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# Asset Concentration Risk and Insurance Solvency Regulation*

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**Abstract**

Historical evidence like the global financial crisis from 2007-09 highlights that sector concentration risk can play an important role for the solvency of insurers. However, current microprudential frameworks like the US RBC framework and Solvency II consider only name concentration risk explicitly in their solvency capital requirements for asset concentration risk and neglect sector concentration risk. We show by means of US insurers' asset holdings from 2009 to 2018 that substantial sectoral asset concentrations exist in the financial, public and real estate sector, and find indicative evidence for a sectoral search for yield behavior. Based on a theoretical solvency capital allocation scheme, we demonstrate that the current regulatory approaches can lead to inappropriate and biased levels of solvency capital for asset concentration risk, and should be revised. Our findings have also important implications on the ongoing discussion of asset concentration risk in the context of macroprudential insurance regulation.

**Keywords:** Microprudential Insurance Regulation, Asset Concentration Risk, Systematic Risk, Idiosyncratic Risk, Sectoral Asset Diversification

**JEL Classification:** G01, G11, G22, G28

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# 1 Introduction

The concentration of assets in terms of individual names (counterparties) or business sectors can have a substantial loss potential for investors. A prominent example for the adverse financial impact of sector concentration risk for the solvency of insurers can be found in the global financial crisis from 2007 to 2009. In 2007, AIG and MetLife concentrated 24% and 21% of their total assets in the real estate sector (McDonald and Paulson (2015)). When the US real estate sector collapsed, these large systematic risk exposures caused substantial losses for both insurers. But even today insurers seem to concentrate their assets in certain business sectors. For instance in 2018, German insurers have 71% of their reported assets invested in the financial sector, exposing them to severe contagion risks (European Insurance and Occupational Pensions Authority (EIOPA) (2019b)).[1] Evidence by the European Insurance and Occupational Pensions Authority (EIOPA) (2018b) shows almost 40 distress events of EU insurers in relation to concentrated asset portfolios from 1999 to 2016.

However, current microprudential frameworks like Solvency II, the US RBC framework and the Global Insurance Capital Standard (ICS) focus in their solvency capital requirements only on asset concentrations in terms of individual names (counterparties), but not in terms of business sectors. For example in Solvency II, sectoral asset concentrations are explicitly considered as an immaterial risk source for the insurer's solvency (European Systemic Risk Board (2020), International Association of Insurance Supervisors (IAIS) (2018b)).[2] However, its regulatory exclusion from solvency capital requirements might lead to conceptually insufficient levels of solvency capital for insurers. For example, the returns of assets within the same business sector are typically more strongly correlated due to common risk exposures than the returns of assets across different business sectors. For an asset portfolio concentrated in a specific sector, the relatively high level of return correlation across assets can raise the volatility of the portfolio's total return due to a lack

[1]The aggregation of all investments with the sector classification code K (financial services) yields the total allocation of assets to the financial sector.

[2]For Solvency II it is stated: "Given that concentration risk is mostly driven by the lack of diversification in issuers to which insurance or reinsurance undertakings are exposed, the market risk concentrations sub-module of the standard formula should be based on the assumption that the geographical or sector concentration of the assets held by the insurance or reinsurance undertaking is not material.", Delegated Regulation (EU) 2015/35, paragraph 62.

of diversification, which increases the severity of tail events. Without considering the additional risk due to the sectoral asset concentration, insurers might not have sufficient solvency capital to cover potential losses.

Surprisingly, the academic literature on asset concentration risk focuses mainly on banks, and the consideration of asset concentration risk in microprudential insurance regulation seems to be mainly based on anecdotal evidence and supervisory judgement (International Association of Insurance Supervisors (IAIS) (2018b), point 429). Therefore, we study two general questions in this paper: i) How do insurers invest their assets in terms of individual names and business sectors? ii) Are the current microprudential approaches, in particular the exclusion of sector concentration risk, appropriate to cover the potential impact of asset concentration risk on insurers' solvency? To study the role of asset concentration risk for the solvency of insurers, we proceed in the following way. In Section 2, we assess quantitatively the name and sector concentrations in the asset portfolios of US insurers as a representative example for insurers' investment behavior.[3] We create a unique data sample by collecting the asset holdings from US insurers' statutory filings with the NAIC from 2009 to 2018 and extend the data by implementing sector classifications to the individual assets. In summary, we find that name concentration risk is well-diversified, but substantial sectoral concentrations to the financial, public and real estate sector exist. Moreover, we find a substantial reallocation of assets from the relatively safe public sector to the riskier financial sector over time, which might indicate a sectoral search for yield behavior of insurers. In Section 3, we briefly summarize the current microprudential regulation of asset concentration risk under the US RBC framework and Solvency II. Although asset concentration risk leads to similar loss exposures for insurers in different jurisdictions, we find that both frameworks differ in the regulatory consideration of name concentration risk, but share the exclusion of sector concentration risk from the solvency capital requirements.

Given the substantial sector concentrations we find in the insurers' asset portfolios, we quantitatively assess in Section 4 in an empirically calibrated model the potential impact of the regulatory exclusion of sector concentration risk on insurers' solvency capital. By means of a solvency capital allocation scheme, we disentangle the solvency capital allocation for asset concentration risk in

[3] The public access to granular firm-level investment data for insurers in the European Union is strictly limited, but we include in our analysis related reports by the European Insurance and Occupational Pensions Authority (EIOPA) that are aggregated at the country-level.

distinct components for name and sector concentration risk. Our findings show that sector concentration risk can have a substantial impact on insurers' solvency, since it amounts to 15% of the portfolios' total solvency capital in our baseline model. Moreover, we find that the solvency capital allocations for name and sector concentration risk interact with each other. Their interdependence leads to an estimation bias on the solvency capital allocation for name concentration risk under the current microprudential approaches that exclude sector concentration risk.[4] Regarding the regulatory implications of our findings in Section 4.6, we suggest to consider sector concentration risk in insurers' asset portfolios as a material risk source. For a future improvement of microprudential regulation, stronger public disclosure requirements regarding insurers' asset concentrations should be discussed as well as explicit solvency capital charges for sector concentration risk in order to mitigate the estimation bias on name concentration risk.

Asset concentration risk has been studied frequently in the banking literature. Findings by Beck et al. (2021), Grippa and Gornicka (2016), Düllmann and Masschelein (2007) and Gordy (2003) show that the sectoral concentration in banks' loan portfolios has a substantial impact on the solvency of banks. However, asset concentration risk has received little attention in the insurance literature so far, although, for instance, insurers have large credit portfolios as well (European Systemic Risk Board (2020)), and although the investment behavior of insurers has been studied from many perspectives in the context of insurance regulation, for instance regarding fire sales (e.g. Ellul et al. (2011)), reaching for yield behavior (e.g. Becker and Ivashina (2015)) or procyclicality (e.g. Bijlsma and Vermeulen (2016), Bank of England (BoE) (2014)). Since the lack of evidence of the impact of asset concentration risk on the solvency of insurers has been a major obstacle for regulators so far (International Association of Insurance Supervisors (IAIS) (2018b)), our findings contribute important insights to better understand insurers' investment behavior with regard to asset concentration risk and can help to improve the corresponding microprudential approaches.

In macroprudential insurance regulation asset concentration risk is also currently discussed as a source for systemic risk (European Systemic Risk Board (2020), European Insurance and Occupational Pensions Authority (EIOPA) (2019a), International Association of Insurance Supervisors (IAIS) (2018a)). It is therefore important to consider potential counteracting stability effects, i.e.

[4] The result of portfolio invariant solvency capital allocations in the regulation of asset concentration risk only holds under strict theoretical assumptions with regard to portfolio granularity and asset dependence, which typically do not apply to real-world asset portfolios (e.g. Gordy (2003)).

on the level of the individual institution's stability and the system's stability, if micro- and macroprudential actions on asset concentration risk are not properly aligned with each other, as findings by Wagner (2010) suggest. Therefore, our findings regarding the microprudential insurance regulation of asset concentration risk can serve as a basis for discussing the corresponding synchronization of micro- and macroprudential insurance regulation.

The rest of the paper is structured as follows. Section 2 gives quantitative evidence on concentration risk in insurers' asset portfolios. Section 3 discusses current microprudential frameworks in terms of the US RBC framework and Solvency II. Section 4 provides quantitative evidence of asset concentration risk for insurers' solvency. Section 5 concludes.

## 2 Asset Concentration Risk

Asset concentration risk generally refers to an investor's lack of diversification regarding various risk exposures, for instance, single names (counterparties), business sectors, geographical areas or asset classes like stocks or bonds (Basel Committee on Banking Supervision (1999)). We focus our analysis on name and sector concentration risk, since both concentration types are related to distress events for insurers in the past. Anecdotal evidence by McDonald and Paulson (2015) shows for several US insurers asset concentrations in the real estate sector in the range of 20% of their total asset values in 2007, which caused substantial losses during the global financial crisis period from 2007 to 2009. The European Insurance and Occupational Pensions Authority (EIOPA) (2018b) reports almost 40 cases of insurer distress in the European Union from 1999 to 2016 that were related to concentrated asset portfolios. Although a lack of risk diversification typically increases an asset portfolio's loss potential (European Insurance and Occupational Pensions Authority (EIOPA) (2014)), empirical evidence on insurers' name and sectoral asset concentrations is largely missing. Thus, it is unclear how concentrated insurers' asset portfolios are, and whether excluding sectoral asset concentrations from microprudential solvency capital requirements is appropriate.

In the subsequent section we provide empirical evidence on US insurers' asset concentrations with regard to names (counterparties) and business sectors. Thereby, we follow the literature and define name concentration risk as an accumulation of idiosyncratic risk exposures with single counterparties, which can typically be diversified in large and granular asset portfolios (International

Association of Insurance Supervisors (IAIS) (2018b)). Sector concentration risk is defined as an accumulation of systematic risk exposures with business sectors, which can result in undiversifiable losses that are typically triggered by macroeconomic shocks (e.g. Grippa and Gornicka (2016), Düllmann and Masschelein (2007), Committee of European Banking Supervisors (2006), Basel Committee on Banking Supervision (2006)).

## 2.1 Data

Assessing the name and sector concentrations is a difficult task, since the financial statements of insurers typically do not contain sufficient information to identify single names or the sectoral asset distribution in the investment portfolios.[5]

We overcome the lack of publicly available data by using the statutory filings of US insurers with the National Association of Insurance Commissioners (NAIC) as a basic data sample. As the US insurance sector is one of the largest and most developed worldwide, it may be considered as a representative example for the investment behavior of insurance companies with regard to asset concentration risk. We include regulatory asset data with regard to investment schedules A (real estate), B (mortgage loans on real estate), D (bonds, preferred and common stocks) and BA (other invested assets, esp. private equity funds, real estate funds and hedge funds) and collect the data from SNL Financial (S&P Market Intelligence). The statutory filings contain the CUSIP numbers of the invested assets, but do not contain specific information on the corresponding business sectors the assets belong to. Thus, we extend the data sample by asset-to-asset CUSIP matching with further databases containing sectoral classifications of these assets.

Regarding the asset values, we follow the US National Association of Insurance Commissioners (NAIC), which typically uses the reported book/adjusted carrying value (BACV) of the assets in their regulatory analyses. Moreover, the BACV provides a stable measure for the insurers' strategic asset allocation decisions and is also the basis for the asset concentration risk capital charges under the US regulatory RBC framework (e.g. National Association of Insurance Commissioners (NAIC) (2018), National Association of Insurance Commissioners (NAIC) (2017b)). The entire dataset

[5]For a similar discussion with regard to the banking sector, see Beck et al. (2021). For EU insurers, regulatory reporting requirements have been substantially increased in the aftermath of the global financial crisis in 2007-09, but public access to granular data that allow the assessment of name and sector concentrations is still limited (Regulation (EU) No 1374/2014, Regulation (EC) No 1893/2006).

includes 4942 insurers registered by a company code with the NAIC over the time period from 2009-2018. Our data covers in 2018 invested assets worth 5800 bn US-$, which represents almost 90% of all invested assets reported by US insurers in 2018 (National Association of Insurance Commissioners (NAIC) (2019)).[6] In 2018, we have sector classifications for 87% of the assets in our sample due to our sectoral classification strategy. A detailed description of the steps taken is given in Appendix A.1.

## 2.2 Name Concentrations in Insurers' Asset Portfolios

An insurer's yearly name concentration is measured as the aggregated book/adjusted carrying value (BACV) for assets that belong to the same issuer (identified by the first six CUSIP digits), divided by the insurer's total BACV over all assets in a given year. Table 1 summarizes the findings.

We find for US insurers that name concentration risk is generally well-diversified. On average, the asset accumulation to a single name (counterparty) amounts to 0.5% of an insurer's total assets. Thus, the average insurer's exposure to idiosyncratic shocks from a single entity is small, which is in line with the current microprudential focus on limiting name concentration risk under the US RBC framework.[7] However, we find 986 insurers in the sample that have a name concentration larger than 90% of their total assets in a given year. These insurers are mainly small insurers with an average value of their total assets of around 39 million US-$, and most of these insurers concentrate their investments in the US Government as counterparty (CUSIP digits 912828 and 912810). Another large part of these very concentrated investments refers to affiliated group investments, in which institutions invest in other institutions belonging to the same group. However, there are several concentrated investments undertaken by private placements for which we could not identify the corresponding counterparties through the given CUSIP numbers.

## 2.3 Sector Concentrations in Insurers' Asset Portfolios

Table 2 shows the sectoral distribution of US insurers' total assets in 2018. In general, US insurers show a broad spectrum of sectoral investments and hold assets from every sector as classified

[6]The difference mainly stems from excluding cash and derivative instruments from our sample. We include affiliated investments in the data, since these investments are also subject to idiosyncratic and systematic risk exposures and thus, require solvency capital for the parent company under the US RBC framework or Solvency II.

[7]See chapter 3.1 for more details.

| Min | 25% | Median | Mean | 75% | Max |
|---|---|---|---|---|---|
| 0% | 0.02% | 0.09% | 0.50% | 0.32% | 100% |

Table 1: Summary Statistics on Name Concentrations of US Insurers

The table shows summary statistics on the yearly name concentrations of the assets held by 4942 US insurers from 2009-2018. For each insurer, the book/adjusted carrying value (BACV) of assets is aggregated by names in terms of the first six digits of the assets' corresponding CUSIP numbers, since these 6 digits uniquely identify an asset's issuer (name). The insurer's name concentration is the aggregated BACV for assets that belong to the same issuer divided by the insurer's total BACV over all assets in a given year. Data comprises investments from the schedules A, B, D, and BA of the insurers' statutory filings with the NAIC and is collected from SNL Financial (S&P Market Intelligence).

by the Global Industry Classification Standard (GICS). However, some sectoral imbalances are apparent. The largest allocation refers to investments in the financial sector with 33% of the total assets, followed by investments in the real estate sector with a fraction of 13.3% and investments in the public administration sector with a fraction of 9.7%, which comprises mainly sovereign and municipal debt instruments. US insurers have moderate investment levels in the industrials sector (6.1%) and the utilities sector (4.7%), and regarding the remaining GICS sectors rather minor investment levels below 3.5%.

| Sector | Allocation (%) |
|---|---|
| Financials | 33.0 |
| Real Estate | 13.3 |
| Public Administration | 9.7 |
| Industrials | 6.1 |
| Utilities | 4.7 |
| Consumer Staples | 3.5 |
| Energy | 3.5 |
| Information Technology | 2.9 |
| Consumer Discretionary | 2.5 |
| Materials | 2.0 |
| Communication Services | 1.9 |
| All Other Sectors | $< 1.0$ |
| Unclassified Assets | 13.5 |

Table 2: Sectoral Distribution of US Insurers' Total Assets in 2018

The table shows the sectoral distribution in percent of US insurers' total assets in 2018. The sectoral asset allocation/concentration is the aggregated book/adjusted carrying value (BACV) of all sector-specific assets held by the insurers in the sample divided by the aggregated BACV over all reported assets in 2018. The US insurance sample in this year consists of 4010 US insurers. Investment data comprises schedules A, B, D, and BA from the insurers' statutory filings with the NAIC, hence, real estate investments, mortgage loans, stocks, bonds and other long-term assets. Investments from Schedule A (real estate) and Schedule B (mortgage loans on real estate) are subsumed under the real estate category. Data stems from SNL Financial (S&P Market Intelligence) and sectoral asset classifications are CUSIP matched with sectoral classification variables from additional databases as explained in Appendix A.1. "Unclassified Assets" refers to assets which we cannot link to specific business sectors.

Appendix A.2 shows the empirical distribution of the asset allocations to the five most important sectors at the individual insurer-level. The allocations to the public sector are substantially right skewed, suggesting several insurers to have highly concentrated asset portfolios. Especially small insurers concentrate their asset portfolios substantially by investing in relatively safe sovereign debt assets.[8] For the financial sector, affiliated investments play an important role for the highly concentrated asset portfolios, especially in context of common stock investments in parent, subsidiaries and affiliates.[9] Regarding the real estate, utilities and industrial sectors, there is only a small variation in the sectoral asset allocations around their low mean values.

Figure 1 shows the time series of US insurers' sectoral asset concentrations with regard to the five most important sectors. Whereas the asset concentrations in the financial sector increase continuously and smoothly from 30% to 35% until 2017, the asset concentrations in the public administration and real estate sector decline continuously, from 15% to 13% and 10% to 5%, respectively. Interestingly, from 2017 to 2018, the asset concentrations in the real estate sector increase, whereas they decrease in the financial and public administration sector. The allocation of assets to the utilities and industrials sectors is almost persistent around 5% to 6%.

The time series of the sectoral asset allocation suggests that insurers continuously reallocated their assets from the public sector, i.e. public debt instruments with typically relatively low systematic risk exposures, to assets from the riskier financial sector, and after 2017, to assets from the riskier real estate sector. More specifically, Figure 2 shows the average yearly reallocations in the five most important sectors at the insurer-level. It indicates that insurers reduced, on average, their investments in the public sector by 80 basis points (0.8%) per year, whereas they increased, on average, their financial sector investments by 50 basis points (0.5%) per year. They also decreased their average investments to the real estate sector, which, however, shows an upwards trend after 2017 according to Figure 1. For the utilities and industrial sectors, there is only a small average increase in the allocation levels. Since sector concentration risk is not explicitly considered in the solvency capital requirements of the US RBC framework (see Section 3), the asset reallocation to systematically riskier sectors might indicate a sectoral search for yield behavior of insurers. The finding is in line with Becker and Ivashina (2015), who show that insurers tend to raise their invest-

[8] Most important assets in these concentrated portfolios are US Treasury Notes with 6-digit CUSIP 912828.

[9] Corresponding assets with reported line numbers 9100001-9199999.

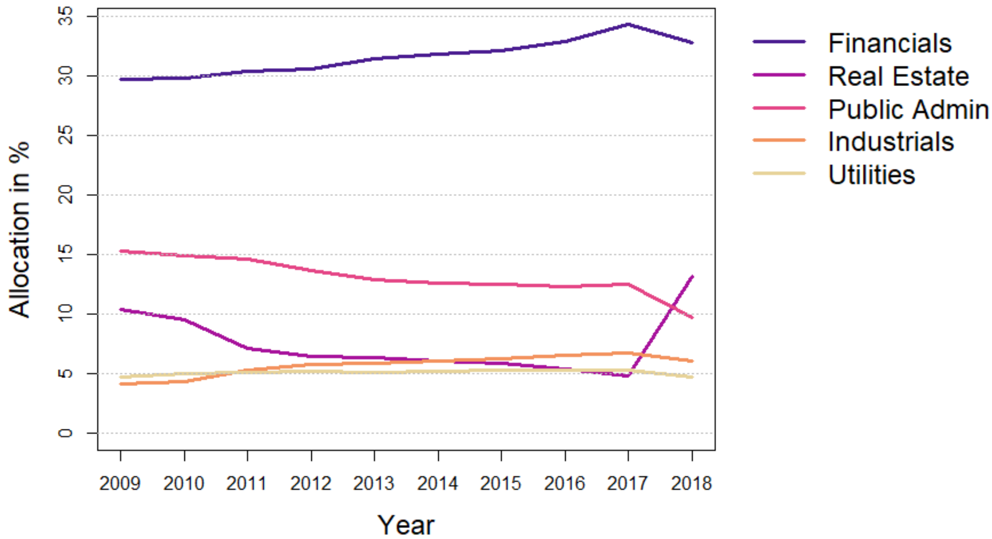


Figure 1: Time Series of Asset Concentrations in the Five Most Important Sectors

The figure shows the time series of the sectoral asset concentrations of all 4942 US insurers from 2009-2018 in the sample. The sector concentration is the aggregated book/adjusted carrying value (BACV) of all sector-specific assets held by the insurers in the sample divided by the aggregated BACV over all reported assets in a given year. The five most important sectors are ranked by the insurers' total investment volume in 2018 (see Table 2).

ments in riskier bonds in a given rating category as it does not require additional solvency capital within that rating category.

For insurers in the European Union, granular data for studying the name and sector concentrations in the asset portfolios is publicly not available. However, the European Insurance and Occupational Pensions Authority (EIOPA) (2020) publishes sectoral asset concentrations for EU insurers in 2019 at the aggregated country-level.[10] Table 3 shows the five most important sectors for EU insurers in 2019. Danish insurers have the highest financial sector exposure with roughly 80% of total assets (sector K), whereas Croatian insurers have the lowest value with 17%. The mean ratio across all countries is almost 43%. Assets in the banking sector are captured in the subsector K64 (financial services), which, on average, comprises the largest fraction of insurers' financial sector investments. Thus, there is a strong economic link between banks and insurers, which can lead to severe financial contagion effects in case of a banking shock International Monetary Fund (IMF)

[10] Appendix A.3 gives an overview of EU insurers' allocations in 2018 and 2017, which shows a similar sectoral asset distribution compared to 2019.

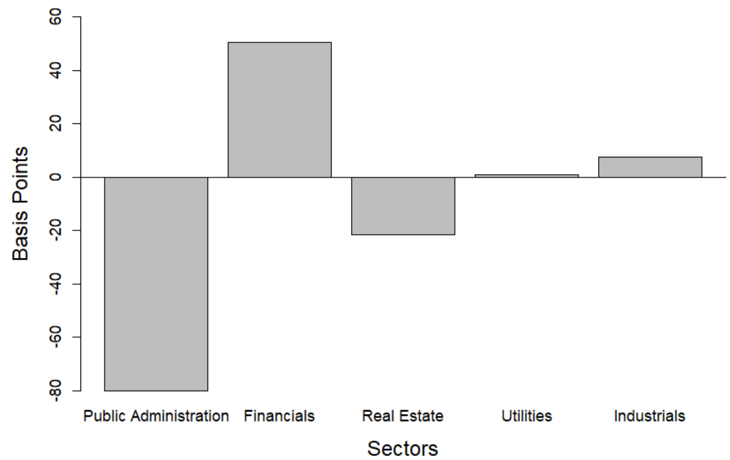


Figure 2: Average change in the sectoral allocation per year

The figure shows the average yearly change in the insurers' sectoral asset concentrations from 2009-2018 in basis points. The illustrated sectors are the five most important sectors according to the total invested volume in 2018. The sector concentration is the aggregated book/adjusted carrying value (BACV) for all sector-specific assets held by an insurer divided by the total BACV over all assets held by an insurer in a given year.

(2018). Regarding the public sector including the investments in government debt instruments, Hungarian insurers have the highest exposure with 68%, and the mean value is 35%. Norwegian insurers are particularly exposed to the real estate sector with 12% of their total assets and the mean value over all countries is 3.3%. Besides the manufacturing sector (mean value of 4.2%) and the electricity and gas sector (mean value of 1.8%), all other sectors have a mean value of less than 1.6%.

| NACE Sector | Min | Max | Mean |
|---|---|---|---|
| K - Financial and Insurance Activities | 17.2% (Croatia) | 80.0% (Denmark) | 42.7% |
| K64 - Financial Services | 8.7% (Croatia) | 63.4% (Iceland) | 29.9% |
| O - Public Sector | 2.1% (Iceland) | 68.3% (Hungary) | 34.9% |
| C - Manufacturing | 0.2% (Romania) | 11.6% (Finland) | 4.2% |
| L - Real Estate | 0.5% (Romania) | 12.2% (Norway) | 3.3% |
| D - Electricity and Gas | 0.1% (Croatia) | 4.0% (United Kingdom) | 1.8% |

Table 3: Overview of the Most Important Sector Concentrations for EU Insurers in 2019

The table shows the minimum, maximum and mean ratio at the country-level of insurers' sectoral asset allocations in 2019. Data is based on NACE classification and provided by European Insurance and Occupational Pensions Authority (EIOPA) (2020). K64 is a subsector of the financial sector K and mainly comprises banking-like activities.

US and EU insurers have strong asset concentrations to the public, financial and real estate sector, which can cause severe financial contagion risks for insurers in case of a systematic shock in these sectors. For example, findings by International Monetary Fund (IMF) (2018), Chen et al. (2013) and Allen and Carletti (2006) underline the substantial spillover risk of shocks from banks to insurers that can deplete insurers' solvency. Acharya et al. (2014) show a reinforcing link between sovereign and bank credit risk in case of a banking shock, which can threaten insurers' financial condition as a double-hit scenario, since both sectors are consistently predominant in the insurers' sectoral asset allocations over time. Düllmann and Masschelein (2007) show that sector concentrations in banks' credit portfolios can increase the required economic capital to back up losses by more than 37%, which should also apply to the large credit portfolios of insurers (e.g. European Systemic Risk Board (2020), National Association of Insurance Commissioners (NAIC) (2019)).

# 3 Microprudential Regulation of Asset Concentration Risk

We briefly discuss the solvency capital requirements for asset concentration risk given by the US Risk-Based Capital framework (RBC) for US insurers and Solvency II for EU insurers.[11] For an international perspective, we briefly discuss the requirements under the Global Insurance Capital Standard (ICS) according to its current version 2.0 in Appendix A.4. It might be subject to substantial changes after its testing period 2020-2024 (International Association of Insurance Supervisors (IAIS) (2020)).[12]

## 3.1 Solvency Capital Requirements under the US Risk-Based Capital Requirements (RBC)

The US regulatory system has different formulas for determining risk-based capital requirements for Life, P&C and Health insurers. For the sake of simplicity, we focus the discussion on P&C insurers.[13] The total risk-based capital requirement (RBC) for an insurer at the company action level is given by

[11]For an overview of the regulatory consideration of asset concentration risk in the banking sector under Basel III, we refer to European Systemic Risk Board (2020).

[12]The ICS is planned to constitute a global regulatory framework for internationally active insurance groups and global systemically important insurers, and currently undergoes a monitoring period with annual confidential reporting.

[13]For life insurers, see for instance National Association of Insurance Commissioners (NAIC) (2017b).

$$RBC = R_0 + \sqrt{R_1^2 + R_2^2 + R_3^2 + R_4^2 + R_5^2 + R_{cat}^2} \tag{1}$$

where the $R$-terms denote the risk-based capital for: $R_0$ - affiliated assets, $R_1$ - fixed income assets, $R_2$ - equity assets, $R_3$ - credit risk, $R_4$ - reserves underwriting risk, $R_5$ - premium underwriting risk and $R_{cat}$ - catastrophe risk.

Asset concentration risk is captured by an additional capital charge to the 10 largest fixed-income and equity investments and added to the corresponding capital requirements $R_1$ and $R_2$, respectively (National Association of Insurance Commissioners (NAIC) (2017a)). The capital requirement is determined by aggregating all equity and debt instruments issued by single counterparties in order to find the 10 largest total counterparty exposures. Then, for these 10 large exposures the asset-specific capital factors are doubled, but limited to a maximum factor of 30%. Several specific assets are excluded from a concentration risk charge, for instance, class 1 (low credit risk) and class 6 (high credit risk) bonds, bonds guaranteed by the US government and affiliated stocks and bonds. Unaffiliated common stocks have a risk charge of 15% of their book/adjusted carrying value. For bonds the risk charges have been recently updated and range from class 2 bonds with 1.4% to class 5 bonds with 30%, with former charges of 1% to 10%, respectively (National Association of Insurance Commissioners (NAIC) (2017a), National Association of Insurance Commissioners (NAIC) (2017b)).

Moreover, regarding the fixed income portfolio, there is an additional risk charge depending on the overall number of different counterparties in the portfolio, i.e. on the portfolio's granularity (bond size factor adjustment). The amount of risk-based capital for the fixed-income portfolio is multiplied by a specific diversification factor reflecting a lower loss potential for a more granular fixed-income portfolio. According to the 2017 proposals, a capital factor of 7.8 is implemented to the risk-based capital under $R_1$ for a maximum number of 10 different counterparties in the total debt portfolio, a factor of 1.75 for up to 100 different counterparties, a factor of 1 for up to 200 different counterparties, a factor of 0.8 for up to 500 different counterparties and a factor of 0.75 for more than 500 counterparties (National Association of Insurance Commissioners (NAIC) (2017b)). Thus, the framework offers an incentive for insurers to spread their investments over a large number of individual names (counterparties) and thus, to reduce the portfolio's idiosyncratic risk exposure.

## 3.2 Solvency Capital Requirements under Solvency II

Solvency II permits EU insurers to either use an individual (partial) internal model or to use a modular standard formula for determining the regulatory solvency capital requirements (SCR) based on market values for assets and liabilities. Both approaches are intended to achieve a one-year solvency level of 99.5%, which implies a capital requirement based on the Value at Risk (VaR) of changes in the insurer's equity capital with a confidence level of 99.5%. Since the majority of EU insurers uses the standard formula, which reflects changes in the insurer's solvency condition based on predetermined shock and stress scenarios, we focus our discussion on the standard formula's requirements for asset concentration risk (European Insurance and Occupational Pensions Authority (EIOPA) (2018c), European Union (2015)).

Asset concentration risk is covered in an explicit sub-module within the market risk module. Since Solvency II assumes well-diversified asset portfolios for the calculation of solvency capital requirements, the concentration risk sub-module aims to mitigate losses stemming from a lack of idiosyncratic risk diversification, i.e. a lack of diversification across different names (counterparties) in the portfolio (European Insurance and Occupational Pensions Authority (EIOPA) (2014)). A concentration risk capital charge is required if the insurer's aggregated investment in a single name exceeds a predetermined threshold in a range of 1.5% to 15% of the insurer's total assets, depending on the credit rating of the asset. The capital requirements by this sub-module are applicable to financial instruments like i) bonds, ii) loans other than residential mortgage loans, iii) equity and iv) property investments. Government bonds issued by EEA member states in their domestic currency are exempted from concentration risk charges (European Union (2015), European Insurance and Occupational Pensions Authority (EIOPA) (2014)).[14]

Technically, the solvency capital requirement for name concentration risk is intended to cover the loss in the insurer's equity capital that would result from an instantaneous drop in the aggregated value of all assets in the portfolio referring to the same name (counterparty). The solvency capital charge for a specific name (counterparty) is determined as

$$SCR^{SF}_{conc,x} = s_{sf} \; max[A_{conc,x} - T_x A, 0] \tag{2}$$

[14] A threshold of 15% is applied for covered bonds with the best credit rating. Immovable property has a threshold of 10% and a risk charge of 12%. Assets without a credit assignment, like equity instruments, are considered to have a CQS of 5 (European Union (2015)).

where $SCR_{conc,x}^{SF}$ denotes the standard formula's solvency capital requirement w.r.t. the concentration risk of name (counterparty) $x$, $s_{sf}$ the applicable shock factor depending on the credit quality step (CQS) of the asset with respect to name $x$, $A_{conc,x}$ the aggregated value of all assets related to name $x$, $T_x$ the relative excess exposure threshold depending on the credit quality step of name $x$ and $A$ the portfolio's total asset value (European Union (2015)). The solvency capital requirement for the portfolio's total asset concentration risk over all names is then the square root of the sum of squared single name SCRs, i.e. $SCR_{Conc}^{SF} = \sqrt{\sum_{x=1}^{X}(SCR_{conc,x}^{SF})^2}$.

The credit quality steps under Solvency II range from 0 to 6 and reflect external ratings on the loss potential of the asset (European Union (2015)). The excess exposure thresholds and the corresponding applicable shock factors in relation to the weighted average credit quality step of the single name exposure are given in Table 4.

| CQS | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Threshold $T_x$ | 3% | 3% | 3% | 1.5% | 1.5% | 1.5% | 1.5% |
| Risk factor $s_{sf}$ | 12% | 12% | 21% | 27% | 73% | 73% | 73% |

Table 4: Shock Scenarios in Solvency II's Standard Formula

Relative excess exposure thresholds and shock factors according to Solvency II's Standard Formula for Asset Concentration Risk (European Union (2015)).

Since Solvency II explicitly assumes sector concentrations to be immaterial in the insurers' asset portfolios, it focuses only on name concentration risk and thereby on the mitigation of idiosyncratic risk exposures (European Union (2015)). The aggregation of capital requirements over all different names (counterparties) leads to the asset portfolio's total capital requirement in the asset concentration risk sub-module. However, as the aggregation assumes no correlation between these different names (counterparties) in the portfolio, Solvency II neglects the assets' sector-specific linkages due to common risk exposures, i.e. the assets' systematic risk exposures, which can lead to substantially biased solvency capital requirements.

Similar to the US RBC framework, Solvency II reflects only name concentration risk in the solvency capital requirements for asset concentration risk. However, the corresponding capital requirements differ substantially in their calculation, although both frameworks consider name concentration risk similarly as the risk of an accumulation of idiosyncratic risk exposures compared to a well-diversified asset portfolio. While Solvency II focuses on the asset portfolio's idiosyncratic risk exposure to each name (counterparty) in the portfolio, the US RBC framework considers only the 10 largest names in the portfolio. Since both frameworks neglect sector concentration risk in their solvency capital requirements, we analyze in the subsequent section the potential impact of this exclusion on the insurers' solvency capital necessary to back up potential losses in the asset portfolio.

# 4 Asset Concentration Risk and Solvency Capital Requirements

A high sectoral concentration of assets can raise the volatility of the portfolio's return, since assets within the same business sector are typically stronger correlated due to common risk exposures than assets across different business sectors.[15] Thus, compared to an asset portfolio with a low sectoral asset concentration, tail events can become more likely and severe. In the subsequent sections, we develop a solvency capital allocation scheme and analyze, based on an empirically calibrated theoretical approach, the influence of name and sector concentration risk on the solvency capital requirements under the US RBC framework and Solvency II.

## 4.1 The Solvency Capital Allocation Scheme

We consider an insurer that can invest in a large number of $N$ individual assets represented by financial instruments like, for example, stocks or bonds, that are issued by single firms (i.e. names), whereby we assume that each firm belongs only to one specific business sector. For illustrative reasons, we assume that there are only two distinct sectors available for investments. We analyze three exemplary portfolio allocations as illustrated in Figure 3 to develop a general solvency capital allocation scheme with regard to name and sector concentration risk. The portfolios can be generally divided into two distinct parts: One part refers to a non-granular sub-portfolio consisting of a single large name exposure, and the other part represents a granular and diversified sub-portfolio of numerous small name exposures. Since we differentiate between the sectoral distribution of the invested firms across the exemplary portfolios, we can capture the influence of sector concentration risk on the solvency capital.

[15] For example, Table 15 in the Appendix shows substantial variation in the correlation between the sector-specific S&P 500 indices.

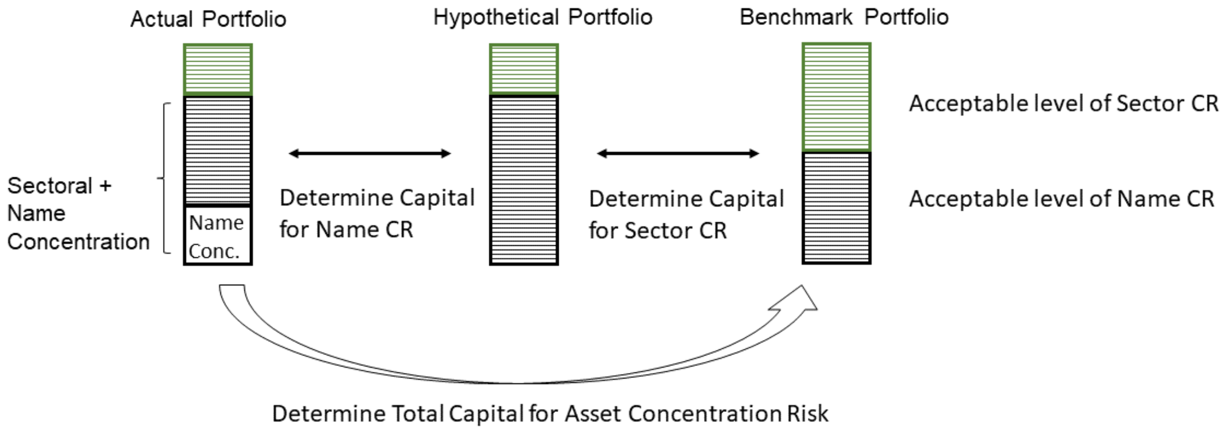


Figure 3: Illustration of the Capital Allocation Scheme for Asset Concentration Risk

CR stands for concentration risk.

We introduce a simplified benchmark portfolio, $PF_{Benchmark}$, which is assumed to represent a well-diversified asset portfolio with regard to concentration risk. Such a benchmark portfolio is typically used by regulatory authorities to determine appropriate risk charges in terms of the deviation of the insurer's real-world asset portfolio from the regulatory assumptions (e.g. European Insurance and Occupational Pensions Authority (EIOPA) (2014), Gürtler et al. (2010)).[16] The benchmark portfolio is not subject to name concentration risk, since investments in names are equally distributed across a large number of individual names, such that each name represents only a small portfolio fraction, and firm-specific idiosyncratic risk exposures vanish. Hence, only the sector-specific systematic risk exposures of the assets remain. The portfolio's overall systematic risk exposure can be influenced by allocating investments across firms of sectors 1 and 2, which leads to sector weightings of $\gamma$ and $1-\gamma$, respectively. In our benchmark portfolio, we assume that a volatility minimizing sector weighting, $\gamma_{reg}$, constitutes a well-diversified portfolio in terms of sector concentration risk that leads to a regulatorily acceptable level of the portfolio's total systematic risk exposure. Thus, the solvency capital requirement of the benchmark portfolio would neither include a name nor a sector concentration risk charge.

The second portfolio, $PF_{Actual}$, consists of one large name exposure with a portfolio fraction of

[16] The identification of such a benchmark portfolio for asset concentration risk is a difficult task for regulators, since asset diversification has an ambiguous role for financial stability. It typically increases the individual institution's solvency due to a lower distress risk resulting from a lower volatility in the portfolio's return. But asset diversification can also destabilize the entire system of institutions, if it raises the correlation of the institutions' asset portfolios due to higher levels of common exposures in the asset holdings across the institutions (Wagner (2010)).

$\alpha$, the rest of the portfolio with a fraction of $1-\alpha$ is equally distributed across $N-1$ individual names. Firms in this portfolio stem from both sectors. This portfolio illustrates an actual (real-world) asset portfolio of an insurer, which is subject to both, name and sector concentration risk. In order to explicitly disentangle asset concentration risk into name and sector concentration risk, we introduce a hypothetical portfolio, $PF_{Hyp}$, which represents a portfolio with the same sector distribution like $PF_{Actual}$, however, without any name concentration.[17]

We use the portfolio's Value-at-Risk (VaR) to reflect the insurer's capital requirements based on economic capital.[18] By calculating solvency capital requirements for each portfolio, we are able to map the insurer's solvency capital allocation to name and sector concentration risk. Table 5 summarizes our solvency capital allocation scheme. A transition from the benchmark portfolio to the hypothetical portfolio would increase the portfolio's sector concentration, since the sector weights deviate from the regulatory weights, i.e. $\gamma_{hyp} > \gamma_{reg}$. A transition from the hypothetical portfolio to the actual portfolio would add the name concentration risk. The total asset concentration risk and its solvency capital requirement (SCR) is the difference between the VaR of the actual and the benchmark portfolio and is attributable to sector concentration risk and name concentration risk. The difference in the VaR between the hypothetical portfolio and the benchmark portfolio gives the sector concentration risk SCR and the difference between the actual portfolio and the hypothetical portfolio yields the SCR-allocation to name concentration risk.[19]

The literature offers a variety of capital allocation schemes (e.g. Dhaene et al. (2012), Urban et al. (2004)). Our approach is similar to the marginal risk contribution or with-without allocation approach by Merton and Perold (1993). Therefore, the proposed capital allocation derives the additional VaR of the actual portfolio due to asset concentration risk by comparing it with the VaR

[17]The allocation scheme can be extended by introducing more than two sectors to make it more realistic. However, it would not affect the main implications of the capital allocation scheme, which aims to derive the general impact of the current regulatory exclusion of sector concentration risk from the solvency capital requirements for asset concentration risk under the US RBC framework and Solvency II.

[18]Since we introduce a normal distribution in our bivariate return model in Section 4.3, the VaR is sub-additive. Moreover, Danielsson et al. (2013) discuss the appropriateness of the VaR for fat-tailed distributions and Gürtler et al. (2010) show that the VaR is an appropriate measure for concentration risk in banks' credit portfolios.

[19]The suggested SCR allocation is a decision-oriented capital allocation. We determine the change in the SCR by firstly starting with the benchmark portfolio, secondly adding sector concentration risk, and thirdly adding name concentration risk. Thus, we end up in $PF_{Actual}$. It is, of course, also possible to go the alternative way: firstly start with the benchmark portfolio, secondly adding name concentration risk, and thirdly adding sector concentration risk. For this, we can introduce a Portfolio C for the hypothetical portfolio that has the same name concentration risk as $PF_{Actual}$, but a benchmark sector weighting $\gamma_{reg}$. Then the name concentration risk SCR can be determined by: $VaR_{PF_C}$-$VaR_{PF_{Benchmark}}$. The sector concentration risk SCR would be: $VaR_{PF_{Actual}}$-$VaR_{PF_C}$.

| Risk | Formula | | |
|---|---|---|---|
| Total Asset Concentration Risk | $VaR_{PF_{Actual}}$ | $-$ | $VaR_{PF_{Benchmark}}$ |
| Sector Concentration Risk | $VaR_{PF_{Hyp}}$ | $-$ | $VaR_{PF_{Benchmark}}$ |
| Name Concentration Risk | $VaR_{PF_{Actual}}$ | $-$ | $VaR_{PF_{Hyp}}$ |

Table 5: Capital Allocation Scheme for Asset Concentration Risk

For example, $VaR_{Hyp}$ stands for the Value-at-Risk of the hypothetical portfolio.

of the well-diversified regulatory benchmark portfolio. A conceptually similar allocation scheme has been used in the standard formula of Solvency II to derive the solvency capital requirements for name concentration risk (European Insurance and Occupational Pensions Authority (EIOPA) (2014)).

### 4.2 The Asset and Solvency Model

For the solvency capital allocation scheme, we introduce a parsimonious asset model and look only at profits and losses of the asset side of an insurer's balance sheet.[20] We consider a one-year time horizon and determine capital requirements based on the Value-at-Risk (VaR) of the insurer's change in equity capital with a confidence level of 99.5%. At $t = 0$ the insurer can invest in $N$ individual assets represented by financial instruments issued by single firms $i$, whereby each firm belongs only to one specific business sector $j$. The return of a financial instrument of name $i$ in sector $j$ and the market return follow a bivariate process represented by

$$\begin{pmatrix} r_m \\ r_{ij} \end{pmatrix} \sim N \left[ \begin{pmatrix} E[r_m] \\ E[\beta_{ij} r_m] \end{pmatrix}, \begin{pmatrix} \sigma_m^2 & \rho_{ij,m}\sigma_{ij}\sigma_m \\ \rho_{ij,m}\sigma_{ij}\sigma_m & \sigma_{ij}^2 \end{pmatrix} \right] \tag{3}$$

It can be explicitly expressed by means of a Cholesky factorization as

[20] For illustrative reasons, we assume that the insurer's underwriting portfolio does not significantly influence the level of name and sector concentration risk in the insurer's asset portfolio. Section 2 shows that all insurers in the sample, i.e. life, P&C and health insurers, allocate most of their investments only to three different sectors despite the differences in their underwriting portfolios. Hence, it suggests a negligible influence of the underwriting business on the sectoral asset concentration.

$$r_m = E[r_m] + \sigma_m \epsilon_m \tag{4}$$

$$\beta_{ij,m} = \frac{\rho_{ij,m}\,\sigma_{ij}\,\sigma_m}{\sigma_m^2} = \frac{\rho_{ij,m}\,\sigma_{ij}}{\sigma_m} \tag{5}$$

$$r_{ij} = \beta_{ij,m}\, r_m + \sigma_{ij}\sqrt{1-\rho_{ij,m}^2}\,\epsilon_{ij} \tag{6}$$

$$r_{ij} = \sigma_j\,\rho_{j,m}\,(\frac{E[r_m]}{\sigma_m} + \epsilon_m) + \sigma_j\sqrt{1-\rho_{j,m}^2}\,\epsilon_{ij} \tag{7}$$

where $r_{ij}$ is the one-year return of a financial instrument of firm $i$ in sector $j$, $\beta_{ij,m}$ is the firm's beta or sensitivity to economic changes which are approximated by systematic movements of the market's overall return $r_m$, $\sigma_{ij}$ stands for the individual firm's constant total risk in terms of the standard deviation of its return, $\epsilon_{ij}$ is a stochastic standard normally distributed noise term for the idiosyncratic risk part and $\rho_{ij,m}$ denotes the linear correlation coefficient between the returns of firm $i$ in sector $j$ and the overall market.[21] The one-year market return in Equation (4) is given by $r_m$ and incorporates a constant trend in terms of an expected value, $E[r_m]$, and a noise term as the product of the market return's constant volatility, $\sigma_m$, and a stochastic innovation term given by $\epsilon_i$, which follows a standard normal distribution. Both noise terms in the model are assumed to be i.i.d. and have zero covariance and unit variance. For the sake of simplicity, we assume the same correlation coefficient between a firm's return and the market return for all firms within the same sector and the same constant total volatility for all firms within the same sector. Hence, we drop the firm-specific sub index $i$ such that the notation simplifies to $\rho_{ij,m} = \rho_{j,m}$ and $\sigma_{ij} = \sigma_j$ in Equation (7).

The single-factor model, in which the return of a security is linearly related to the market index as single factor (Sharpe (1963)), decomposes each financial instrument's return as in Equation (7) into a systematic and an idiosyncratic risk part. The systematic part maps potential changes in the macroeconomic condition to which every firm is exposed to and hence, is not diversifiable for the investor. For example, changes in the interest rate or oil price shocks are a source of systematic risk which is assumed to equally affect the returns of all firms within the same business sector and, hence, constitute the sector's systematic risk exposure. Then, each asset's systematic risk exposure

[21] Similar return models are used, e.g., by Brownlees and Engle (2017), Weiß and Mühlnickel (2014), Düllmann and Masschelein (2007). Moreover, the assumption of normally distributed asset returns in context of a solvency capital analysis is used in the literature by, for example, Braun et al. (2017) and Niedrig (2015).

can be approximated by co-movements with a broad market index, such that the dependence across assets and sectors can be expressed by the assets' correlation with the market's return.[22] The second term of the return model in Equation (7) constitutes the firm-specific idiosyncratic risk part. It can be typically diversified in portfolios with a large number of different assets. The term $1-\rho_{j,m}^2$ refers to the part of the asset's return that is related to idiosyncratic risk.

The insurer's solvency capital requirement is based on the one-year loss in its asset portfolio. With $r_P$ being the portfolio's return, the change of the insurer's equity capital $\Delta Equity$, i.e. its profit or loss, is given by

$$\Delta Equity = A_1 - A_0 = A_0\, r_P \tag{8}$$

The mean and variance of the equity change, $\Delta Equity$, are given by

$$\mu_{\Delta Equity} = A_0\, E(r_P) \tag{9}$$

$$\sigma^2_{\Delta Equity} = A_0^2\, Var(r_P) \tag{10}$$

The insurer's solvency capital requirement is calculated by a Value-at-Risk approach that maps, independent from the RBC's modular approach or Solvency II's standard formula, the "true" risk situation of the insurer. Hence, we apply Solvency II's general idea of keeping an insurer solvent for the next year with a probability of 99.5%. It can be expressed by the closed form solution (e.g. Braun et al. (2017), Gatzert et al. (2008)):

$$SCR_{VaR} = \mid \mu_{\Delta Equity} + z_{0.5\%}\, \sigma_{\Delta Equity} \mid \tag{11}$$

$$= A_0 \mid E(r_P) + z_{0.5\%}\, Std(r_P) \mid \tag{12}$$

where $z_{0.5\%}$ stands for the 0.5% quantile of the standard normal distribution.

For each of the three asset portfolios necessary for our solvency capital allocation scheme, i.e.

[22]Single-factor models are still used for regulatory purposes, for instance, in the European banking regulation (e.g. Grippa and Gornicka (2016), Basel Committee on Banking Supervision (2014)). Meric and Meric (1989), for instance, show that the variation in sector-specific asset returns is largely explained by the first principal component. Multi-factor models, which assume multiple systematic risk factors for business sectors (e.g. Düllmann and Masschelein (2007), Basel Committee on Banking Supervision (2006)), can be used as well for studying asset concentration risk. A higher number of risk factors would make the asset model substantially more complex and would not extend our main results. In our model, we aim to study the general impact of the current regulatory exclusion of sector concentration risk on the solvency capital allocation, for which the single-factor model is sufficient.

the well-diversified benchmark portfolio with investments in sectors $j \in (1,2)$, the actual portfolio, and the hypothetical portfolio (see Figure 3), the expected return and the return's variance is given by:[23]

$$E[r_{PF_{Benchmark}}] = E[r_m]\,(\gamma_{reg}\,\rho_{1,m}\,\frac{\sigma_1}{\sigma_m} + (1-\gamma_{reg})\,\rho_{2,m}\,\frac{\sigma_2}{\sigma_m}) \tag{13}$$

$$Var[r_{PF_{Benchmark}}] = (\gamma_{reg}\,\sigma_1\,\rho_{1,m} + (1-\gamma_{reg})\,\sigma_2\,\rho_{2,m})^2 \tag{14}$$

For the actual portfolio with a single name exposure of $\alpha$ and investments in sectors $j \in (1,2)$, the portfolio's expected return and variance are given by

$$E[r_{PF_{Actual}}] = E[r_m]\,(\gamma\,\rho_{1,m}\,\frac{\sigma_1}{\sigma_m} + (1-\gamma)\,\rho_{2,m}\,\frac{\sigma_2}{\sigma_m}) \tag{15}$$

$$Var[r_{PF_{Actual}}] = \alpha^2\,\sigma_1^2\,(1-\rho_{1,m}^2) + (\gamma\,\sigma_1\,\rho_{1,m} + (1-\gamma)\,\sigma_2\,\rho_{2,m})^2 \tag{16}$$

For the hypothetical portfolio with investments in sectors $j \in (1,2)$, the portfolio's expected return and variance are given by

$$E[r_{PF_{Hyp}}] = E[r_m]\,(\gamma\,\rho_{1,m}\,\frac{\sigma_1}{\sigma_m} + (1-\gamma)\,\rho_{2,m}\,\frac{\sigma_2}{\sigma_m}) \tag{17}$$

$$Var[r_{PF_{Hyp}}] = (\gamma\,\sigma_1\,\rho_{1,m} + (1-\gamma)\,\sigma_2\,\rho_{2,m})^2 \tag{18}$$

### 4.3 Calculation of the Regulatory Solvency Capital Requirements

We aim to compare the solvency capital requirements based on the VaR approach with capital requirements given by the US RBC framework and Solvency II's standard formula. To prevent distortions due to including other risk sources, and to keep the model as simple as possible, we conduct the solvency capital calculation for an equity portfolio consisting purely of unaffiliated common stocks listed in developed markets. Hence, only the equity risk charge and the concentration risk charge have to be applied in both regulatory frameworks.[24] The total assets are scaled to one unit, i.e. $A_0 = 1$.

[23] A detailed explanation is given in Appendix A.5.

[24] Including other asset classes, like bonds or loans, would not alter the main implications of the model, since introducing these asset classes affects the regulatory risk charges in the model, but not the general impact of sector concentration risk on the allocation of solvency capital to asset concentration risk, which is the focus of our analysis.

Table 6 shows the regulatory formulae to calculate solvency capital requirements under the US RBC framework and Solvency II's standard formula in case of a P&C insurer (National Association of Insurance Commissioners (NAIC) (2017a), European Union (2015)). For equity risk, Solvency II implies a given shock factor to the asset value of 39% and the RBC framework implies a shock factor of 15%. As for the asset concentration risk, we have only in the insurer's actual portfolio one large name exposure with a fraction $\alpha$ in terms of total assets. The residual part of the actual portfolio is spread over a large number of name investments, such that each residual name is assumed to have a sufficiently small fraction of the total portfolio that is below the regulatory threshold level under Solvency II. As unaffiliated common stock investments get a credit quality step of 5 in Solvency II's standard formula (see Table 4), it implies for the benchmark and hypothetical portfolio a threshold level of 1.5% of the total assets for these investments in order to constitute sufficiently small investments. Hence, $\frac{1}{N} \leq 0.015$, i.e. a total number of single assets $N \geq 67$ is needed to vanish the portfolio's name concentration risk charge under Solvency II for these sufficiently small investments. For the actual portfolio with the one large name exposure with a fraction $\alpha$, we also assume a total of 67 investments, which leads to an even lower portfolio fraction of 1.5% for each residual name investment. The RBC framework always considers 10 investments for the asset concentration risk charge.

| | Solvency II | US RBC |
|---|---|---|
| Equity Risk | $0.39\, A_0$ | $0.15\, A_0$ |
| Concentration Risk | $\sqrt{(s_{sf}\, max[A_0(\alpha - T_\alpha),\, 0])^2 + \sum_{i=2}^{N}(s_{sf}\, max[A_0(\frac{1-\alpha}{N-1} - T_i),\, 0])^2}$ | $\alpha\, A_0\, s_{rbc} + 9\, \frac{1-\alpha}{N-1}\, A_0\, s_{rbc}$ |
| Total Portfolio Risk | $\sqrt{(SCR^{SF}_{Equity})^2 + (SCR^{SF}_{Conc})^2}$ | $\sqrt{(R_{2,\, equity} + R_{2,\, conc})^2}$ |

Table 6: Regulatory Formulae for the SCR Calculation

This table shows the regulatory formulae to calculate the solvency capital requirements under Solvency II and under the US RBC-Framework for a P&C insurer. It is assumed that the insurer invests in unaffiliated common stock investments. $SCR^{SF}_{Equity}$ and $SCR^{SF}_{Conc}$ stand for the solvency capital derived under Solvency II's standard formula for equity risk and concentration risk, respectively. $R_{2,\, equity}$ and $R_{2,\, conc}$ stand for the solvency capital derived under the RBC framework for equity risk and concentration risk, respectively. $\alpha$ denotes the fraction of the large name exposure in the actual portfolio. For the benchmark and hypothetical portfolio without any large name exposure, the $\alpha$-term can be interpreted as a sufficiently small portfolio fraction.

## 4.4 Calibration

For illustrative reasons, we limit our analysis to two distinct sectors and assume that assets within the same business sector have the same expected return and volatility. As proxies for the sectors we use the S&P 500 Financial (sector 1) and the S&P 500 Energy (sector 2). We denote a fraction of 68% to the financial sector according to the high financial sector allocations of German insurers in 2017 as a real-world example (see Table 14 in the Appendix), and we approximate the correlation of the assets' returns to the market return by the correlation coefficients between the respective sector indices and the S&P 500 Composite index (see Table 15 in the Appendix). For the actual portfolio, we assume one large investment in a stock of sector 1 with 10% of the portfolio's total assets. Hence, $\alpha > 1.5\%$, which is the applicable threshold level under Solvency II for unaffiliated common stocks.

Determining of the acceptable level of sector concentration risk in the regulatory benchmark portfolio is crucial to the analysis. In both regulatory regimes capital charges for name concentration risk are based on the deviation of an asset portfolio to a well-diversified benchmark portfolio, we follow this approach and use the minimum variance portfolio allocation between both sectors as a benchmark level, yielding $\gamma_{reg}$ for sector 1. The volatility minimizing fraction for the financial sector is 32% and 68% for the energy sector.[25] Any deviation in the sector concentrations of a portfolio would then be associated with a higher systematic risk exposure. Unaffiliated common stocks get a credit quality step of 5 in Solvency II's standard formula and a given shock factor of $s_{sf} = 73\%$ to the asset's value. The US RBC framework implies to double the risk-based shock factor for unaffiliated common stocks, i.e. $s_{rbc} = 30\%$ of the asset's value. Table 7 summarizes the parameters used for the analysis.[26]

## 4.5 Results

Table 8 shows the baseline results for the benchmark, the actual and the hypothetical portfolio. The US RBC framework requires solvency capital for name concentration risk in each portfolio, since it determines the capital requirement based on the 10 largest investments. For the actual port-

[25] See for details Appendix A.6.

[26] We expect our results to hold as well for other parametric specifications, since these do not influence the conceptual consideration of asset concentration risk with respect to the solvency capital requirements of both regulatory frameworks.

| Parameter | $\sigma_m$ | $E[r_m]$ | $\sigma_1$ | $\sigma_2$ | $\rho_{1,m}$ | $\rho_{2,m}$ | $\alpha$ | $\gamma$ | $\gamma_{reg}$ | $s_{sf}$ | $s_{rbc}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Calibration | 17.9% | 10% | 26.8% | 22.4% | 0.86 | 0.66 | 10% | 68% | 32% | 73% | 30% |

Table 7: Calibration Parameters for the Solvency Capital Analysis

The table contains annualized values for the return volatility (standard deviation) of the S&P 500 Composite ($\sigma_m$) as well as of the S&P 500 Financials ($\sigma_1$) and the S&P 500 Energy ($\sigma_2$). The calculation is based on weekly return data (Datastream) from January 1990 to June 2018. The correlation coefficients $\rho_{1,m}$ and $\rho_{2,m}$ show the Pearson correlation of the returns between the S&P 500 Composite and the S&P 500 Financials and Energy sectors (Table 15 in Appendix A.6 gives an overview). $\alpha$ and $\gamma$ denote the large name's portfolio fraction and that of sector 1, respectively. $\gamma_{reg}$ is the minimum variance sector weighting that leads to the regulatory acceptable level of sector concentration risk. $s_{sf}$ and $s_{rbc}$ give the shock factors for unaffiliated common stock investments under Solvency II and the US RBC framework, respectively.

folio, the 10 largest investments consists of the single large name exposure with fraction $\alpha = 10\%$, and 9 small investments with portfolio fractions of 1.36%.[27] For the benchmark and hypothetical portfolio, name concentration risk is charged on 10 small investments with equal fractions of 1.49%.[28] Regarding the capital requirements derived under Solvency II, the concentration risk charge applies only to the actual portfolio due to the 10% single name exposure. Since all remaining assets have a portfolio fraction below the given threshold level of 1.5%, no concentration risk has to be charged for these small investments under Solvency II.

Interestingly, the US RBC framework requires substantially lower levels of solvency capital than the Solvency II approach. Regarding the actual portfolio, an EU insurer has to set almost 40% of its total investments as additional capital aside, whereas the US insurer has to set 22% of the total investments aside. The large difference mainly stems from a substantially lower equity capital charge in the US RBC framework compared to Solvency II (15% vs 39%, respectively). However, both approaches require less solvency capital than the VaR approach, which charges for the actual portfolio 41% of the investments as solvency capital.

The total solvency capital requirements for the different portfolios are relatively close to each other within a given regulatory framework. Between the hypothetical portfolio and the benchmark portfolio, which only differ in their sector concentrations, there is no difference in the solvency capital requirements within Solvency II or the RBC framework. This is not surprising, since both portfolios are granular in terms of name exposures, but sector concentrations are not reflected by the regulatory capital requirements. Hence, microprudential insurance regulation provides a solvency

[27] The equal fractions of the residual name investments are derived by: $\frac{1-0.1}{67-1} = 1.36\%$, with $N = 67$ as the total number of assets in the portfolios.

[28] The equal fractions of all name investments are derived by: $\frac{1}{67} = 1.49\%$.

| SCR | Benchmark | Actual | Hypothetical |
|---|---|---|---|
| $Solvency\,II_{equity}$ | $0.3900A_0$ | $0.3900A_0$ | $0.3900A_0$ |
| $Solvency\,II_{conc}$ | 0 | $0.0620A_0$ | 0 |
| $Solvency\,II_{total}$ | $0.3900A_0$ | $0.3949A_0$ | $0.3900A_0$ |
| $RBC_2$ | $0.1500A_0$ | $0.1500A_0$ | $0.1500A_0$ |
| $RBC_{2,\,conc}$ | $0.0448A_0$ | $0.0668A_0$ | $0.0448A_0$ |
| $RBC_{total}$ | $0.1948A_0$ | $0.2168A_0$ | $0.1948A_0$ |
| $VaR$ | $0.3516A_0$ | $0.4128A_0$ | $0.4116A_0$ |

Table 8: Baseline Results of the Solvency Capital Calculation

The table shows the solvency capital requirements for the benchmark, actual and hypothetical portfolios under Solvency II's standard formula, the US RBC framework and the VaR approach. The regulatory requirements are derived as summarized in Table 6, the VaR is based on a 99.5% confidence level. The portfolios' expected returns are for the benchmark, actual and hypothetical portfolios: 9.74%, 11.40%, 11.40%. The standard deviations of the portfolios' returns are: 3.04%, 4.18% and 4.16%.

capital incentive for insurers to reduce name concentration risk in their asset portfolios, i.e. to transform the actual portfolio to either the hypothetical or the benchmark portfolio. However, there is no incentive for insurers to lower sector concentration risk in their asset portfolios, i.e. to transform the hypothetical portfolio to the benchmark portfolio, although results of the VaR measure show that the sectoral asset distribution has a substantial impact on the solvency capital required to cover losses. The difference in the solvency capital between the insurer's actual portfolio and the regulatory benchmark portfolio is 6 percentage points, since the riskier financial sector (sector 1) has a substantially higher weight in the actual portfolio compared to the benchmark portfolio (68% vs 32%, respectively).

In order to assess the potential bias on solvency capital requirements due to the regulatory exclusion of sector concentration risk, Table 9 shows the capital allocation based on the proposed with-without allocation scheme. Regarding the VaR approach, which is sensitive to sector-specific systematic risk exposures, most of the total solvency capital for asset concentration risk has to be set aside for sector concentration risk ($0.0600A_0$), not for name concentration risk ($0.0012A_0$). More specifically, the fraction of the sector concentration risk capital to total concentration risk capital is 98%. With regard to the total solvency capital requirement of the actual portfolio ($0.4128A_0$), the sector concentration capital amounts to almost 15% and name concentration risk only to 0.3% in the VaR approach. Thus, the risk-adequate solvency capital requirement for sector concentration risk can be substantial, and its exclusion from capital requirements under the US

RBC framework and Solvency II can lead to a potentially severe estimation bias. While name concentration risk is substantially overestimated in current regulatory frameworks compared to the economic VaR approach ($0.0220A_0 > 0.0049A_0 > 0.0012A_0$), sector concentration risk is severely underestimated, since it is explicitly excluded ($0 = 0 < 0.06A_0$). The empirical findings on insurers' asset concentrations in Section 2 underline this regulatory incentive structure. Name concentration risk is found to be well-diversified in the insurers' asset portfolios, whereas substantial sector concentrations in the public, financial and real estate sector exist.

| Risk | VaR | Solvency II | RBC |
|---|---|---|---|
| Total Asset Concentration Risk | $0.0612A_0$ | $0.0049A_0$ | $0.0220A_0$ |
| Sector Concentration Risk | $0.0600A_0$ | 0 | 0 |
| Name Concentration Risk | $0.0012A_0$ | $0.0049A_0$ | $0.0220A_0$ |

Table 9: Results of the Capital Allocation Scheme for Asset Concentration Risk

This table shows the solvency capital allocation with regard to total asset concentration risk, sector concentration risk and name concentration risk under the Value-at-Risk (VaR) approach, and the solvency capital requirements given by Solvency II and the US RBC framework. The allocation scheme is given in Table 5. Since the risk factors for name and sector concentration risk in our return model are linearly independent, the combination of their variances add up to the total variance in the VaR approach.

Moreover, although the noise terms for systematic and idiosyncratic risk in our return model are uncorrelated, the solvency capital allocations for name and sector concentration risk influence each other. The interdependence of the solvency capital allocations for name and sector concentration risk goes back to the VaR calculation according to Equation (12). The mean return of the actual portfolio (Equation 15) does not depend on the portfolio's idiosyncratic risk exposure, since higher idiosyncratic risk does not get compensated through a higher expected return. It is the standard deviation of the portfolio's return, $Std(r_p)$, that mainly drives the solvency capital allocation in terms of a concave function. The first term determines the name concentration risk, and the portfolio's exposure to idiosyncratic risk and the second term determines the sector concentration risk and the portfolio's exposure to systematic risk. Euler's theorem on capital allocation implies an additive risk decomposition between name and sector concentration risk, since the standard deviation of the portfolio's return is continuous, differentiable and homogeneous of degree one with regard to the portfolio weights of the name and sector concentration risk factors, i.e. $\alpha$ and $\gamma$ (Rosen and Saunders (2010), Tasche (2008)). Thus, the contribution of name concentration risk to the portfolio's total solvency capital, $C_\alpha$, is given as a function of the first derivative of the volatility of the portfolio's return with respect to the portfolio's weight of the large name investment, $\alpha$. It is given by (see Equations (12) and (16)):

$$\begin{aligned} C_\alpha &= \alpha \, \frac{\partial Std(r_P)}{\partial \alpha} \\ &= \frac{\alpha^2}{Std(r_P)} \, \sigma_1^2 \, (1 - \rho_{1,m}^2) \end{aligned} \tag{19}$$

Now, if more assets are allocated to the riskier sector, the standard deviation of the portfolio's return, $Std(r_p)$, increases due to a higher sector concentration risk (higher $\gamma$). However, the portfolio's allocation to the name investment, i.e. $\alpha$, and the associated level of idiosyncratic risk exposure, $\sigma_1^2 \, (1 - \rho_{1,m}^2)$, remain constant. Thus, the marginal solvency capital contribution of name concentration risk shrinks for an increasing level of sector concentration risk. Hence, excluding sector concentration risk from the regulatory solvency capital requirements for asset concentration risk under the US RBC framework and Solvency II leads to two different types of estimation bias: First, no solvency capital is allocated for sector concentration risk, which can lead to a lack of solvency capital necessary to back up potential losses from the aggregated systematic risk exposures of all sector-specific assets. Second, the regulatory solvency capital allocation for name concentration risk is technically over- or underestimated if the sector concentrations in the insurer's real-world asset portfolio are not taken into account.[29]

### 4.6 Regulatory Implications

The explicit regulatory exclusion of sector concentration risk from the solvency capital requirements for asset concentration risk under the US RBC framework and Solvency II should be generally reconsidered. In particular, our results show that sector concentration risk is a material risk source for an insurer's solvency. Thus, it is necessary for regulators to define the benchmark levels of sectoral asset concentrations that are acceptable from a microprudential perspective in order to improve the current regulatory frameworks. Any deviation from these benchmark levels in an insurer's asset portfolio could then be considered as an increase in sector concentration

[29] Gürtler et al. (2010) come to a similar conclusion for banking regulation under the Basel framework, in which the regulator's definition of a well-diversified portfolio includes low levels of name and sector concentration risk. If the real-world asset concentration risks in banks' credit portfolios deviate from these assumptions, a technical estimation bias on the corresponding solvency capital allocations follows automatically.

risk that should be mitigated. These sectoral benchmark levels could be defined by sector-specific threshold levels in terms of the portfolio's total asset value or by using concentration measures like the Herfindahl-Hirschman-Index. The main regulatory aim in that regard is to set appropriate regulatory incentives for insurers to diversify their assets from a sectoral perspective, which reduces both, the portfolio's systematic loss potential due to sector concentration risk and the estimation bias on the solvency capital allocation for name concentration risk. Two potential ways seem to be particularly promising to achieve that aim: stricter public disclosure requirements and explicit solvency capital requirements for sectoral asset concentrations.

For example, US and EU insurers are required to conduct an "Own Risk and Solvency Assessment" (ORSA) in order to evaluate the adequateness of the calculated solvency capital requirements against all material risks insurers are exposed to from an economic and regulatory perspective. Although Section 2 highlights, for example, the substantial sectoral asset concentrations for EU insurers, their public solvency and financial condition reports (SFCR) do not contain detailed information about these sector concentrations. However, the public disclosure of the exact sectoral asset allocation of insurers could result in market discipline effects by investors against those insurers that invest too risky with regard to asset concentration risk. Alternatively, or in addition, an explicit solvency capital charge for sector concentration risk could be introduced, similar to the approach already applied to determine the solvency capital requirements for name concentration risk. A solvency capital add-on depending on the level of the portfolio's sectoral asset concentrations could set incentives for insurers to diversify their assets in a way that the regulatory benchmark assumptions are met. If we look into regulatory frameworks for banks, sector concentration risk in credit portfolios can be explicitly charged with solvency capital (e.g. European Systemic Risk Board (2020), Bank of England (2017)). An explicit solvency capital charge in insurance regulation would lead to a conceptually similar consideration of sector concentration risk for banks and insurers and can thus mitigate regulatory arbitrage. Interestingly, an explicit solvency capital charge for sector concentration risk is currently discussed in macroprudential insurance regulation to reduce systemic risk (European Systemic Risk Board (2020)). However, it is also necessary to consider sector concentration risk adequately in microprudential insurance regulation, since regulatory actions can have counteracting effects on the stability levels of both, individual institutions and entire systems (Meuleman and Vennet (2020), Wagner (2010)).

The regulation of sector concentration risk will be costly for insurers. On the one hand, a stricter public disclosure of sectoral asset concentrations leads to higher reporting costs for insurers. However, given the already strict reporting requirements on the insurers' assets, the marginal cost burden for insurers to include the sectoral distribution of their assets should be limited. On the other hand, implementing sector-specific threshold levels limits insurers' investment decisions, which could make it even more difficult for insurers to generate asset returns, for instance, to cover guaranteed returns in the life insurance sector. Thus, it becomes a difficult task for regulators to decide on the adequate threshold levels of sectoral asset concentrations to increase the insurers' solvency levels and at the same time to support their role as risk takers for policyholders.

# 5 Conclusion

Current microprudential regulatory frameworks like the US RBC framework and Solvency II take only the concentration of assets with regard to individual names (counterparties) in their solvency capital requirements into account, but not the concentration of assets with regard to business sectors. Thus, the accumulation of sector-specific systematic risk exposures in the asset portfolios remains unconsidered.

By using a unique dataset of US insurers' asset holdings from 2009 to 2018, we find that name concentration risk is generally well-diversified with an average name concentration of 0.5% of total assets, but substantial sector concentrations exist. For instance, in 2018, US insurers had 33% of their total assets invested in the financial sector, 13% invested in the real estate sector and 10% in the public sector. We also find indicative evidence for a sectoral search for yield behavior, as insurers have mainly reallocated assets from the relatively safe public sector to the riskier financial sector over time. The comparison of the solvency capital requirements for asset concentration risk between an economic Value-at-Risk (VaR) approach, the US RBC framework and Solvency II's standard formula shows that sector concentration risk can be a substantial risk source for insurer's solvency. In our baseline analysis, sector concentration risk contributes to 15% of the total solvency capital, whereas name concentration risk is almost negligible. Hence, the current exclusion of sector concentration risk from solvency capital requirements can potentially lead to insufficient solvency capital levels. Moreover, we find that the solvency capital allocations for name and sector concentration risk interact with each other, which implies that the current regulatory exclusion of sector concentration risk can lead to technically over- or underestimated solvency capital requirements for name concentration risk.

Therefore, insurance regulation regarding asset concentration risk should be revised, particularly in terms of creating an incentive for insurers to diversify their assets with regard to business sectors. Potential regulatory changes could be to increase public disclosure requirements of the sectoral asset allocation of the insurer's portfolio, which would foster market discipline. In addition, an explicit solvency capital add-on for sector concentration risk would lower an insurer's default risk directly, and, by avoiding extreme sector concentrations, mitigate the estimation bias in the solvency capital requirements for name concentration risk.

# A Appendix

## A.1 Data for Name and Sector Concentrations in Insurers' Asset Portfolios

We collect the insurers' filings with the NAIC from 2009 to 2018 from SNL Financial (S&P Market Intelligence). Our analysis is based on raw data as reported by life, health and property&casualty insurers to the NAIC with regard to investment schedules A (part 1: real estate), B (part 1: mortgage loans on real estate), D (part 1: bonds; part 2, section 1: preferred stocks; part 2, section 2: common stocks) and BA (part 1: other invested assets, esp. private equity funds, real estate funds and hedge funds). The data does not contain assets held by insurers on separate accounts.

The raw dataset provides the assets' CUSIP numbers and book/adjusted carrying values. We match the assets' CUSIP numbers with sector classification variables stemming from several other data sources: Bloomberg, Datastream, CRSP, MSRB and SNL Financial. For the sector classifications, we use the Global Industry Classification Standard (GICS) as the main sectoral classification system. If a GICS classification is not available for a given asset, we aim to get the Thomson Reuters Economic Sector variable or the NAICS sector variable if available in this order. Public Administration is originally not included in the GICS system, but we add it as an additional sector to comprise the typically large public debt investments of insurers.

For assets we cannot match with a sector classification variable, we use the line numbers that are reported with the assets and match them with the GICS classification system if possible. We classify schedule A and B investments as real estate sector investments.[30] For fund investments, we employ a "look-through" approach and classify these investments to a specific sector only if we are able to get information on the funds' actual investments. If we have no clear information for a fund investment, we denote it as unclassified in the sample. We exclude investments with a negative book/adjusted carrying value. We also exclude investments that are described as housing tax credits, since it is unclear which sectoral risk exposure is most appropriate to describe the value of this asset type, for example, the public, the real estate or the financial sector.

Table 10 gives an overview of the insurance sector's total book/adjusted carrying value (BACV)

[30] For instance, McDonald and Paulson (2015) also include the direct real estate investments of financial institutions as a sectoral asset exposure to the real estate sector.

in our sample. For example, in 2018, our sample comprises assets with a value of 5800 billion US$. For 87% of the total assets, we have a sector classification in 2018, hence, 13% of the total assets cannot be allocated to a specific business sector.

| Year | Total BACV (bn US$) | Sectoral Coverage |
|---|---|---|
| 2018 | 5803 | 0.87 |
| 2017 | 5133 | 0.86 |
| 2016 | 4980 | 0.84 |
| 2015 | 4779 | 0.83 |
| 2014 | 4738 | 0.82 |
| 2013 | 4600 | 0.82 |
| 2012 | 4410 | 0.81 |
| 2011 | 4332 | 0.80 |
| 2010 | 4169 | 0.79 |
| 2009 | 3949 | 0.79 |

Table 10: Data Coverage of the US Insurance Sector's Assets in our Sample

The table shows our sample of the US insurance sector's total assets as book/adjusted carrying value (BACV) per year. The sample includes 4942 insurers that are registered with the NAIC by a company code. The column "Sectoral Coverage" shows the extent of the total assets for which we have a sectoral classification. Investment data stems from SNL Financial (S&P Market Intelligence).

## A.2 Sectoral Asset Allocation of US Insurers

The following Table 11 and Figure 4 highlight the sectoral asset allocation of US insurers at the individual firm-level.

| Sector | Mean | Median | StD |
|---|---|---|---|
| Public Administration | 0.35 | 0.27 | 0.28 |
| Financials | 0.36 | 0.34 | 0.18 |
| Real Estate | 0.04 | 0.01 | 0.09 |
| Utilities | 0.04 | 0.02 | 0.04 |
| Industrials | 0.05 | 0.04 | 0.05 |

Table 11: Mean, Median and Standard Deviation (StD) of the Sectoral Asset Allocations of US Insurers

The table shows the mean, median and standard deviation (StD) of the asset allocations to the five most important sectors from 2009-2018. The sample includes 4942 US insurers and the depicted sectors are the five most important sectors according to the total invested volume in 2018. The sector concentration is the aggregated book/adjusted carrying value (BACV) for all sector-specific assets held by an insurer divided by the total BACV over all assets held by an insurer in a given year.

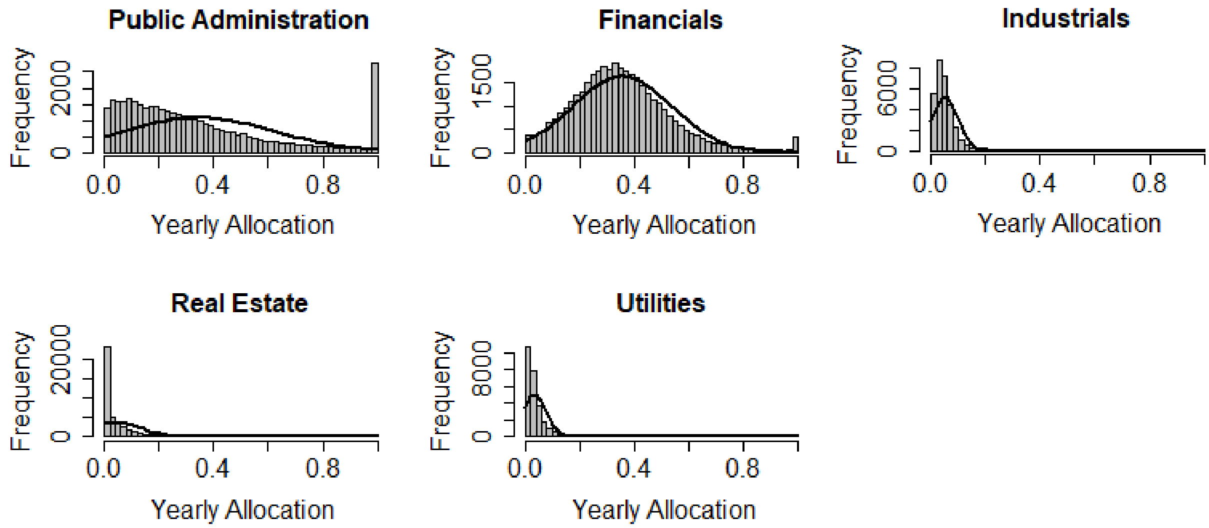


Figure 4: Distributions of Asset Allocations to the Five Most Important Sectors at the Insurer-Level

The figure shows the sectoral asset allocations of all 4942 US insurers from 2009-2018. The straight line shows normal distributions with mean and standard deviations as given by the respective data. The sector concentration at the insurer-level is the aggregated book/adjusted carrying value (BACV) of all sector-specific assets held by the individual insurer divided by the insurer's aggregated BACV over all reported assets in a given year. The five most important sectors are ranked by the insurers' total investment volume in 2018 (see Table 2).

### A.3 Sectoral Asset Allocation of EU Insurers

Table 12 highlights the sectoral asset allocations to the five most important sectors for EU insurers in 2018, Table 13 for the year 2017.

| NACE Sector | Min | Max | Mean |
|---|---|---|---|
| K - Financial and Insurance Activities | 17.6% (Croatia) | 70.6% (Germany) | 42.4% |
| K64 - Financial Services | 8.6% (Croatia) | 56.6% (Iceland) | 30.4% |
| O - Public Sector | 2.4% (Iceland) | 67.2% (Hungary) | 35.2% |
| C - Manufacturing | 0.3% (Hungary) | 11.2% (Finland) | 3.9% |
| L - Real Estate | 0.2% (Poland) | 12.0% (Norway) | 2.9% |
| D - Electricity and Gas | 0.1% (Hungary) | 5.8% (Iceland) | 1.9% |

Table 12: Overview of the Most Important Sector Concentrations for EU Insurers in 2018

The table shows the minimum, maximum and mean ratio at the country-level of insurers' sectoral asset allocations in 2018. Data is based on NACE classification and provided by European Insurance and Occupational Pensions Authority (EIOPA) (2019b). K64 is a subsector of the financial sector K and mainly comprises banking-like activities.

| NACE Sector | Min | Max | Mean |
|---|---|---|---|
| K - Financial and Insurance Activities | 18.3% (Croatia) | 68.2% (Germany) | 40.6% |
| K64 - Financial Services | 8.1% (Croatia) | 55.0% (Iceland) | 30.7% |
| O - Public Sector | 4.3% (Iceland) | 71.9% (Romania) | 34.2% |
| C - Manufacturing | 0.2% (Hungary) | 9.0% (Slovenia) | 3.9% |
| L - Real Estate | 0.08% (Lithuania) | 12.4% (Norway) | 2.6% |
| D - Electricity and Gas | 0.07% (Croatia) | 5.0% (Iceland) | 2.0% |

Table 13: Overview of the Most Important Sector Concentrations for EU Insurers in 2017

The table shows the minimum, maximum and mean ratio at the country-level of insurers' sectoral asset allocations in 2017. Data is based on NACE classification and provided by European Insurance and Occupational Pensions Authority (EIOPA) (2018a). K64 is a subsector of the financial sector K and mainly comprises banking-like activities.

Table 14 shows the sectoral asset allocations for Germany in 2017 as an exemplary insurance market in the EU. The largest fraction is allocated to financial and insurance activities with 68% of the total assets (NACE Code K), followed by the public sector (NACE code O) with almost 18%, which reflects the insurers' large holdings of sovereign debt. The third largest sectoral allocation with almost 2% of total assets is in the real estate sector (NACE code L).

| NACE Sector | Fraction (%) |
|---|---|
| K - Financial and Insurance Activities | 68.19 |
| O - Public administration and defence; compulsory social security | 17.63 |
| L - Real estate activities | 1.99 |
| C - Manufacturing | 1.73 |
| T - Activities of households as employers | 1.46 |
| remaining sectors: D, H, J, M, N, B, F, U, G, S, Q, E, I, R, A, P | $< 1.0$ |
| Unreported NACE | 4.83 |

Table 14: Sectoral Asset allocations of German Insurers in 2017

The table shows the sector-specific allocation in terms of total assets of German insurers in 2017. Data is based on NACE classification and we aggregate the different reported sub-allocations for the NACE K code into a single total allocation. Unreported NACE denotes the allocation of assets that is reported without a NACE code. Data is provided by European Insurance and Occupational Pensions Authority (EIOPA) (2018a).

## A.4 The Global Insurance Capital Standard (ICS)

The Global Insurance Capital Standard (ICS) under the version 2.0 focuses only on name concentration risk and neglects sector concentrations in insurers' asset portfolios. However, it differs substantially in the calculation of the capital charge for asset concentration risk compared to Solvency II and the US RBC framework (International Association of Insurance Supervisors (IAIS)

(2020)). Most fundamentally, it does not include certain asset thresholds. Instead, it calculates the capital charge for asset concentration risk by means of a dynamic granularity adjustment. Under the level 2 document, the solvency capital requirement for asset concentration risk is applicable for equity and fixed income instruments and defined as

$$SCR_{conc}^{ICS} = 0.71656(\frac{\sum_{E_i > 1} (E_i - T)\,(d\,K_i^{eq} + K_i^{cr})}{d\,K^{eq} +\, K^{cr}} + T) \tag{20}$$

Thereby, the insurer's aggregated exposure to a counterparty, $E_i$, is reflected against a dynamic threshold level $T$, which has a value such that the total number of large exposures in the portfolio with $E_i > T$ lies between 10 and 100. Then, the resulting name exposures are applied to given equity and credit risk factors, i.e. $K_i^{eq}$ and $K_i^{cr}$, respectively. The equity risk charge is adjusted by a specified factor of $d = 0.95$, and the resulting value is weighted by the insurer's total risk charges for equity and fixed income instruments ($K^{eq}$, $K^{cr}$).[31]

### A.5 Portfolio Moments

In the following, it is shown how the formulas for the mean and variance of the portfolios given in Figure 3 are derived. We hereby refer to the actual portfolio which combines both, name and sector concentration. With regard to the other portfolios, an analogous approach can be used.

Given the return of a financial instrument (asset) of firm i in sector j as shown in Equation (7),

$$r_{ij} = \sigma_j \rho_{j,m} (\frac{E[r_m]}{\sigma_m} + \epsilon_m) + \sigma_j \sqrt{1 - \rho_{j,m}^2}\,\epsilon_{ij} \tag{21}$$

Let $N$ denote the number of overall assets, $M$ the number of assets linked to sector 1 and $Q$ the number of assets linked to sector 2, such that $N = M + Q$ and $i \in (N, M, Q)$. By $\gamma$ and $1 - \gamma$ we denote the fraction of the portfolio's total assets invested in assets of sector 1 and 2, respectively. By $\alpha$, we denote the portfolio fraction of the large single name exposure stemming from sector 1 in the benchmark case. Hence, it must hold $\alpha \leq \gamma$. If we assume that, besides the large name exposure $\alpha$, all other names are equally distributed in the portfolio, the overall return of the actual

[31] The IAIS states in a former document (International Association of Insurance Supervisors (IAIS) (2018b)) that this granularity approach is related to work by Gordy and Lütkebohmert (2013). However, the formula differs from the approach mentioned in the literature, and there is no public information how the proposed approach has been derived in detail.

portfolio can be expressed as

$$r_{PF_{Actual}} = \gamma\,(\frac{\alpha}{\gamma}\,r_{11} + \frac{1-\frac{\alpha}{\gamma}}{M-1}\sum_{i=2}^{M} r_{i1}) + (1-\gamma)\,\frac{1}{Q}\sum_{i=1}^{Q} r_{i2} \tag{22}$$

with the discrete annual return for the large name exposure in sector 1 as

$$r_{11} = \sigma_1\,\rho_{1,m}\,(\frac{E[r_m]}{\sigma_m} + \epsilon_m) + \sigma_1\,\sqrt{1-\rho_{1,m}^2}\,\epsilon_{11} \tag{23}$$

and the sum of discrete returns for the other name exposures in sector 1 as

$$\sum_{i=2}^{M} r_{i1} = \sum_{i=2}^{M} \sigma_1\,\rho_{1,m}\,(\frac{E[r_m]}{\sigma_m} + \epsilon_m) + \sigma_1\sqrt{1-\rho_{1,m}^2}\,\epsilon_{i1} \tag{24}$$

and the sum of discrete returns for the name exposures in sector 2 as

$$\sum_{i=1}^{Q} r_{i2} = \sum_{i=1}^{Q} \sigma_2\,\rho_{2,m}\,(\frac{E[r_m]}{\sigma_m} + \epsilon_m) + \sigma_2\sqrt{1-\rho_{2,m}^2}\,\epsilon_{i2} \tag{25}$$

The noise terms $\epsilon_m, \epsilon_{ij}$ are i.i.d. standard normally distributed random variables with zero mean and unit variance and zero covariance. The expected return of the portfolio depends on the sector-specific systematic risk exposure and can be expressed as

$$\begin{aligned} E[r_{PF_{Actual}}] =& E[r_m]\,(\gamma\,\beta_1 + (1-\gamma)\,\beta_2) \\ =& E[r_m]\,(\gamma\,\rho_{1,m}\frac{\sigma_1}{\sigma_m} + (1-\gamma)\,\rho_{2,m}\,\frac{\sigma_2}{\sigma_m}) \end{aligned} \tag{26}$$

For the variance of the portfolio's return, we treat the portfolio as consisting of two sector-specific sub-portfolios. Since the assets are correlated only through the systematic risk component, we can express the variance by

$$
\begin{aligned}
Var[r_{PF_{Actual}}] = &\gamma^2\, Var(\frac{\alpha}{\gamma}\, r_{11} + \frac{1-\frac{\alpha}{\gamma}}{M-1} \sum_{i=2}^{M} r_{i1}) \\
&+ (1-\gamma)^2\, Var(\frac{1}{Q} \sum_{i=1}^{Q} r_{i2}) \\
&+ 2\, \gamma\, (1-\gamma)\, Cov(\frac{\alpha}{\gamma}\, r_{11} + \frac{1-\frac{\alpha}{\gamma}}{M-1} \sum_{i=2}^{M} r_{i1}\, , \frac{1}{Q} \sum_{i=1}^{Q} r_{i2})
\end{aligned}
\tag{27}
$$

For $M, Q \to \infty$ and by setting $(\alpha \geq \frac{1}{N}, \alpha \leq \gamma \leq 1)$ for the actual portfolio and $(\alpha = \frac{1}{N}, \frac{1}{N} \leq \gamma \leq 1)$ for the hypothetical portfolio, and $(\alpha = \frac{1}{N}, \frac{1}{N} \leq \gamma_{reg} \leq 1)$ for the benchmark portfolio, one can derive the means and variances of the portfolio returns in Equations (13)-(18).

### A.6 Calibration Parameters

We assume that the minimum variance portfolio allocation (MVP) leads to an acceptable level of sector concentration risk from the regulatory perspective. For determining that specific allocation between the financial and energy sector, the asset portfolio consists of two sub-portfolios, each including all sector-specific names (assets). Thus, the idiosyncratic risk exposures of the individual names can be neglected and only their sector-specific systematic risk exposures remains. The variance of the portfolio's return is:

$$
\sigma_{PF}^2 = \gamma_{mvp}^2\, \sigma_1^2 + (1-\gamma_{mvp})^2\, \sigma_2^2 + 2\, \gamma_{mvp}\, (1-\gamma_{mvp})\, \rho_{1,2}\, \sigma_1\, \sigma_2 \tag{28}
$$

where $\sigma_1^2$ and $\sigma_2^2$ denote the variance of the sectors' returns (financial, energy), $\gamma_{mvp}$ the portfolio's weight of the assets related to sector 1, and $\rho_{1,2}$ the correlation between the returns of the two sub-portfolios.

The first and second order condition of the total portfolio's variance w.r.t. $\gamma_{mvp}$ yields the volatility minimizing sector allocation for the regulatory benchmark portfolio. It is given by

$$
\gamma_{reg} = \frac{\sigma_2^2 - \sigma_1 \sigma_2 \rho_{1,2}}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1 \sigma_2 \rho_{1,2}} \tag{29}
$$

Table 15 shows the comovement between various US business sectors as categorized by the GICS system. In contrast to Düllmann and Masschelein (2007), who determine the linear dependence structure of the MSCI EMU indices for banks' sector concentration risk, we use the S&P 500 indices. Based on the volatilities for the S&P 500 Financials ($\sigma_1 = 26.8\%$) and the S&P 500 Energy ($\sigma_2 = 22,4\%$), $\gamma_{reg}$ yields 32%.

| | U.S. GICS Sector | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A: | S&P 500 | 1 | 0.86 | 0.66 | 0.92 | 0.80 | 0.78 | 0.55 | 0.69 | 0.73 | 0.91 | 0.68 | 0.41 |
| B: | S&P 500 Financials | | 1 | 0.51 | 0.81 | 0.57 | 0.67 | 0.46 | 0.58 | 0.59 | 0.80 | 0.56 | 0.38 |
| C: | S&P 500 Energy | | | 1 | 0.61 | 0.38 | 0.69 | 0.50 | 0.46 | 0.44 | 0.51 | 0.39 | 0.30 |
| D: | S&P 500 Industrials | | | | 1 | 0.68 | 0.82 | 0.49 | 0.64 | 0.63 | 0.86 | 0.58 | 0.40 |
| E: | S&P 500 Info Tech | | | | | 1 | 0.53 | 0.31 | 0.37 | 0.46 | 0.72 | 0.50 | 0.31 |
| F: | S&P 500 Materials | | | | | | 1 | 0.44 | 0.57 | 0.51 | 0.73 | 0.45 | 0.38 |
| G: | S&P 500 Utilities | | | | | | | 1 | 0.50 | 0.42 | 0.43 | 0.46 | 0.27 |
| H: | S&P 500 Consumer Staples | | | | | | | | 1 | 0.71 | 0.63 | 0.48 | 0.35 |
| I: | S&P 500 Health Care | | | | | | | | | 1 | 0.62 | 0.44 | 0.32 |
| J: | S&P 500 Consumer Discretionary | | | | | | | | | | 1 | 0.61 | 0.42 |
| K: | S&P 500 Telecom | | | | | | | | | | | 1 | 0.25 |
| L: | S&P 500 Real Estate | | | | | | | | | | | | 1 |

Table 15: Correlation Matrix based on US GICS Sectors represented by the S&P 500 Stock Indices

Weekly discrete return data from January 1990 to June 2018 based on total return indices was used to calculate the Pearson correlation coefficient. For real estate, data is from October 2001 to June 2018 due to data availability. Source: Thomson Reuters Datastream.

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