insurers with basic own funds below 10%. Undercapitalized insurers will not be able to increase their allocations of equities and alternative assets in the search for higher returns and portfolio diversification. On the contrary, undercapitalized insurers might be forced to reduce these asset classes in order to match their portfolio's capital requirement with their basic own funds.

In the next section, I analyze how the optimal portfolio weights for the individual asset classes respond to a restriction on insurers' basic own funds.

4.2 Effects on the allocations of individual asset classes

The optimization programs run in Sect. 4.1 can be considered as extreme points. No insurer will strictly adhere to only one of the optimization objectives (SCR or standard deviation). Rather, in practice, it is the combination of both optimizations that is of particular relevance. I therefore include the insurers' basic own funds as an additional constraint into the standard mean-variance optimization. The optimization program is now formulated as follows:

$$\min_{\boldsymbol{w}} : \quad \sigma = \sqrt{\boldsymbol{w}' \, \Sigma_{\mathbf{emp}} w}, \tag{16}$$

Subject to

$$\boldsymbol{w}' M = \mu_{\text{target}} \tag{17}$$
$$w_i \geq 0, \tag{18}$$
$$\boldsymbol{w}' 1 = 1, \tag{19}$$
$$w_i \leq u_i \quad i \in \{1, 2, ..., 6\}, \tag{20}$$

and

$$\text{BOF} \geq \sqrt{\boldsymbol{w}' \, \Sigma_{\mathbf{reg}} w}, \tag{21}$$

where:

- BOF basic own funds of the insurer.

Equation 21 ensures that the resulting SCR (right-hand side) stays below the insurer's basic own funds (left-hand side), while the portfolios are optimized with regard to investment risk (Eq. 16). The BOF serves as an upper boundary, and is given exogenously by the equity capital of the individual insurer. By varying the BOF, it is now possible to derive the optimal portfolio allocation for any given combination of capital budget and target return.

The optimization program is solved for all achievable target returns and for four different levels of BOF (8%, 10%, 12% and 14%). The six panels depicted in Fig. 3 show the target returns on the horizontal axis, and the respective asset weights on the vertical axis. The four levels of basic own funds are indicated by the legends underneath the respective panels. In addition, the unrestricted portfolio weights are
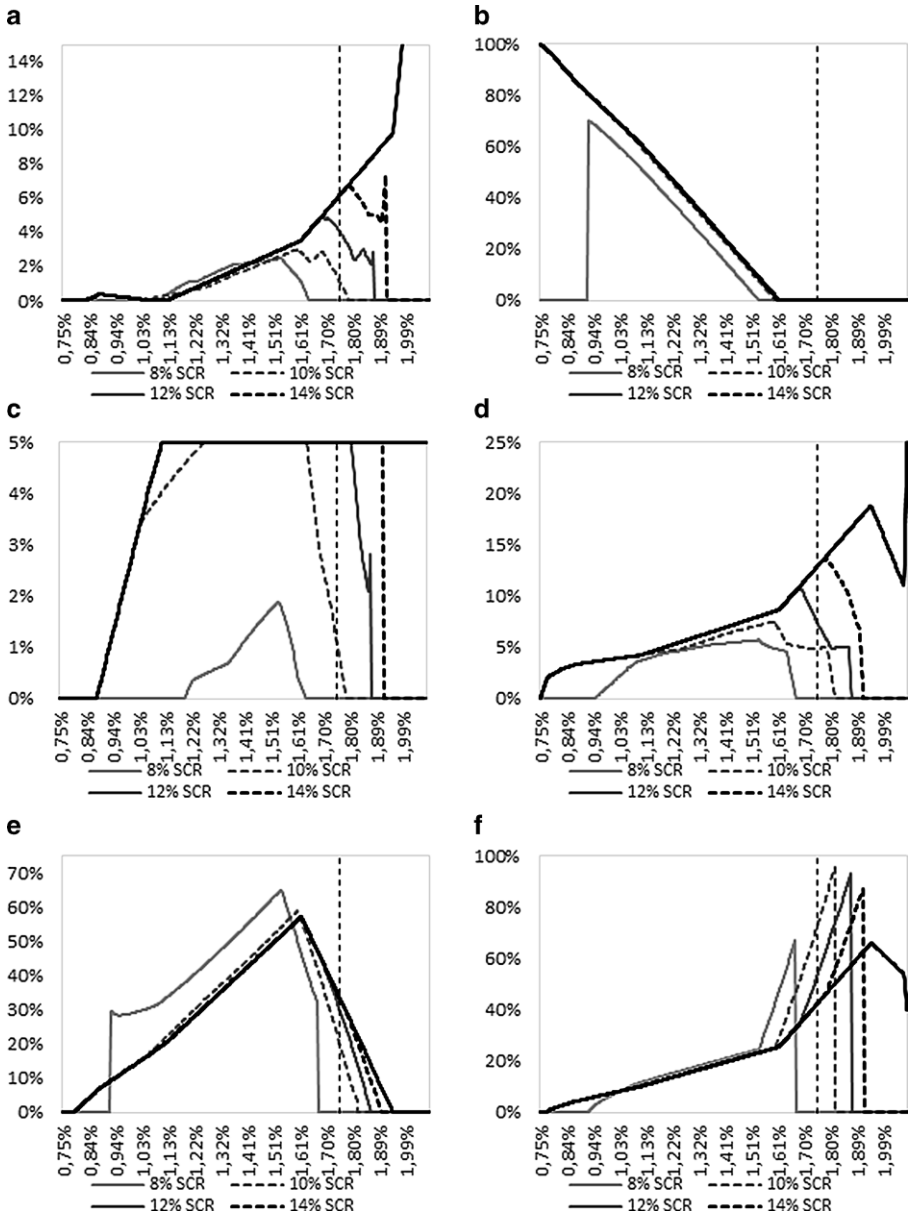
Fig. 3 Optimal Portfolio Allocations for Different Levels of Basic Own Funds, **a** Allocation of Stocks, **b** Allocation of Money Market Instruments, **c** Allocation of Hedge Funds, **d** Allocation of Direct Real Estate, **e** Allocation of Government Bonds, **f** Allocation of Corporate Bonds. Notes: Fig. 3 illustrates the STD optimal portfolio weights for the six asset classes for different given levels of basic own funds. The unrestricted portfolio weights are shown as the solid black line and the quarterly target return of 1.75% is indicated by the dot-dashed vertical gridline

shown as solid black lines and the quarterly target return of 1.75% is indicated by the vertical grid line.

When interpreting the results for a quarterly target return of 1.75%, it becomes evident that stocks, hedge funds and real estate allocations react extremely sensitively to a restriction on insurers' basic own funds. Government bonds are robust to variations in the BOF, and corporate bond allocations do even increase after the basic own funds have been restricted. For high target returns, money market instruments are not a part of the efficient portfolios at all. The results show that the introduction of Solvency II will indeed reverse the trend towards higher quotas for stocks and alternative investments, especially for insurers with a weak equity base. Insurers with basic own funds below 10%, for example, are forced into real estate quotas below 5% and hedge fund allocations below 2%.

5 Conclusions

In 2016, the EIOPA introduced a risk-based capital model for European insurers (Solvency II), and thereby changed the set of rules that had prevailed for previous decades. To analyze the effects of the new regulatory standard on insurers' investment strategy, I conducted several portfolio optimization programs with respect to the capital requirements of the Solvency II standard formula.

My results show that the Solvency II capital requirements impede the construction of mean-variance-efficient portfolios. There are three main reasons for this: (1) The Solvency II standard formula presets very high correlations between the asset classes, and therefore does not reward risk reduction through diversification, (2) the solvency capital requirements for equities and for alternative asset classes are set too high, and (3) Solvency II focuses on the mitigation of interest rate risk, in contrast to the classical mean-variance optimization. While the latter can be deemed economically meaningful, the first two issues must be considered as misspecifications of the Solvency II standard formula. The high regulatory correlation figures and capital requirements for real estate and equities (including hedge funds) may be the result of a principle of prudence, which is reasonable when viewed in isolation. However, with a holistic view, unbalanced and inefficient portfolios are the consequence.

As a consequence, Solvency II increases the portfolios' investment risk and decreases the attainable target return for insurers with a weak equity base. Given that the primary purpose of the regulation is the mitigation of risk, and given that some insurers are already facing an undercoverage in terms of returns, those effects are highly undesirable. However, insurers with above-average amounts of basic own funds (12% or higher) are able to fulfill the Solvency II capital requirements, attain high target returns and attain mean-variance-efficiency at the same time (see Fig. 1). Those insurers do not face a binding constraint with the introduction of the Solvency II capital requirements, as Hoering (2013) stated. On the other hand, insurers with below-average basic own funds (10% or lower) are limited in their attainable target returns. Furthermore, those insurers are not able to attain mean-variance-efficiency irrespective of the target return (see Fig. 1). Undercapitalized insurers are forced to strictly minimize the SCR according to the Solvency II standard formula

when constructing their portfolios. As Fig. 2 illustrates, this increases investment risk in the classical sense and might cause severe asset management biases, as stated by Braun et al. (2015).

Technically, the Solvency II standard formula forces insurers with a weak equity base to reduce assets with a high SCR and no interest rate sensitivity, namely stocks, direct real estate and hedge funds (and presumably all other investments in the equity risk sub-module, in particular "type 2" equities). Small and mid-size insurers with a weak equity base are not able to develop and audit a cost-intensive insurance internal solvency model to evade the standard formula. The regulator could mitigate this issue in the future by allowing for more flexibility when considering revisions to the standard formula.

Appendix

a

b
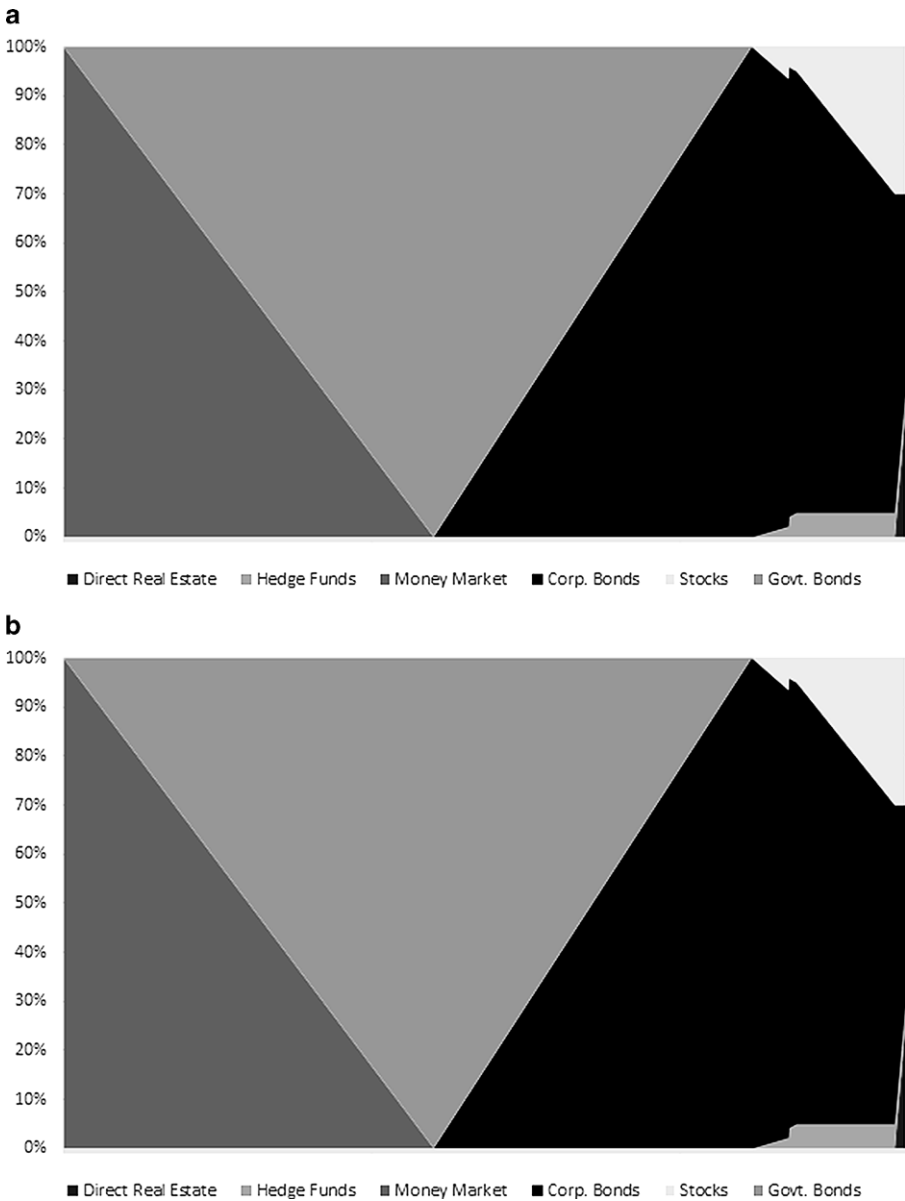
Fig. 4 Optimal Portfolio Allocations. **a** Optimal Allocations for SCR-optimized Portfolios, **b** Optimal Allocations for STD-optimized Portfolios. Notes: Fig. 4 shows the resulting asset allocation for both optimization programs as stated in Sect. 4.1

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