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On the Temptation to Time the Market: Asset Allocation Strategies of Swiss Pension Funds in a Low Interest Rate Environment

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Abstract

In an asset-liability management setting, this study explores potential asset allocation strategies a pension manager under Swiss regulation may consider in an environment where interest rate levels are low. We analyse four distinctive strategies that are benchmarked against market-based pension liabilities: a market-timing strategy that is based on a mean-variance optimal portfolio with liabilities as a short-position asset, an immunisation strategy that is solely based on fixed-income assets and dedicated to hedge against the interest rate risk of pension liabilities, as well as naïve buy-and-hold and fixed-weights strategies. As the recent period of low interest rates is relatively short, we expand the sample size by adjusting return time-series to a common negative level of interest rates using a theoretical asset pricing approach. Moreover, we model relevant regulatory requirements for Swiss pension funds. Using a simple one-factor return estimator, we find the market-timing strategy to deliver superior returns out-of-sample. However, the market-timing investor may also face substantial funding risk depending on her risk preference and initial funding level. Alternative and international assets with unhedged currency exposure add relatively less value to a market-timing portfolio. While slightly inferior to the market-timing strategy, the fix-mix and buy-and-hold strategies exhibit good financial performance. The fix-mix strategy appears to outperform a buy-and-hold strategy in terms of both generated returns and funding risk. This is robust to changes in risk preference and initial funding levels. Moreover, our results suggest that a fix-mix strategy often exhibits less funding risk than a market-timing strategy, even though it does not allow for an active management of pension liabilities. The immunisation portfolio is found to be inferior. It exhibits poor financial performance and appears to structurally underperform its liability benchmark, leading to high funding risk. We relate this underperformance to a regulatory minimum interest requirement that is set above the riskless market rate, creating incentives to allocate towards riskier assets. Our results suggest a market-timing strategy may be attractive due to the high returns generated. However, we find the performance of the market-timing strategy to be considerably sensitive to errors in return estimation. Depending on the exposure to estimation risk, a market-timing pension manager may be better off to hedge her liabilities using an immunisation strategy.

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List of Abbreviations

Abbreviation	Definition
ADS	Arrow-Debreu-Securities
ALM	Asset-Liability-Management
CAPM	Capital Asset Pricing Model
CRRA	Constant Relative Risk Aversion
DB	Defined Benefit
DC	Defined Contribution
MDD	Maximum Drawdown
MSE	Mean Squared Error
OASI	Old-Age and Survivors' Insurance
REIT	Real Estate Investment Trust
SDF	Stochastic Discount Factor
SNB	Swiss National Bank
SPI	Swiss Performance Index
SPT	State Preference Theory
VaR	Value at Risk

1 Introduction

Unlike conventional institutional investors, pension funds are considered liability-driven investors. This is particularly true for pension funds who guarantee benefits that are paid out to retirees at some predetermined time in the future. In contrast to asset-only investors, their primary motive is not merely to maximise the return of their assets. Instead, pension funds also need to ensure that their guaranteed obligations are sufficiently funded in any market condition. In this study, we explore potential strategies on how pension managers may allocate assets in an environment of low interest rates when also pension liabilities need to be considered.

This section is aimed to outline the challenge that pension funds in general, and pension funds under Swiss regulation in particular, are facing. We argue that, given a period of low or even negative interest rates, Swiss pension funds may find themselves in a dilemma between generating returns and managing their liabilities. Further, we state our research questions and conclude this section with an overview of the scientific approach and the structure of this study.

1.1 Problem Statement

From 1999 to 2003, S&P 500 pension funds went from a cumulative surplus, the market value of assets less pension liabilities, of $258 billion to a deficit of $225 billion leading to funding gaps that are in some cases even larger than the market capitalisation of the plan sponsor (Credit Suisse First Boston, 2003). During this period, the Dot-com bubble burst and the stock market turned down. At the same time, interest rates decreased from 6.0% to 0.75% (FRED, 2020). As a consequence, pension funds experienced severe financial turmoil as not only their assets decreased but also the market value of pension obligations rose. In fact, cumulative assets only shrunk by approximately 11.8% while pension liabilities grew by more than 30% throughout the same period (J.P.Morgan, 2011). This disproportional growth of liabilities relative to the assets illustrates the importance for pension funds to manage their liabilities as closely as their assets.

The current low interest rate environment may impose immense pressure on a pension's capability to fund its liabilities. Like all financial claims that occur in the future, pension benefits are discounted to reflect the opportunity cost of capital. The present value of the pension liabilities is then inversely dependent on its discount rate. If the discount rate increases, the value of liabilities decreases and vice versa. Typically, the claims on these obligations are considerably long-dated. Therefore, the sensitivity of the pension liabilities towards changes in their discount rate may be substantial. In case the discount rate is based on an appropriate market interest rate, the value of pension liabilities is marked-to-market. That is, it reflects a fair value that accounts for the prevailing market conditions and eventually allows for an economic view on the magnitude of the pension's obligations. Therefore, when market interest rates decline – as occurred in all major economies over the past decade – the market value of pension liabilities increases. This surge in liabilities, ceteris paribus, may in turn weaken the pension funds' net financing position considerably.

In particular countries in central and northern Europe, interest rates have experienced unprecedented low levels in recent years. With a reduction of its overnight deposit rate by 75bps to -0.75% in early 2015 (Swiss National Bank, 2015), the Swiss National Bank [SNB] was the first and only central bank to lower (and keep) its key interest rate this deep in the negative spectrum. Before the financial crisis in 2008, Swiss interest rates have been at levels just below 3%. Thus, within a period of seven years, the overnight deposit rate dropped by almost 4%. Relative to the drop in US rates in the example above, this decline might appear less significant. However, pension liabilities typically exhibit large and positive convexity (Gajek et al., 2005), leading to a relatively larger interest rate sensitivity if the level of interest rate is lower.

Pension benefits in Switzerland are largely guaranteed by a minimum conversion rate of the total pension contributions, which is determined by the Swiss pension regulator [1]. Therefore, future cashflows to retirees are generally predetermined, exposing pension liabilities to (potentially large) interest rate risk. Swiss pension managers may, therefore, be concerned to hedge the liabilities against adverse market movements such as a further decline of interest rates. For this purpose, they typically allocate a substantial amount of long-maturity government bonds or high-grade corporate bonds towards their portfolio. As they provide relatively stable, long-term cash-flows and exhibit the same inverse relationship to interest rates, these fixed-income assets are considered good hedges against changes in pension liabilities. However, according to a study by Credit Suisse (2017), Swiss pensions reportedly reduced their share of fixed-income securities in favour of more risky assets such as stocks, real estate and alternative assets, instead of allocating more bonds to hedge liabilities against a further drop of interest rates. While the reduction of

[1] Further details are provided in Chapter 3.1.

bonds may have been in expectation of rising interest rates, Swiss pensions experienced a lengthy period of low interest rates, exposing pension liabilities to even more interest rate risk.

Nonetheless, this environment of low interest rates may have even enforced the pension manager's decision to reduce allocation to fixed-income assets. Historically, the Swiss pension scheme relies substantially on gains on the capital market as a so-called third-party contributor. While long-term bonds may be a good tool to mitigate the interest rate risk of pension liabilities, they often yield negative nominal rates over the past recent years. In fact, as of the time of writing, Swiss 10 year government bond yields are globally the lowest, overtaking those of Japan in early 2015 (FRED, 2020). As a consequence of their low or even negative yields, a large allocation to Swiss government bonds for the purpose to hedge liabilities may be expensive for Swiss pension funds. Therefore, Swiss pensions funds might find themselves in a dilemma between allocating bonds to hedge their liabilities and generating sufficient returns. Indeed, in a survey among Swiss pension managers, 93% of the respondents state the current low interest rate environment constitutes one of their main challenges they are facing (Credit Suisse, 2017). This burden might even be amplified as the Swiss pension regulator requires to pay a minimum interest rate on a contributor's account that, with 1.0%, is set (far) above a riskless market interest rate[2]. As Swiss pension funds compete on the amount of interest paid to contributors, they may want to pay even higher interest rates. Thus, given a period of low interest rates, pension managers might also have structural motives to reduce bond allocation in favour of more risky assets.

In a study on the financial health of Swiss pension funds, the Swiss pension regulatory authority OAK BV (2019) reports an imbalance of CHF 7.2 billion, as a consequence of increased liabilities mainly due to lower discount rates. Swisscanto (2019), one of the largest pension funds in Switzerland, proposes to close this gap by "optimising returns". They argue that returns may be improved by reducing the home bias, (i.e. allocation to domestic securities), increasing allocation to private markets and reducing the allocation to bonds. This proposal illustrates the problem Swiss pension managers are facing. Assets have to be allocated strategically to provide competitive financial performance and to satisfy the regulatory requirements in an environment of low interest rates. At the same time, pension managers have to consider liabilities and their corresponding funding risk. Thus, different approaches to overcome this dilemma may be considered.

[2]Potential implications of the regulatory minimum interest rate are discussed in Chapter 3.1.

1.2 Research Question

This study aims to explore the implications of some regulatory requirements and a prolonged low interest rate environment on the allocation strategy of Swiss pension funds. More specifically, this thesis seeks to contribute to following research question:

How can Swiss pension managers allocate their assets to maximise the financial performance while mitigating the underfunding risk of pension liabilities, given an environment of low interest rates?

This further implies whether pension funds benefit from allocating risky assets on the cost of near-riskless fixed-income assets and how this may affect the liability funding capabilities. In case they do benefit, it may be interesting to which extent diversification across international or alternative assets may contribute. Even more motivating is whether a pension manager has the ability to strategically select the right securities at the right time to outperform a pension manager who only seeks to hedge her liabilities. This, in turn, raises the question of whether risk tolerant investors are incentivised to seek high returns by frequently trying to time the market and therefore potentially imposing additional funding risk. On the other hand, pension managers may want to allocate risky assets without frequent adjustment to changing market conditions. A gambling for redemption effect may be particularly relevant in case the pension is already underfunded due to risen liabilities as a result of the low interest rates. To prevent a further increase in liabilities net of assets, a conservative pension manager, on the other hand, may want to fully hedge her portfolio against these risks. Therefore, we aim to study an investor in differently risky conditions as well as different risk and asset allocation preferences to get a better understanding of the potential benefits and disadvantages of the individual strategies.

1.3 Scientific Approach

The analysis in our study is based on established literature on asset-liability management that provides the foundation for the proposed allocation strategies. To derive conclusions within the requirements of a scientific study, we follow the specifications provided by research for experimental methods in business. This study pursues a deductive approach, which is considered as "the most common view of the relationship between theory and research" (Bryman & Bell, 2009). Based on existing literature and frameworks, this study deduces a hypothesis or research question (see previous Section 1.2) that is analysed empirically. Furthermore, the deductive approach of this study is linked to positivist research. A positive approach implies that the research is independent and objective in relation to its results and findings and thereby allows for generalisations within specific areas (Catterall, 2000). In addition, this study aims to fulfil primary criteria for the evaluation of research: reliability, replication, and validity. Reliability describes the consistency of the measures in this study such that the results are repeatable which is typically not an issue for financial time-series. Replication is closely related to reliability and implies that the research details procedure and methods such that the study can be replicated using the same methodology. Validity is concerned with the issue that potential findings must be adequate to test the hypothesis as well as the generalisations resulting from the analysis (Bryman & Bell, 2009).

Figure 1: The Process of Deduction (Bryman & Bell, 2009).

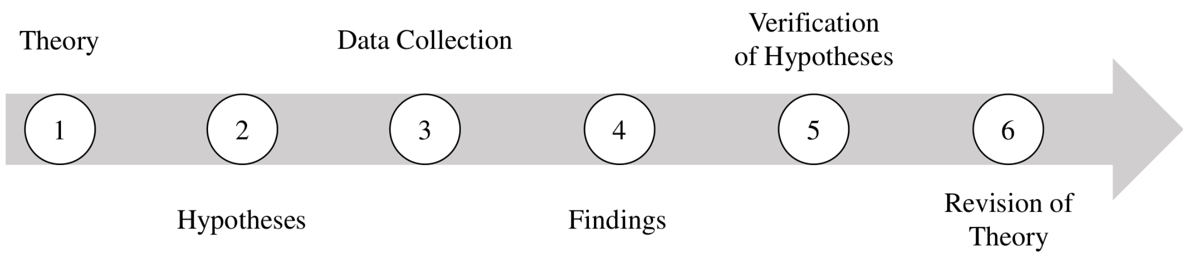


Figure 1 shows the linear process of a deductive approach. The foundation of the deductive approach is the theoretical understanding of the particular topic that the study seeks to address. Based on a conceptual framework (see Chapter 3.2), the research is deduced upon a hypothesis that will be tested throughout the work. The third step of our research requires an in-depth analysis to determine the "operational terms" (Catterall, 2000) for which data is collected. Subsequently, the data is translated into meaningful results by applying an appropriate method (see Chapter 7). In the fifth step, the findings are analysed to answer the research question within the predefined theoretical framework. The final step involves an inductive approach, in which the research turns the attention towards the origin and basis of the study - the theoretical framework (see Chapter 9.1) (Bryman & Bell, 2009).

Contrasting Figure 1, a deductive approach may not be an entirely linear process. Often, research appears to be an iterative process where researchers re-evaluate their approach based on external factors such as new theoretical ideas, the relevance of the dataset or missing data for the corresponding hypothesis (Bryman & Bell, 2009).

1.4 Structure

This study is organised as follows: Chapter 2 is dedicated to giving an overview of the general mechanics of pension funds as well as on distinctive features of the Swiss pension scheme. Chapter 3 describes in detail the two pillars our analysis is built on, the Swiss pension regulations and the proposed asset allocation strategies that pensions might undertake. In Chapter 4, we discuss previous findings and non-findings in relation to our study. During the subsequent Chapter 5, we shortly summarise the empirical asset allocation of Swiss pension funds over the past years and its implication on pension's performance. Chapter 6 comprises a description of how we derive the data we use for our analysis. Importantly, it includes a detailed illustration of how the data is adjusted to resemble a low interest rate environment. Our research methodology is described in Chapter 7, whose results are presented throughout Chapter 8. In Chapter 9, we discuss the implication of these results, limitations of our research as well as the potential for further research. Finally, the study is concluded in Chapter 10.

2 Introduction to Swiss Pension Funds

In this chapter, we outline the general purpose of a pension system and provide an overview of the fundamental mechanics of the pension industry. Subsequently, we introduce specific features of the Swiss pension fund system. Finally, we discuss some of the challenges that Swiss pension funds are currently facing besides the low interest environment outlined in Chapter 1.1.

2.1 Pension Fund Fundamentals

A pension system fulfils the purpose of securing a minimum income for all pensioners during their retirement time. The system is set up to reward previously working individuals with ensured post-retirement earnings which are similar to the individuals' former living standards. Besides, it also aims to support people who have not been able to work due to different circumstances. The pension system facilitates consumption equalisation by requiring people to deposit money for their retirement. This allows individuals to eliminate future income uncertainties and to actively plan their post-employment life. One can argue that this social balancing system leads to an increase in overall wealth, as, on the one hand, it creates the foundation of labour peace through social partnership and, on the other hand, increases the purchasing power of retired individuals. The pension system is operated by so-called pension funds, which can either be a part of the employer's organisation or an independent institution. The employee's post-retirement ensured financial income will be financed by periodic contribution payments through the employee and/or by the employer. The function of a pension fund is to manage and invest the deposited assets during their working lifespan in order to pay retirement pensions or the collected retirement capital.

Pension systems of different countries vary in their characteristics. However, pension plans can be divided into two categories. Capital-based pensions, commonly referred to as defined contribution [DC] plans, are funded by the employer and/or employee via periodic payments as well as by realised returns on investments financed by previous contribution payments. The future benefits are based on accumulated capital at the retirement age. Recently, DC plans have become increasingly popular and are currently the dominant form of plans in the private sector on a global level. This plan type grants employees more flexibility in planning their retirement wealth as well as in receiving tax benefits. However, pension funds do not have any obligations regarding the performance of a pensioner's managed capital nor ensuring sufficient funding for the post-retirement life. This construct favours pension funds significantly, as the industries greatest risk exposure, the investment risk, can be transferred to retirees. Another common type of pension plans are salary-based pensions which are referred to as defined benefit plans [DB]. These plans provide employees with an ex-ante defined and guaranteed fixed income after their retirement. Retirement payments are based on the individual's salary and, if provided by the employer, they may depend on the years of employment at the company. Therefore, the employee may have little to no control over the retirement fund. The pension fund or the employer is responsible for the asset allocation and distribution of the total contribution payments. As a consequence, pension funds carry investment risks. DB plans can be found more frequently in the public sector than in the private sector.

In this section, we outline essential balance sheet items of a generic pension fund and the reasons for fluctuations in these items. The asset side of a typical pensions fund's balance sheet aims to reflect the fair value of a pool of assets at the reporting date. Cash, equity and fixed-income securities as well as alternative investments are considered to be the major positions. Generally, there are three main sources for variations of this asset pool. First, a regular inflow of contributions which initially increase the cash position and will later be turned into investments. Second, realised returns on these investments lead to variations in the fair asset value. The last major source of a balance sheet's variation is a pension fund's various payment obligations. These may either be in the form of retirement expenses or, in exceptional cases, transfers of an insured's total capital when switching pension funds, buying real estate or founding a company[3]. The liability side of a pension fund's balance sheet is the result of an actuarial calculation based on several estimated inputs such as life-expectancy, salary rates, inflation, and further economic key figures. The most critical items of the liabilities involve the pensioners' retirement assets, reserves for investment fluctuations, and retirement payment obligations. We identify three main causes that account for frequent movements of a pension fund's obligations.On the balance sheet, future obligations are reported as their present value by applying a predefined discount rate. In Switzerland, each pension fund individually determines a technical discount factor for future cash flows are discounted. This will be discussed in more detail in Chapter 3.1. The present value of the liabilites is continuously adjusted either due to the course of time or to variations in discount rates. Moreover, changes in actuarial assumptions can lead to significant positive or

[3]These options are subject to Swiss legislation (BVV2 §28, 2013). They can vary for other nations.

negative adjustments. Finally, cash outflows will reduce the liabilities as a counterpart of the outflowing assets.

2.2 The Swiss Pension System

The Swiss pension system is based on three pillars. Payments into the pillar system start with the 25th birthday and last until the retirement age, which is 65 for male and 64 for female Swiss citizens. The first pillar is the state pension, the so-called old-age and survivors' insurance [OASI]. It is statutory and guarantees the minimum subsistence level for pensioners. The pension can account for CHF 2,350 maximum per month, which is below the minimum salary in Switzerland. Contributions to the OASI are directly deducted from the monthly salary and are equally split between employers and employees. Also disability insurance is included in the first pillar. It compensates individuals for potential financial consequences if their work abilities are affected due to health restrictions. Generally, the financing of this pillar is based on a distribution process, set up through a generation sharing process in which the working population contributions are approximately equivalent to the pay-outs of the retirees.

The second pillar is the occupational benefit plan, commonly known as pension funds. In contrast to the first pillar, occupational pensions are an entirely self-funded system in which individuals save and pay directly for their pension benefits in the course of a capitalisation process. In Switzerland, the participation in an occupational benefit plan is mandatory with a minimum statutory contribution rate in relation to the contributor's age. The occupational provision plan complements the OASI. Together, they cover approximately 60% of the last salary received prior to retirement. However, there are optional pension plans in place if an individual desires to devote more capital for their retirement. Only the second pillar is within the scope of this study as it resembles the traditional set-up of a pension fund introduced in Chapter 2.1.

The third pillar comprises private provisions and aims to complement the remaining pillars with various forms of additional capital accumulation in the form of securities, savings accounts, or life insurances. In contrast to the first and second pillar, participation is optional. The private provision pillar is divided into two sections. Pillar 3a has been created to incentivise the working population to further invest in their retirement as contributions that are made as private provision are eligible for tax deductions. These payments are capped and will be devoted to predefined investment mixes of various securities. Pillar 3b mainly covers other special constructs which resemble the form of life insurances, trust accounts, and further investment deposits. Although pension funds, in addition to insurance companies and banks, offer to manage third pillar funds, these are not in the scope of this study as they differ significantly in their characteristics from traditional pension fund savings.

2.3 Current Challenges for the Swiss Pension System

In this section, we will briefly introduce further challenges the Swiss pension system is currently facing. The severe implication of a low interest environment on pension funds has been discussed in Chapter 1.1 and is not covered in this section. In 2018, the Swiss federal office for statistics registered 1,562 pension funds in Switzerland with a total investment volume of CHF 876 billion. In total, over 4.2 million people are insured and actively contribute, while almost 800 thousand retirees are receiving pension payments. Over the last decade, the total investment volume increased by 63% from CHF 539 billion, while the number of pension funds decreased by 35% to 2,435 registrations. Avenir Suisse (Cosandey, 2013) determined that since 1998 the registered number of pension funds dropped on average by 4.2% per year. The decline is particularly severe for small pension funds that insure less than 100 individuals. In contrast, the number of more sizeable pension funds with over 1000 insured persons rose on average by 1.5% per year. This may be attributed to the increased cost as a result of the rising regulatory complexity (Swisscanto, 2019).

Pension funds are considerably affected by the development of the life expectancy, the economy, and society. Over the last decade, a consistently increasing amount of people reached the retirement age and are thus eligible for retirement payments. In 1948, the remaining life expectancy of a 65-year-old person was just under 13 years. By today, this life expectancy has grown to 21.3 years (Credit Suisse, 2017). This poses a significant challenge to the financial health of the second pillar. If the promised retirement payments remain unchanged, the risk may increase that the life retirement capital is not sufficient until the point of death. Once the capital is exhausted, further pension payments will have financial consequences for the pension fund. However, if some of the life retirement capital is still left at a person's point of death, pension funds have the legal right to collect the money. On average, pension funds are negatively affected due to the increasing life expectancy. Furthermore, the birth rate declined during the last decades. In 1948, on average a woman gave birth to 2.54 children, whereas today this number dropped to 1.52 children (Credit Suisse, 2017). Furthermore, the so-called baby boom occurred during 1954 and 1964 with a substantial temporary increase in births, and this generation is now slowly embracing the retirement age. As a result, the number of retirees is growing faster than the number of people going into employment. Sixty years ago, there was an average of about six workers per pensioner. Today only 3.3 workers per pensioner are registered, with a continuously decreasing trend. As a result, the advantages of an inter-generational provision system of Switzerland slowly diminish as pension funds need to expect a substantial capital outflow in the near future as the contribution payments may not be able to cover the retirement payments, leading to potential liquidity issues. In a study conducted by Credit Suisse (2017), it is estimated that in 2015 CHF 5.3 billion have been redistributed from active insured individuals to pensioners. Over half of the pension funds have identified this issue as their primary concern. Swiss pension funds also worry about the current trend of part-time work. The Swiss pension system was conceived at a time when marriage and traditional roles between men and women represented the prevailing social model. However, society and the structures of employment changed, and thereby challenges the functionality of the old-age insurance system. Since the scope of old-age provision largely depends on income, part-time employees with low wages are particularly at risk of underfunding their occupational pension plans. The legislature is challenged to modify the system in the near future to allow more flexibility for the pension planning of part-time employees before and to prevent the pension system from being affected negatively (Credit Suisse, 2014).

3 Theoretical Framework

This Chapter aims to frame the theoretical setting of our study. First, we introduce the country-specific regulatory framework and its potential impact on investment activities of Swiss pension funds. During the second section, we discuss implications of investors who manage assets from a liability-driven perspective in an environment of low interest rates. Given these circumstances, we propose different strategies and their distinctive features a pension manager may want to pursue.

3.1 Swiss Pension Regulatory Framework

A distinction between DB and DC pension plans is essential for liability-driven investors as it implies fundamental differences from a risk-bearing perspective. In DC plans, contributions to the retirement funds are predefined and the insured individuals carry the investment risk. Contrary, DB plans describe predefined retirement payments where the market risk bearer is the pension fund. Even though in Switzerland, the pension scheme resembles mostly DC plans, the government ensured through special mechanisms manifested in the legislature that the risk-bearing party is the pension fund. These mechanisms transfer some of the DB characteristics into Swiss DC plans (White, 2002). This DC-DB hybrid scheme is the outcome of a long-lasting political debate between pre-existing pension funds, unions, companies, and employers as well as the impacts of the oil crisis in 1974.

One typical DB characteristic embedded in Swiss DC schemes is a conversion rate. It is used to calculate the size of the pension benefits based on the accumulated capital at retirement. It is worth noting that the conversion rate is only applicable for the so-called obligatory contribution, which consists of mandatory pension fund payments with a yearly salary up to CHF 84,600. If the annual income exceeds the threshold, contribution payments based on the salary surplus will be categorised as supplementary contributions. The lower bound of the conversion rate for the mandatory contribution is determined by Swiss law and has last been changed in 2004 to a level of 6.8% (BVG §14 Abs. 2, 2013). The yearly retirement payments can then be calculated with a multiplication of the conversion rate and the accumulated capital. In a numerical example with an accumulated capital of CHF 1 million, this would result in a guaranteed yearly retirement payment of CHF 68,000 until death. Pension funds are obligated to further ensure the payments with its own assets in case the retirement capital is not sufficient for all payments until death. The minimal conversion rate implies a life expectancy after the retirement of 15 years, which is not in line with the current life expectancy of 21.3 years in Switzerland (Credit Suisse, 2017). The supplementary contribution does not have a boundary defined by the legislature and can be determined by the individual pension fund. It is typically lower than its obligatory counterpart in order to balance out the high costs related to the obligatory contribution. The conversion rate for the supplementary contribution is currently set between 5% and 5.5% (Swisscanto, 2019). This mechanism will not be implemented in this study, as no pay-outs are be modelled. However, it illustrates that Swiss DC schemes also carry the most important DB characteristics, defined retirement payments.

Another important DB feature embedded in the legislation is that all Swiss pension funds are required to guarantee a minimum interest rate, commonly referred to as BVG minimal interest rate, to be accredited to the insured individual savings account. The BVG minimum interest rate is determined by the Swiss government and is based on the expected return of government bonds, corporate bonds, shares, and real estate (BVG §15 Abs. 2, 2013). Similar to the conversion rate, the BVG minimal rate is only applicable to the so-called obligatory contribution category and is typically set higher than current government bond yields. As a result, pension funds may be incentivised to further invest into other asset classes that exhibit higher expected returns than government bonds, implying higher volatility on the assets and consequently more risk. The minimum interest rate attributed to the individual savings account was 4% from 1985 until 2002 and has been steadily lowered in recent years to the current level of 1% in 2019. If a pension fund realised investment returns above the minimum return, they can choose to redistribute part of the return by increasing the interest rate on the retirement capital. Each institution's board determines its interest rate applicable to the saving accounts, which is fundamental when pension funds compete for customers in the industry. The minimal interest rate for the supplementary contribution category is not regulated and is again determined by the board of each institution. The rate is generally lower than the BVG minimum interest rate and amounts to an industry average of 0.25% for the last three years (Swisscanto, 2019). In this study, we will only consider the framework laid out for the mandatory contribution.

Another unique feature of Swiss pension regulation is the valuation of pension liabilities. According to international accounting standards, the pension's fund provision capital should be evaluated on a discount rate determined by a basket of current bond yields on the market. When future pension payments are equated with coupons of fixed-income securities, pension liabilities can be valued with the same logic as coupon bonds. The present value of the pension liabilities can then be determined by the total present value of all future cashflows. This technique is based on the IAS19 regulation and implies that pension funds value their liability according to the current market conditions. In contrast, the Swiss mechanism discounts liabilities using a flat constant discount rate, the so-called technical interest rate (BVG §52e Abs. 2, 2013). This rate is used to discount the pension fund's future obligations and accruals, not to be confused with the retirement assets and the BVG minimal interest rate. The liability discount rate is the same for all maturities and does not reflect the market yield curve. Furthermore, this rate can be determined by the pension fund itself, without significantly deviating from a reference rate published by the legislature. The formula for the reference rate is set by experts and corresponds to the addition of one-third of the current 10-year government return and two-thirds of the average pension fund's return over the last 20 years (FRP 4 §8, 2015). However, the reference formula is controversial in the Swiss pension industry, since the technical discount rate of every Swiss pension fund is currently lower than the reference rate (Hodel, 2017). Generally, the logic behind the technical discount rate is to represent a realistic long-term return expectation of a pension fund. Since the financial crisis, the technical interest rate has consistently declined to an industry average of 2%, half of its previous level, which was mainly driven by the challenging low interest rate environment. This declivity draws negative implications for the funding ratio as well as the conversion rate.

The funding ratio is a key figure in the industry and is calculated by dividing the pension funds' asset value by the value of its liabilities. A funding ratio above one indicates that the institution is able to cover all its future expenses and vice versa. In Switzerland, the legislature requires the calculation of the technical funding ratio (BVV2 §44, 2013), which corresponds to the net assets divided by actuarially valued liabilities using the technical discount rate. Declining technical discount rates increase the liabilities which, in turn, decreases the technical funding ratio, ceteris paribus. This may have negative implications on the general trust in the pension fund. As a rule of thumb, the technical funding ratio drops by 5% for a 0.5% reduction of the technical discount rate. However, Schmid (2011) states that the technical funding ratio is not suitable as a risk measurement figure, as only the asset side is dependent on market fluctuations. Furthermore, since each pension fund can individually determine their technical discount rate, it leads to the lack of transparency and comparability of discount rates. Many experts have drawn attention to this problem and claim a change in the legislature to eliminate estimation inaccuracies in the technical discount rate (Hodel, 2017). In our study, we use the economic funding ratio instead of the technical funding ratio to ensure a non-biased performance measurement. By applying the economic funding ratio, both sides of the balance sheet are valued based on current market conditions. The liabilities are discounted according to the market interest rates; In this study, the corresponding rate is the 10-year Swiss government yield to account for the long maturity of pension liabilities. An economic funding ratio answers the question of whether the pension fund's capital covers the promised retirement benefits in market terms at the time of valuation. In the following, all funding ratios mentioned in relation to actual Swiss pension funds are technical funding ratios, and all mentioned funding ratios in relation to the methodology of this study are of market-based nature. Primarily in times of a low interest rates, the (risk-free) market interest rate resides several hundred basis points below the technical discount rate. This implies that the reported technical funding ratio may be substantially higher than the economic funding ratio, as the present value of future obligations of the economic funding ratio is calculated with a lower discount rate leading to relatively higher liabilities.

Recently, many Swiss pensions have reduced their technical discount rate to relieve some of the long-term pressure on the liabilities, as a lower rate can be used to verify a reduction for the conversion rate for the supplementary contributions category. In general, the conversation rate is lowered by approximately 0.3% for every decrease of 0.5% of the technical discount rate. Since adjustments to the technical discount rate are subject to strong implications in terms of conversion rate and valuation of liabilities, the discount rate is closely monitored by regulations experts to ensure that the mechanics are not misused. Another implication is that Swiss pension funds are required to use the technical discount rate, which can lead to statements of under- or overfunding if a company also reports under IAS19 (Hodel, 2017).

The asset substitution problem in the theory of corporate finance describes how companies with a debt-overhang are incentivised to invest in riskier assets than desired by bondholders. Debt-overhang expresses a condition, in which a large amount of debt prevents a company from further borrowing money. By allocating resources in riskier projects, the company can partially transfer its downside risk to the debt issuers, as the equity value is floored and cannot become negative. The increased risk would effectively lower the fair value of debt as well as raise the fair value of equity (Gavish & Kalay, 1983). This implication may be transferred to an underfunded pension fund, which could also be incentivised by riskier investments, transmitting its risk on pensioners and increasing its fair equity value. However, due to the severe consequences for society if a pension fund goes bankrupt, the Swiss regulation requires that pension funds invest within some risk boundaries by setting up investment policies. The objective is to ensure one of the most substantial risk-mitigating measures in finance: diversification. The legislature further requires pension funds to limit its investments in debt instruments of a single entity to 10% (BVV2 §53ff., 2013). Furthermore, it is required that a pension fund may not invest more than 50% of its assets in equities, of which only 5% of its assets can be devoted to a single security. The investments into real estate are capped for single properties at 5% and in total at 30%, of which maximally one third can be allocated in foreign real estate. Furthermore, category caps are enforced for covered bonds and alternative investments with 50% and respectively 15% of the total assets.

If the technical funding ratio of a pension fund sinks below 90%, the board is obliged to inform the supervisory authority as well as customers or employees of the pension fund and has to develop a restructuring plan (BVV2 §44, 2013). In the reorganisation plan, the pension fund has to reach a surplus within five to seven years, in severe cases a maximum of ten years. The most common remedial measure is to lower the minimal interest rate on assets for the restructuring period. The BVG minimum interest rate can be reduced by up to 0.5% below its current value (BVG §65d, 2013). Further measurements involve remedial contributions from employers and insurers or special contributions from employers. However, if a pension fund is underfunded, it may not reduce the guaranteed pension payments at the time of retirement. If a pension fund is not able to meet its liabilities during the restructuring plan or even goes bankrupt, the BVG security fund comes into effect (BVV2 §44, 2013). The main task of the BVG security fund is to guarantee the benefits of all insured persons in the 2nd pillar in the event of insolvency of pension funds.

3.2 Asset Liability Management in a Low Interest Rate Environment

Asset-liability management [ALM], sometimes also referred to as liability-driven investing, has received increased awareness over the last decade. As its name implies, the central motive of ALM is to allocate assets relative to the investor's liabilities as a benchmark. Thus, in contrast to an asset-only investor whose primary concern is to maximise the Sharpe ratio of the return on assets, the main objective of an ALM investor is to ensure that liabilities are sufficiently funded in any market condition.

The increased attention towards ALM, in particular for institutional investors with guaranteed long-maturity liabilities such as life insurers and DB pension funds, stems from a general decrease in market interest rates. Given a fixed future stream of pay-outs, a reduction of its discount rate would, ceteris paribus, lead to an increase in the current market value of these pay-outs. Liabilities of Swiss pension funds typically have a weighted average life of between 12 and 20 years (KPMG, 2019). As discount rates have an exponentially increasing impact on distant future cashflows, Swiss pensions are exposed to significant interest rate risk. As a consequence of the recent decline in interest rates and a corresponding increase in the market value of liabilities, pension managers have to pay increased attention to ALM to prevent a further decrease in the funding ratio.

A low interest rate environment may also impact the asset side of a pension scheme's balance sheet. Given an expected continuance of low interest rates reflecting the economic growth, expected future returns on assets may be smaller as well (Schich et al., 2011). Hence, a low interest rate environment might impose a burden on both the asset and liability side of the pension's balance sheet. This becomes particularly challenging if the market returns on assets fall below the minimum return that is required to cover the BVG minimum interest rate on the pension's contribution capital.

Generally, an ALM investor could invest in assets that perfectly replicate her liabilities. Any shock on the pensions' liabilities would then have an equivalent shock on the assets without an effect on the funding ratio. This can be done ex-ante by choosing risk-less assets whose cashflows are accurately replicating those of the liabilities, assuming that the liability cashflows are known. This strategy is commonly known as "cashflow matching". It is a simplistic, almost assumption-free, risk-minimising technique to accommodate the substantial market risk of pensions' long-term liabilities. However, as suitable securities that match these cashflows are limited on the market, a pure cashflow matching strategy is often impractical. Even if enough appropriate securities were available, a portfolio that exactly matches the payout-streams would require relatively high upfront cost as all cashflow-matching securities have to be purchased beforehand. A less strict version of the cashflow matching approach is the so-called “dedication”. In a dedicated bond portfolio, coupons are accumulated until the liability date, and subsequent cashflows are used for future liability requirements (Fabozzi et al., 1990; Gold & Peskin, 1988). In essence, a dedicated bond portfolio is an allocation method that minimises the cost of the bond portfolio under the constraint of matching liability cashflows. As the portfolio is chosen ex-ante, no further adjustments are required to ensure that future pay-outs are closely matched.

If an ALM investor is only concerned about specific risks such as interest rate or inflation risk affecting the liabilities, she can also protect the portfolio against these individual risks. This strategy is commonly referred to as “immunisation”, first formulated by Fisher and Weil (1971). It is not required to match cashflows of assets and liabilities when applying the immunisation technique. Instead, only the sensitivities of the portfolio value with regards to the relevant risk-factor need to be matched. If pension managers want to immunise their portfolio against interest rate risk, the sensitivities to changes of the interest rate – the duration – of assets and liabilities must be equal.

Duration is an early concept to measure the price volatility of bonds suggested by Macaulay (1939). The Macaulay duration of a bond is the weighted average maturity of the present value of coupon payments and the principal. Hence, a zero-coupon bond will always have a Macaulay duration equal to its maturity. A more precise measure of a bond’s interest rate sensitivity is the so-called modified duration. It takes the varying schedules of coupon payments into account by directly measuring the bond’s interest rate sensitivity as the first derivative of the bond’s price with respect to its discount rate. Thus, the modified duration is equal to the Macaulay duration if interest rates are continuously compounded. In the following part of this study, we refer to modified duration only as duration. The duration of a portfolio is simply the weighted average of the individual asset durations.

As prices do not change linearly relative to changes in interest rates, a standalone duration measure is a reliable estimation for small interest changes only. The second derivative of a bond’s price function with regard to its interest rate is a measure of its convexity; or the duration sensitivity of interest rate changes. Interest rate risk can be more accurately measured by taking the non-linear property of a bond’s price function into account. Thus, by ensuring the asset convexity to match at least that of the liabilities, the duration gap cannot become negative. That is, the asset duration would not fall below the liability duration.

Immunising a portfolio against interest rate changes by matching the duration of assets and liabilities is not without shortcomings. The immunisation of liabilities against interest rate risk implicitly assumes that the yield curve is flat. This is inevitable as the duration measure – also convexity – takes only one interest rate into account. Hence, when we refer to an interest rate change, we assume that the whole yield curve is shifting parallelly[4]. In addition, duration matching assumes that interest rate changes are instantaneous and infinitely small. Naturally, this assumption is uncommon in practice. As we are using monthly returns in this study, we do not expect large changes in interest rates. One major point of criticism is the need for a constant rebalancing of the duration matching portfolio that results from periodic changes of durations and convexities (Gajek et al., 2005). As discussed in further detail in Chapter 4 below, this periodic rebalancing can become very costly, especially if interest rates are decreasing. Maloney and Logue (1989) argue that the cost of rebalancing may make the duration matching approach more expensive than matching the liability cashflows upfront.

Typically, an immunisation portfolio only includes fixed-income assets. A pension manager, however, may want to include riskier assets to meet or exceed the minimum interest payable or to take advantage of the upside potential of assets relative to the pension liabilities. Immunising the interest rate risk of a portfolio that also includes equity assets would be appealing. This would require estimating the assets' interest rate sensitivity. However, this is considerably more complex than for bonds, as cashflows of risky assets, such as stocks, are usually not pre-determined, and interest rates may affect both cashflows and their discount rate. In Chapter 4 below, various attempts to estimate equity duration are discussed. However, we argue that these do not satisfy the needs of ALM managers to immunise long-term portfolios.

We refer to the activity of an ALM investor who chooses assets to partially or fully mimic the market value of future pay-outs as liability-hedging. A cashflow matching or immunisation approach that includes fixed-income assets only and aims at keeping the ratio of assets and liabilities close to one may be considered as a conservative or risk-mitigating strategy. However, a pension manager might seek to maximise the funding ratio by trying to estimate the return of a

[4] In practice, a pension manager also cares about the yield curve mismatch. If the short and long maturity interest rates move in opposite directions, the duration measure might stay the same. Hence, for an immunisation against non-parallel interest rate changes, the duration must be matched along the entire yield curve.

portfolio that exceeds the return of the liabilities. We refer to this approach as market-timing or risk-taking strategy. We define market-timing more broadly as periodic and frequent buying and selling of securities in order to outperform a benchmark by estimation of future returns and their variability. This naturally requires to make some assumption on the future distribution of both assets as well as the benchmark which in this study is the projected value of pension liabilities.

ALM can also be seen as a portfolio choice problem that includes both fixed-income and non-fixed income assets based on their return potential as well as their liability-hedging capabilities (van Binsbergen & Brandt, 2011). As such, one way of approaching ALM may be to consider a conventional asset-only portfolio optimisation where the investor is holding the liabilities as a short-position asset. As pension manager are typically long-term ALM investors, the portfolio selection problem does not include cash as a risk-free asset. The reason is that cash as a short-term money market instrument is not truly risk-free and will be discussed in further detail during subsequent chapter.

Besides taking the preference to match liabilities into account, this approach also incorporates a motive to time the market given the assumption that risk-premia are time-varying. A risk-affine ALM investor might want to engage in market-timing activities to maximise the short-term asset returns relative to those of the liabilities. Analytically, a portfolio can then be decomposed into a speculative portfolio and a liability-hedging portfolio similar to Campbell and Viceira (2005). While the former is dedicated to providing access to risk premia, the latter is needed to accommodate unexpected changes in risk factors that affect liability returns[5]. Depending on her risk aversion, a pension manager would then allocate more weight towards the speculative portfolio if she is risk-affine and less otherwise. Thus, each portfolio serves distinct objectives of a pension scheme: on the one hand, the goal to provide sufficient funding of future pay-outs and, on the other hand, the motivation to maximise the return on assets that is paid out in exceedance of the minimum requirement. We measure these two motives in terms of returns that are distributed back to contributors as well as the funding risk of liabilities.

An essential precondition to be able to time the market is the capability to estimate the distribution of future returns. However, there is substantial uncertainty if and to which degree asset returns

[5]Interestingly, Swiss pension funds appear to be among the least likely to split their asset allocation into a speculative portfolio and a liability hedging portfolio according to a survey of mostly European pension funds conducted by Martellini et al. (2014).

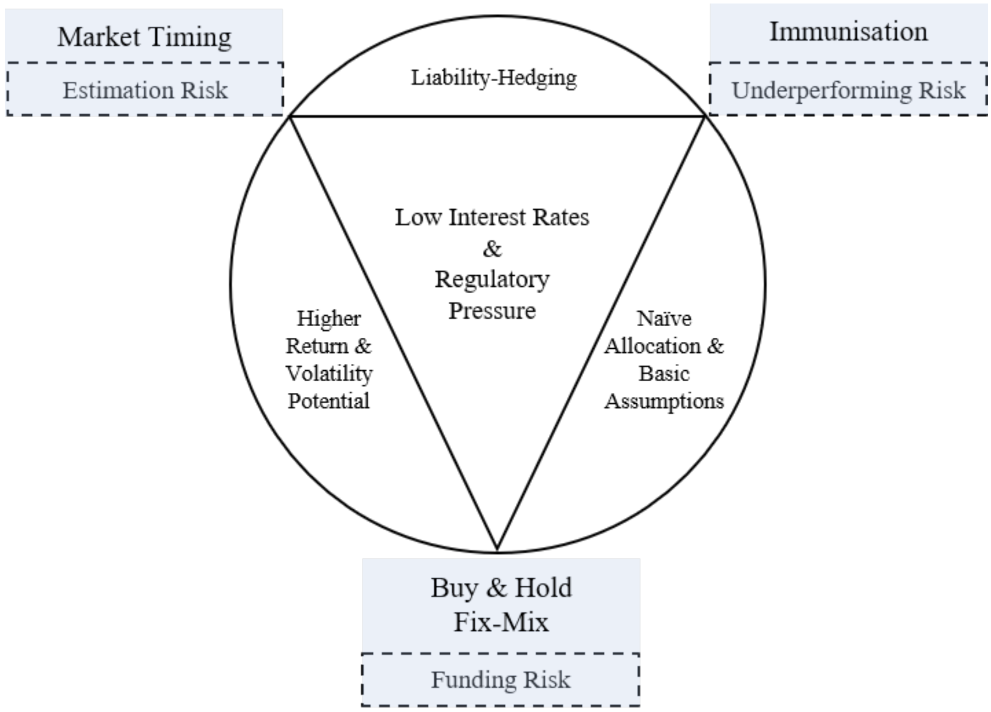
can be predicted, making it challenging to identify the optimal market-timing portfolio. If expected returns cannot be reliably estimated, a market-timing strategy might be erroneous and even be outperformed by a more simplistic approach that requires fewer assumptions. The issue of return predictability and its potential impact on portfolio selection is elaborated in further detail in Chapter 4 below.

A pension manager may not be confident in the predictability of returns to be able to consistently time the market, yet still want to earn risk premia of equity assets. She then might engage in simple buy-and-hold or fix-mix strategies, disregarding that risk-premia are time-varying. Here, initial portfolio weights are chosen at the beginning of the investment horizon. While a fix-mix strategy requires periodic rebalancing to keep these weights constant, a buy-and-hold strategy simply involves the initial purchase of the portfolio, which remains unbalanced throughout the investment horizon. Constant rebalancing of the fix-mix strategy is consistent with a constant relative risk aversion [CRRA] assumption and thereby may exhibit smaller risk relative to a buy-and-hold approach (Infanger, 2008). By allocating assets naïvely (i.e. without further assumption on return distribution), the need to periodically estimate a distribution of future returns becomes obsolete. Thus, the immediate appeal of these naïve approaches is that portfolio selection is known ex-ante and estimation errors of return predictions can be avoided.

There is a substantial body of empirical research investigating the performance of actively traded portfolios that involve market-timing features relative to simple buy-and-hold and fix-mix strategies. Some of these findings are discussed in the subsequent Chapter 4.

Both fix-mix and buy-and-hold strategies are static by nature as portfolios are selected ex-ante and thereby are either directly or indirectly (by means of fixed portfolio weights) pre-determined. As a consequence, these approaches cannot involve any dynamic risk management methods. The same also rules out the periodic conditioning of portfolio selection on the development of the pension's liabilities. The consideration of liabilities can therefore only be incorporated into the initial choice of the portfolio at the beginning of the investment horizon. Thus, it can be regarded as an ALM strategy to a limited extent only. Nevertheless, asset allocation strategies of pension managers often exhibit characteristics of buy-and-hold investors or determine long-term target weights in practice (Badaoi et al., 2014; Hoevenaars et al., 2008).

Figure 2: Characteristics of the Proposed Asset Allocation Strategies



All the strategies discussed above have their distinct advantages and disadvantages for a Swiss pension manager in light of low market interest rates and minimum return requirements. A conservative approach to immunise the portfolio against interest rate changes is designed to ensure sufficient funding if interest rates are declining. The approach to match interest rate sensitivities of assets and pension liabilities is straightforward and requires few assumptions. However, it may as well be expensive, and returns might be below the minimum rate required by the regulator. An approach to increase funding by trying to time the market, on the other hand, has the potential to provide sufficient returns that exceed those of the liabilities. Nevertheless, this requires the ability to reliably forecast expected returns which may turn out to be difficult to achieve. If a pension manager desires to include risky assets to the portfolio, naïve buy-and-hold or fixed-weight approaches do not require an estimation of the future return distribution. Nonetheless, these approaches appear to be static from an ALM perspective, as an integration of the liabilities as a benchmark into the allocation process is not feasible. Therefore, both fix-mix as well as buy-and-hold strategies are considerably exposed to funding risk.

Of course, these allocation strategies are extreme cases in their pure form, of which pension funds in practice may want to integrate partial features only. This could be temporary, between investment horizons or as weighted averages of their total portfolio. For example, pension managers might set a long-term target portfolio composition of five years with constant weightings. During this horizon, they might deviate from these fix targets for tactical market-timing reasons. Otherwise, they may simply hold a diversified portfolio without frequent rebalancing. While a constant share of the portfolio might generally serve as a speculative portfolio allocating assets that provide risk premia, the other part of the portfolio may be dedicated to fixed-income assets for liability hedging-hedging purposes.

4 Literature Review

In this Chapter, we discuss previous findings and indications on pension funds motives to allocate assets to more or less risky assets that may incentivise pensions towards one of the aforementioned strategies. It will be shown that long-term, liability-driven investors exhibit distinct objectives and risk-characteristics as opposed to common asset-only investors. Further, pensions may face regulatory inducements to increase the riskiness of their assets for enhanced funding reports even though their market-timing capabilities may be limited. While some scholars find market-timing portfolios to beat naïve asset allocation, others suggest the opposite. Based on findings on equity interest rate sensitivities, we contend immunisation portfolios that include risky assets as impractical for ALM investors. Finally, we present arguments why ALM investors might withhold from allocating less risky assets in a low interest environment.

The literature on strategic asset allocation that includes liabilities is little overall, and naturally less during periods of low interest rates in particular. This is mainly due to two practical and somewhat related facts. First, historically seen almost no regulatory regime or accounting framework evaluated the fair value of pension liabilities closely (Hoevenaars et al., 2008). As a result, investors' decision on strategic asset allocation was primarily considered in an asset-only setting. Notable exceptions being Sharpe and Tint (1990) and Leibowitz (1987) who early on developed a single-period optimisation model explicitly taking pension liabilities through an asset-liability surplus framework into account. This neglect of liabilities, however, has not changed until recently, as short and long-term interest rates have been declining globally, often to a level just above zero or even negative rates such as in some northern European countries or Switzerland. This prolonged low interest rate environment led to the increased attention of regulators and scholars to pensions' liabilities and discount rates and their consideration within investors' strategic asset allocation decisions.

Empirical studies on optimal asset allocation are often based on the early work of Merton (Merton, 1969, 1971, 1973) and his theoretical concept of multi-period portfolio choice. If investment opportunities are time-varying, investors seek to manage their exposure to shocks in prices of their financial assets and therefore giving rise to intertemporal hedging demand. This implicitly assumes that the investor believes in her ability to time the market. Amongst others, Fama and

French (1989) have established an empirical relationship between macro-economic variables and future expected returns supporting the argument of predictability of asset returns. Campbell and Viceira (2003; 2002) have developed an approximate analytical solution to Merton's intertemporal model that could not yet be solved in closed form. Even though a long-term asset-only investor is analysed in their model, interesting inferences can be drawn from their findings. The authors are using a vector autoregression approach to establish a linear-quadratic relationship between portfolio weights and state variables. In particular, excess bond- and stock returns as well as the treasury rate are estimated by several predictor variables, namely, the short-term interest rate, the dividend-price ratio and the yield spread between short-term and long-term bonds. Due to their analytical approach, no short-term or borrowing constraints are applied. Using quarterly US market data from 1952 to 1999, they find a significant negative relationship between stock excess returns and the lagged nominal short-term interest rate. However, the coefficient for bond excess returns to the lagged nominal short-term interest rate is positive, also statistically not significant. Thus, for an optimal portfolio of an asset-only investor, the Campbell-Viceira approach indicates an increased allocation to a riskier asset class in favour of bonds when short-term nominal interest rates are decreasing, ceteris paribus. Bams et al. (2017) have replicated the Campbell-Viceira approach extending the sample until the last quarter of 2014. They show that from a market-timing perspective, bond allocation should have been underweighted relative to equity allocation since the beginning of the subprime crisis in late 2007 which the authors define as the start of the low interest rate environment. However, they find that pension fund in fact did the opposite and on average reduced equity allocation in favour of bonds.

Another interesting finding of Campbell and Viceira (2002) is that the optimal portfolio choice for a long-term investor is different than from the optimal allocation for a short-term investor. They combine a myopic portfolio, which is, in fact, a standard mean-variance portfolio, and a hedging portfolio that takes into account the hedging demand of a risk-averse investor facing time-varying investment opportunities. In contrast to short-term portfolios, they find that long-term investors replace the risk-free asset in their optimal portfolio allocation by long-term inflation-indexed bonds or nominal bonds in case inflation risk is low. This is not surprising as for long-term investors the risk-free asset is not risk-free as it has to be refinanced at uncertain future rates. As a consequence, a long-term nominal bond might bear even less risk as to the so-called risk-free asset.

Several scholars have studied pension funds from an asset-liability perspective. Schich et al. (2011) discuss the impact of a prolonged low interest rate environment on the financial stability of DB pension funds. They argue that low interest rates may affect both the asset and liability side of their business. The liability side through a lower discount rate leading to an increase in market value of the liabilities. If the duration of the pensions' assets is shorter than its liabilities, the market value of assets increases less than the market value of liabilities resulting in a decline of the funding ratio. On the other hand, in expectation of continued low interest rates, a lower level of interest income would lead to lower expected returns on assets. Both effects, a higher market value of liabilities and a decline in asset returns, may put pensions into trouble paying their guaranteed returns. The authors conclude that this may create incentives to increase exposure towards more risky investments to "gamble for redemption" as long as the regulator does not prevent these incentives.

Andonov et al. (2017) as well as van Binsbergen and Brandt (2011) study asset allocation incentives of US DB pension funds that are induced by the regulator. They both find that public pension funds are incentivised to increase allocation towards risky assets in order to improve their reported funding ratio as well as disincentivised to hedge interest rate risk. This results directly from the unique financial accounting principles. The rate for which public pension funds discount their liabilities is linked to the expected return. In contrast, US corporate pensions discount liabilities using corporate bond yields that are smoothed over various horizons depending on the regulatory regime. Thus, public pension funds profit from better reported funding if they increase asset risk. The same is true for corporate pensions if the liability discount rate is smoothed over long horizons. Furthermore, public and to some limited extend corporate pensions have no motive to the hedge interest rate risk of their liabilities as either expected returns or overly smoothed bond yields are used as discount rates instead of market interest rates. This shows an interesting problem: different regulations for liability discount rates have implications on the reported funding ratio. This potentially leads to adverse effects on asset allocation and liability-hedging motives and eventually the funding of liabilities on a marked-to-market basis. Therefore, US public pension funds are incentivised to allocate riskier assets and to try to time the market while pensions whose liabilities are market-based are condemned to hedge their liabilities carefully.

In a linear regression framework, Bams et al. (2017) study the asset allocation of US pension funds during a low interest rate environment. Their finding is in line with the regulatory incentives described above: public pensions have substituted bonds in favour of equity. On the other hand, US corporate pensions who do not benefit from more considerable asset risk have substantially reduced their exposure to equity and increased exposure to fixed-income assets instead. The authors also find that US public pension funds are severely underfunded compared to corporate pension plans whose liabilities are only moderately underfunded. They relate this difference to the regulatory differences of public and corporate pensions in the US that is also found by Andonov et al. (2017).

A first step to apply the ALM problem as an extension of Mertons's (1969; 1971), intertemporal portfolio selection problem has been undertaken by Merton (1993) where he studies a University's asset allocation decision to manage an endowment fund. Bridging the gap between the portfolio choice literature and asset-liability management of a pension scheme, Hoevenaars et al. (2008) and van Binsbergen and Brandt (2011) incorporate pension liabilities into a portfolio optimisation problem. While the former consider alternative assets in addition to traditional stock and bond allocation and solve the problem for an approximate analytical solution, the latter consider stocks and bonds only, but solve the dynamic programming problem numerically under various constraints.

Among alternative asset classes and for varying horizons, Hoevenaars et al. (2008) find that commodities provide good risk diversification but low liability-hedging capabilities due to its low market correlation. Hedge-funds have similar but less distinct characteristics. They also consider listed real estate funds but do not find them to behave very differently to stocks. The authors conclude that alternative assets are adding substantial value to ALM investors. Van Binsbergen and Brandt (2011) impose short-sale and Value at Risk constraints as well as penalties for additional financial contributions by the sponsor in case of underfunding. However, they show that instead of mitigating risk, these constraints may encourage risk-taking if liability discount rates are smoothed during a low interest environment.

Both, Hoevenaars et al. (2008) and van Binsbergen and Brandt (2011), use vector auto-regressions similar to Campbell and Viceira (2002) to empirically estimate expected returns based on state variables and lagged returns. Hoevenaars et al. (2008) predict an inverse relationship of the short-term interest rate and future stock returns and a positive relation to bond returns, also weakly significant. This implies higher expected stock returns during an environment of lower interest rates and lower expected returns for bonds. Thus, ceteris paribus, an investor would be incentivised to substitute bonds for stocks if interest rate decline. Van Binsbergen and Brandt (2011) also find, that the short-term rate negatively predicts expected stock returns while the long-term rate shows a positive coefficient. When liabilities are discounted with the long-term rate, this implies that liabilities decrease when stock returns increase and vice versa. Thus, from an ALM perspective, an investor would decrease its stock allocation if the funding ratio shrinks.

An optimal portfolio decision and thereby the capability to time the market is critically dependent on the predictability of returns. The price-dividend ratio, taken as a proxy for the present value of future cashflows that are discounted with time-varying discount rates, is often attributed to reliably forecast expected stock returns, even more for long horizons (Campbell & Shiller, 1988; Fama & French, 1988). Further state variables have been added to the list of potential return predictors: the short-term interest rate (Fama & Schwert, 1977; Glosten et al., 1993) and the yield spread as the difference between long-term and short-term government bond yield (Campbell & Shiller, 1991; Fama & French, 1989).

In a portfolio choice setting, Campbell and Viceira (2003; 2002) find the dividend-price ratio and the short-term nominal interest rate to forecast stock returns and the yield spread to be a good predictor for bond returns. Brandt and Santa-Clara (2006) and Hoevenaars et al. (2008) also find the credit spread as a significant predictor for stock returns.

However, the evidence of return predictability is controversial. Ang and Bekaert (2006) study the predictive power of dividend yields to forecast returns across several markets that also include European countries such as UK, France, and Germany. Interestingly, they find the predictability of the dividend yield to be statistically insignificant for long horizons, neither robust across markets nor across various sample periods. These results are directly contradicting the aforementioned research focusing on the explanatory power of dividend yields or price-dividend ratios, respectively, that is often taken as conventional wisdom. The authors further suggest that return predictability is not reliable for long horizons. Nevertheless, they find excesses returns to be predictable at short horizons. Instead of the dividend yield, their results suggest that the short-term interest rate provides the most robust forecasting power. In a similar study, Campbell and Yogo (2006) find evidence that confirms these results, suggesting that the predictivity of the dividend yield is weak while the forecasting power of the short-term interest rate is sufficiently robust.

In a series of studies, Cochrane (2007), Goyal and Welch (2008) as well as Campbell and Thompson (2008) explore the question of whether stock returns are generally predictable out-of-sample. The former argues that if returns are not predictable, it must be the future dividend growth that is predictable to explain varying dividend yields. His results indicate substantial economic significance and further imply that the variation in price-dividend ratios exclusively explains expected excess returns rather than growth in dividends. Nonetheless, the statistical significance for these predictions is small for conventional tests. An alternative hypothesis incorporates under the null that if returns are not predictable, future dividend growth is in fact predictable. In a joint-test for both return and dividend predictability, Cochrane (2007) finds that the lack of evidence for the latter provides significant proof that is must be returns which are predictable.

Campbell and Thompson (2008) also argue in favour of return predictability. They study the predictive power of forecast regressions on which they impose restrictions for coefficient signs and forecast returns. In particular, they argue that rational investors would not use negative equity premium forecasts and thus suggest truncating these forecasts to zero. Their results show that most prediction models outperform the historical sample mean forecast. Nevertheless, out-of-sample performance of these non-linear regressions on predictive state variables is marginal. However, the authors suggest that even weak explanatory power is valuable for mean-variance optimising investors.

Goyal and Welch (2008), on the other hand, argue that the power of out-of-sample return prediction is insufficient for an investor to profitably time the market. In a comprehensive study, they show that none of the predictor variables described above can significantly forecast equity premia out-of-sample. In addition, they compare the mean squared error of the return forecasts with that of the sample mean. They find that often the sample mean outperforms the predictor variables, including the dividend-price ratio and dividend yield. Moreover, their results indicate that most prediction models have not been stable in-sample. The authors suggest that evidence for return predictability may stem from publication bias towards significant results as nonfindings might appear less interesting.

Investors are in fact interested in the actual future returns from today's perspective. Thus, if the findings of Goyal and Welch (2008) are robust and prediction models are not stable, investors can not be sure that forecasting returns that have worked in the past will still be applicable for the future. McLean and Pontiff (2016) have studied the out-of-sample performance of prediction variables after academic research of their forecasting capabilities is published. They assume predictability may result from mispricing and thus, constitute an arbitrage opportunity that can be exploited. Their results support this assumption, as they find that returns of portfolios which have been constructed to utilise these arbitrage opportunities to substantially decline post-publication. Interestingly, they do not find return predictability to vanish entirely. The authors relate this to market frictions preventing arbitrageurs from eliminating the mispricing entirely.

Consequently, investors are left with considerable uncertainties if return predictability exists and even if it does – which models provides robust out-of-sample results. In addition, there is evidence that even if models are found that forecast returns out-of-sample, this effect might be not stable or even decay over time. Even if second moment estimations of future return distributions are reported to be less challenging (Merton, 1980; Nelson, 1992), doubt whether the market can be profitably timed appears to be justified. Pension managers might then consider alternative approaches that do not require a periodic estimation of return distribution.

As mentioned in Chapter 3.2, ALM investors' main concern is to provide funding for their liabilities. Hence, they do not necessarily have to try to time the market. Instead, they may match the cashflows of liabilities using a dedication strategy or immunise their portfolio against adverse movements of the underlying interest rate.

The initial construction of a dedicated portfolio is generally seen as more expensive than the setup of an immunised portfolio (Fabozzi et al., 1990). However, a dedicated portfolio does not require any rebalancing as it is structured to ex-ante provide full coverage of the liabilities. An immunisation strategy, on the other hand, requires constant rebalancing as risk-factor sensitivities are changing over time. Additional expenses of this rebalancing may offset or even exceed the initial cost advantage overdetermination (Maloney & Logue, 1989).

Large fixed-income portfolios in particular for long maturities may cause further difficulties for ALM managers. Gold and Peskin (1988) were among the first to discuss market shortcomings for long-duration bonds in an ALM setting. They argue that long-maturity bonds provide relatively lower returns due to supply and liquidity restrictions than they would otherwise. The liquidity of long-term bonds depends on the risk-aversion of investors to bear the substantial market risk involved in holding these bonds. Also, the supply is often limited as long-maturity bonds demanded from ALM investors for the purpose of liability-hedging are issued mostly by governments.

Domanski et al. (2017) explore the demand for long-duration bonds from long-term institutional investors in an environment of declining interest rates. They argue from an ALM perspective where investors often face a negative duration gap[6]. That is, the duration of an investor's obligations is larger than the duration of her assets. Given a negative duration gap, liabilities are more sensitive against a drop of interest rates than assets. A decline in long-term interest rates would then further increase this duration mismatch. As liabilities often exhibit higher convexities than assets, liability durations increase even faster. When long-term investors attempt to increase asset durations by buying even longer-dated bonds, they move farther out the yield curve. Provided that a sufficiently large market share consists of ALM investors, such as pensions or life insurers who compete for long-duration bonds, a negative feedback loop may be created. That is, a large demand for long-term bonds that increases prices leads to additional pressure on long-term yields which in turn increases the duration gap. The authors find empirical evidence in favour of such negative feedback loops within the EURO area. Similar effects are found in the US mortgage-backed security market (Hanson, 2014; Malkhozov et al., 2016), suggesting a more widespread issue for long-term ALM investors who face substantial costs in attempting to match durations in a low interest rate environment.

Conventionally, duration matching involves fixed-income products only as the predictability of future cashflows provides stable interest rate sensitivities and is therefore best suited for liability-hedging purposes. Many scholars have developed various models to extend the traditional bond-only duration matching by deriving implied equity durations. Among others, Bostock et al. (1989) and Cornell (1999) estimate equity duration as the reciprocal of the dividend yield. Leibowitz (Leibowitz, 1995) proposes an approach to base equity duration on a stock's correlation with the bond market in combination with the duration of the bond market. Dechow et al. (2004)

[6]Interestingly, the median portfolio duration was only 5.3 years for Swiss pension funds in 2015 (Swisscanto, 2015). Given this number has not changed substantially, the duration gap is highly negative, since liability durations reside between 12 and 20 years (KPMG, 2019).

empirically estimate equity duration using the price-earnings and the book-to-market ratio as proxies for interest rate sensitivity. Schröder and Esterer (2016) derive equity durations on the basis of analyst forecasts.

All the various approaches show that it is not straightforward to estimate equity duration. This is not unexpected since interest rate changes affect stock prices not only through the discount rate of its cashflows but also the cashflows themselves. As the proposed proxies are rather crude (Dechow et al., 2004) and empirical results have shown to be substantially different to bond durations and may even switch signs (Cornell, 2000), the use of equity durations for the purpose of immunisation of pension liabilities may be limited[7].

While it may be challenging to add equity to a portfolio for risk immunisation and at the same time its return predictability is uncertain, an ALM investor might still be interested in earning equity risk premia. As discussed in Chapter 3.2 above, a naïve allocation of assets in terms of a simple buy-and-hold or fix-mix strategy may be considered, if the pension manager is not confident to be able to forecast the distribution of expected returns. Sharpe (1975) early investigates potential gains from timing the market relative to simply holding the market portfolio. He argues that profits from market-timing critically depend on superior (i.e. being right 70% of the time) forecasting capabilities, and thus, likely to be moderate at best. If markets are efficient, a prediction of future market movements is not less difficult than individual stock picking. Hence, erroneous attempts to time the market may lead to irreversible opportunity and transaction cost that may result in underperformance of the buy-and-hold benchmark portfolio. Shilling (1992) points out that even though predictability is limited, prevented losses from avoiding bear markets allow for missing out large parts of bull markets while still outperforming a buy-and-hold strategy where investors are fully invested in both, high and lows. Among others, Tang and Whitelaw (2011) and Feldman et al. (2015) find empirical evidence arguing in favour of market-timing capabilities. In a pension ALM setting, Mulvey et al. (2006) and Martellini et al. (2014) find the fix-mix approach to be outperforming a buy-and-hold strategy. On the other hand, Hilliard and Hilliard (2018) find that although a fix-mix strategy exhibits reduced volatility, it is largely outperformed by a buy-and-hold approach. More generally, there is considerable doubt whether actively managed portfolios that are trying to time the market by identifying abnormal return

[7] Also, the variation between estimate is large. While the equity duration estimated by the dividend discount may be as high as 22.5 years for the US stock market (Bostock et al., 1989), Leibowitz (Leibowitz, 1995) estimate the equity duration for the same US market to be 2.8 years.

generating securities can outperform passive strategies that mimic the market. As one of the first, Henriksson (1984) empirically investigated the market-timing performance of mutual funds without finding significant support for the same. Likewise, in more recent studies, French (2008) as well as Fama and French (2010) find that on aggregate active portfolio management net of fees performs worse than a passive investment in the market portfolio.

One may conclude that there is considerable uncertainty in the literature whether an investor is able to or should try to time the market, facing the risk of being worse off than simply holding the market. Not being able to predict liability exceeding returns, however, means an ALM investor is at the mercy of naïve approaches to deliver returns that are sufficient to fund the pension liabilities. This becomes interesting when interest rates are low, and the market value of liabilities may have appreciated more than the corresponding asset values, causing substantial funding risk. If a pension manager decides to immunise the portfolio against interest rate risk, however, she may face substantial cost due to the negative feedback loop described above, which may even be enforced by the Swiss regulator. This again incentivises the investor to increase allocation towards riskier assets. Therefore, it is not clear how ALM investors such as pension funds should optimally invest their assets facing an environment of low interest rates.

5 Performance & Asset Allocation of Swiss Pension Funds

In the following Chapter we provide an overview of the empirical asset allocation and performance of Swiss pension funds over the last two decades. The analysis is done on an aggregate level of the Swiss pension fund industry based on previous studies. Furthermore, we emphasise the period since 2011, when the SNB lowered their 3-month yield target rate to a range of 0%-0.25%. Thereby, we expect to gain insights into how Swiss pension funds perform and allocate their assets when interest rates are at or below zero. In a study by Credit Suisse (2017), 54% of the surveyed pension funds state negative interest rates as the current primary challenge within the industry. As discussed previously, it may become increasingly difficult for pension funds to generate the required return required for the BVG minimal interest rate. Nearly risk-less investments such as federal bonds may even yield negative nominal rates. In order to meet this requirement in the current market environment, pension funds may be induced to take on higher risk.

Figure 3: Key Performance Indicators for Swiss Pension Funds

Average technical funding ratio, target return and realised return for Swiss pension funds for the period of 2005-2018. (Source: Swisscanto (2015; 2019)).

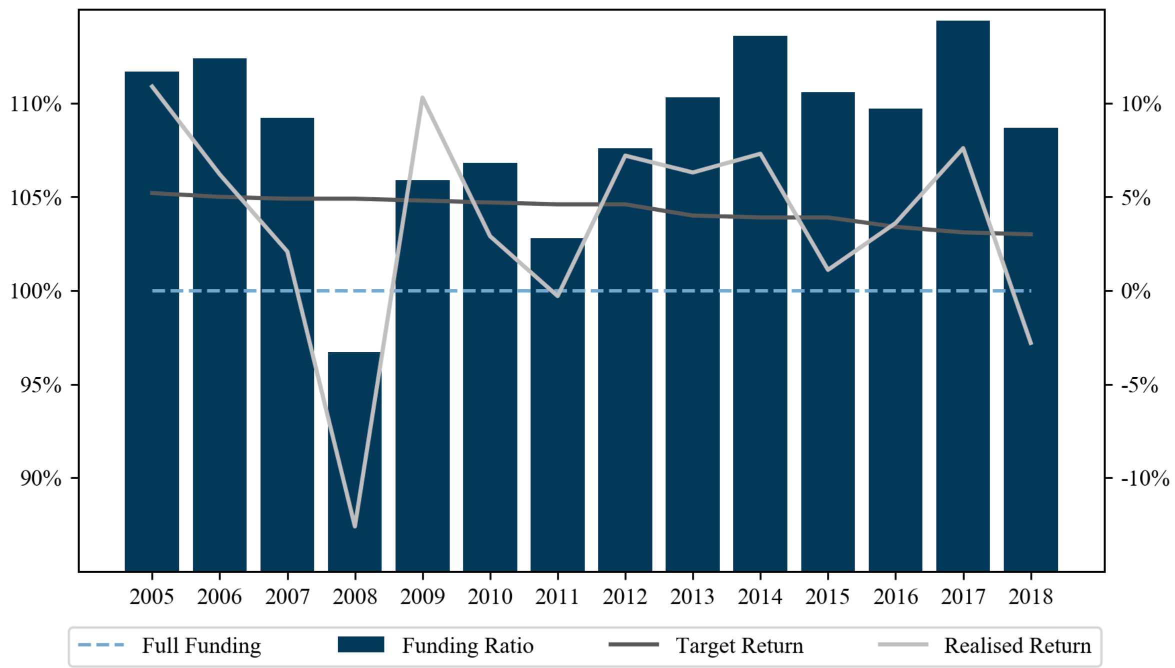


Figure 3 provides an overview of the Swiss pension funds' performance by depicting the average funding ratio and the investment returns for the period 2005-2018 to give an idea of the performance of Swiss pension funds. As discussed in section 3.1, the technical funding ratio may not be a reliable measure of a pension fund's financial health. Nevertheless, it still carries some information about a pension fund's funding status. The technical funding ratio of Swiss pension funds was subject to a large drop in 2008 in the aftermath of the global financial crisis. Almost 60% of all private pension funds have reported a funding ratio below 100% while about one quarter of the total stated levels below 90% from which the regulator requires recapitalisation measures. Only one year before, in 2007, nearly 60% of the Swiss pensions reported a funding ratio of 110% or above, demonstrating the devastating impact of the global financial crisis for the industry. However, most private pension funds managed to recover quickly with only 20% reporting a funding ratio below 100% at the end of 2009. Possible explanations for the quick recovery may be the recapitalisation measurements for several pension funds supported by the employers as well as recovering markets from a potential overreaction at the peak of the crisis. With the beginning of the following decade, a slow but steady increase in the funding ratio is observable. At the end of 2017, almost half of all Swiss private pension funds exhibit a funding ratio above 110%, with an average funding ratio of 108.7%. Public funds, operated by the Swiss government for their employees, tend to have a lower funding ratio with an average of 102,6% in 2018 and further development similar to private pension funds. Potential explanations for the overall lower funding ratio are a more risk-averse approach as well as a lack of expertise due to the competitive market in the pension fund industry (Siegrist et al., 2019). Overall, the steady increase in the funding ratio since the global financial crisis is somewhat surprising considering the equally steady decrease in the technical interest rate from an average of 3.5% in 2009 to the current level of 2%. This implies that Swiss pension funds have generated substantial returns in addition to expenditure reductions as a result of lower minimal interest rates and conversion rates for the supplementary contributions.

The average target rate of return for Swiss pension funds in 2018 was 3%. However, this target rate consistently declined throughout the past years as a result of decreasing minimal return rate and technical discount rates reflecting the overall environment of declining market rates. While the target return in 2008 was set to 4.9%, Swiss Pension funds realised on average a return of -12.6% during the financial crisis. This rate also represents the lowest observation of the average yearly return for the period. The highest average yearly return of 10.9% was observed in 2005, closely followed by 2009 with a yearly return of 10.3%. The average yearly return for the period of 2005-2018 is 3.6%, with a median of 4.9% and an annual standard deviation of 6.1%. In 8 out of 14 years, the Swiss pensions managed to gain positive net returns, defined as the difference between realised and target returns. Nonetheless, this results in an average net annual return of -0.7% as a result of the large outlier during the financial crisis. Since 2011, Swiss pension funds realised an annualised net return of -0.06%, indicating that the target returns could almost be reached. However, it is important to mention that Swiss pension funds profited from a bullish market during this period. The Swiss Performance Index doubled since 2011, starting with nearly 6000 points, reaching its high before the corona crisis when it surpassed 13'000 points. The S&P 500 even managed to nearly triple its value during this time, rising from 1270 points up to 3340 points. In a net asset value-add analysis conducted by McKinsey (2020) Swiss pension funds were underperforming their peers, the Netherlands and Canada, by approximately 60 to 90 basis points. However, Switzerland had the lowest benchmark portfolio volatility due to its more conservative investment strategies. In the following section, we provide detailed insights into the historical asset allocation of Swiss pension funds.

Figure 4: Asset Allocation of Swiss Pension Funds

Aggregate portfolio composition of Swiss pension funds over time (Source: OECD).

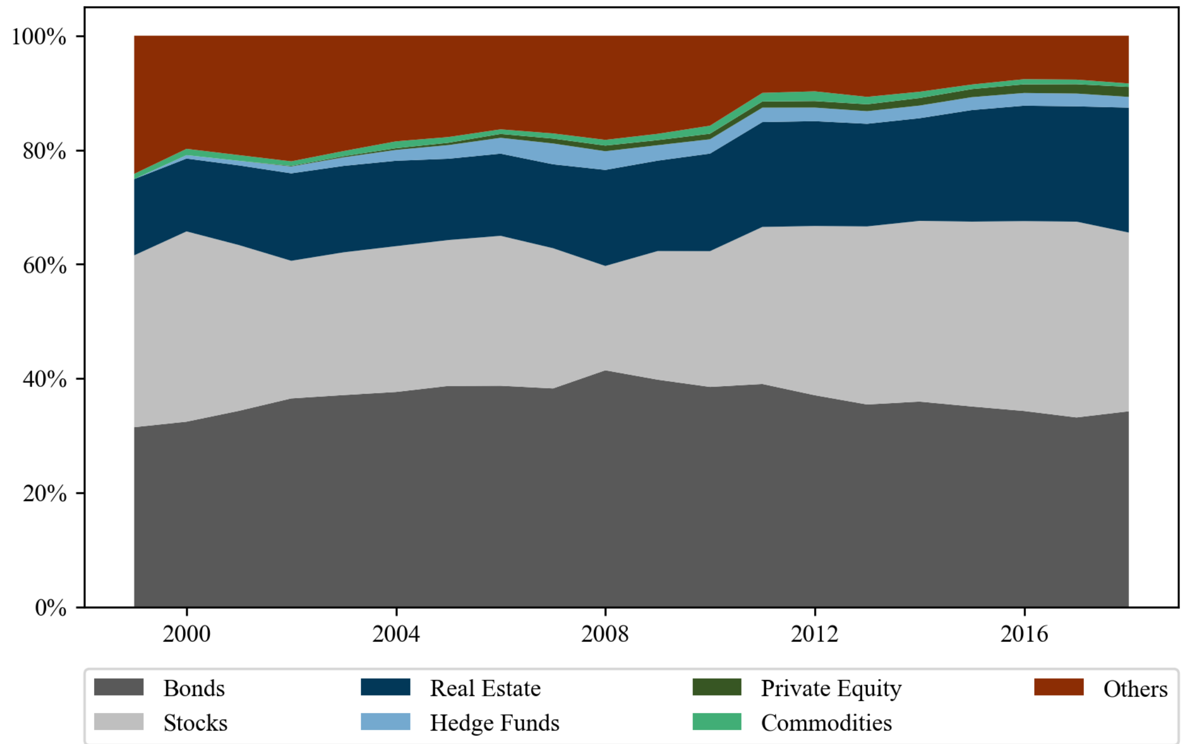


Figure 4 shows the asset allocation for Swiss pension funds, tracked by the Organisation for Economic Cooperation and Development (OECD). Bonds make up for the highest nominal investments varying between 32% to 47% of the total portfolio. The security class includes government bonds, corporate bonds and covered bonds. Government bonds are generally considered to be relatively risk-less assets. The asset allocation ratio for bonds steadily declined since the financial crisis mainly as a result of declining yields and the performance pressure for pension funds (Swisscanto, 2019). As detailed earlier, a divestment from bonds may allow for higher generated returns, however, it may also give rise to higher interest rate risk of pension liabilities. Moreover, since Swiss interest rates have been below zero, Swiss pension funds substituted domestic government bonds for foreign bonds which may be due to their relative higher yields.

Furthermore, one can observe that pension funds typically allocate stocks of 18% to 34% of the total portfolio. Pension fund can profit from the equity characteristics due to their higher risk premium. However, the stock market may also exhibit substantial volatility. In 2008, a sudden drop in allocation to stocks occurred as a result of a collapse of the global financial markets. Nonetheless, the nominal value of equity investments has been consistently increasing over the last decade, implying a shift in asset allocation strategies with a stronger focus on stocks. Generally, Swiss pension funds seem to diversify their stock investments almost equally between domestic and foreign markets. However, it appears a recent asset allocation strategy is more in favour of foreign equity. The quota of foreign equity assets to total equity assets rose to 56.31% in 2018 (Swisscanto, 2019), which may be attributed to the strong performance of foreign stocks.

Interestingly, the share of real estate has been steadily growing over the last two decades. Real estate represents a property of land including buildings on it alongside its natural resources, air and underground rights (KPMG, 2017). A pension fund can either directly invest in real estate by purchasing a property and lease or rent it out, or indirectly by investing in real estate funds. The increase in real estate allocation may result from the strong performance of the Swiss real estate market since the housing price crash in the early 90s. Real estate investments provide stable periodic cashflows through leases and rents as well as a general consistent growth in market value with low volatility. These are attractive features for pension funds who demand stable, long-term cash flows to cover their liabilities. On the other hand, direct investments in real estate are capital intensive and considerably illiquid. Therefore, indirect real estate investments via funds have gained popularity, particularly in foreign markets (KPMG, 2017). While foreign real estate investments used to be scarce in the early 2000s, a recent trend to allocate more resources to indirect foreign real estate is observable. In 2018, about 10% of all real estate investments were placed in the international market, almost twice as much compared to the beginning of the decade.

In terms of other alternative investments, Swiss pensions mainly consider hedge funds, private equity and commodities. Particularly private equity investments experienced strong allocation growth over the last decade. Private equity is an alternative investment class that consists of non-listed capital (Brown & Kaplan, 2019). The asset class is often organised in funds allowing investors to invest in private companies. These investments include acquisitions, funding new technology, expand working capital or to strengthen the balance sheet. Brown et al. (2019) suggests that private equity may currently be an attractive asset class, generating returns that are consistently approximately 2%-3% above stock market returns while showing a lower volatility. Furthermore, due to pension pension fund's long-term investment horizon, they might be able to take advantage of an illiquidity premium that is realised by investments in private equity as well as of further diversification effects.

Hedge funds are actively managed funds in the alternative investment class and are not bound to a specific investment strategy. Its main motive is the maximisation of (short-term) returns, regardless of the overall market development. Moreover, hedge funds are often characterised by a low proportion of equity and frequent use of leverage effects to increase the return on equity (Capocci & Hübner, 2004). At the start of the 21st century, Swiss pension funds increased their allocation towards hedge funds substantially. However, it seems that during last decade a downward trend occurred. This may be result of a recent debate, in which pension funds are accused to be attracted to hedge funds due to their high return potential without being in control of the investments risk exposure (Stewart, 2007). In contrast, pension funds claim that hedge funds reduce investment risk through further diversification as they are less correlated with traditional assets, particularly with stocks. However, this argument is challenged as long-term correlations between equity markets and hedge funds seem to be higher than expected (Stewart, 2007).

A commodity describes a basic good which unifies quality standards for producers and traders in the manufacturing sector. As mentioned in Chapter 4 above, commodities are found to provide good risk diversification properties due to their low correlation with the market. However, commodities are with an average of 1.0% the least allocated alternative asset class in the aggregated Swiss pension portfolio.

In Table 4, the category "Others" consists of different financial products that are not in scope of this study. The largest position of this category are loans and cash & deposit, which have fallen out of favour for pension funds over the last decade, mainly due to the low interest earned in short-term investments (Credit Suisse, 2019).

In a reoccurring survey, Credit Suisse (2012; 2017) provides in depth insights on the Swiss pension industry. The survey of 2012 (Credit Suisse, 2012) discusses the reaction of Swiss pension funds to the prior market crisis and its associated effects such as declining interest rates on their asset allocation. They find that 46% of pension funds reallocated their investments either in favour of real estate (74%), shares (42%) or alternative investments (41%). All reallocations were made at the expense of bonds (Credit Suisse, 2012). However, the low interest environment prevailed longer than expected by market experts. Thus, in 2017, 81% of pension funds reported that they further reduced their allocation towards bonds. Overall, however, it remains the most dominant asset class in the Swiss pensions' portfolios. Among those who divested bonds, 81% reduced the share of Swiss bonds and 40% the share of foreign bonds. At the same time, stock allocation increased steadily. Interestingly, many pension funds raised their investments in foreign stocks despite the recent pressure on the Swiss Franc, which is covered in more detail in Chapter 6.3. Relative to other investment categories, Swiss pensions allocate disproportionally more resources towards domestic real estate. Within the alternative investment class, investments in the subcategories infrastructure and private equity are either new or expanded. Almost a quarter of pension funds who have reallocated their assets have increased their investments in these categories. Hedge funds do not seem to be attractive for Swiss pension funds, as 55% of the respondents do not own any investments in hedge funds and only 15% increased the hedge fund ratio. In addition to a reduction in Swiss bonds, the most frequent action taken by Swiss pension funds as a response to the low interest rates was to shorten the duration (36%). Only 3% of Swiss pension funds reported an expansion of the bond duration. As mentioned in Chapter 3.2, a negative duration gap implies that liabilities are relatively more sensitive to a decline in interest rates than assets (Credit Suisse, 2017). Portfolio durations were reportedly reduced in expectation of increasing interest rates (Swisscanto, 2019). However, as it turned out later, these expectations were not realised. Furthermore, only a few pension funds have indicated that they invest in lower credit ratings (23%) for bonds, both within the investment-grade categories and lower grades (11%) (Credit Suisse, 2017). Therefore, it seems that most pension funds do not consider fixed-income assets as a viable option to achieve the required minimum performance.

The substantial allocation towards stocks and real estate does not imply that immunisation is playing a primary role for Swiss pension funds. This is not unexpected, since traditionally the Swiss pension industry is required to generate above government yield returns which is legally embedded in the BVG minimal interest rate. The cumulative portfolio composition of Swiss pension funds over the last two decades appears to have largely followed the corresponding market development. Thus, one may infer that pension funds do not try to immediately take advantage of market movements, contradicting large-scale market-timing actions. Instead, it seems to be more aligned with a buy-and-hold strategy. This seems to be in line with the Swiss pension survey results of Credit Swiss (2012) discussed above. While 46% of respondents reallocated their assets following the market crisis, 54% appear to have not. However, as the relative allocation of assets is provided on an aggregated level, it is difficult to establish distinctive investment strategies of individual Swiss pension funds. However, as mentioned above, in 2011 almost half of all surveyed pension funds reallocated their assets in response to the low interest rates while in 2017 81% redefined their investment strategy due to the prolonged low interest rates. Therefore, one may argue that some pension managers also strategically adjust their asset allocation in response to substantial changes in the market conditions.

Another characteristic of the asset allocation of Swiss pension funds is the so-called home bias (Swisscanto, 2019). It implies that Swiss pensions tend to invest disproportionally large amounts into the Swiss securities market. While a trend of increased allocation towards international assets is reported (PPCmetrics, 2020), their portfolio may still be less diversified due to the lack of international exposure. This phenomenon may be illustrated in the composition of the share of pension fund assets. Swiss shares account for almost 40% of their total equity exposure (Swisscanto, 2019). If the broad MSCI All Countries World Index is taken for reference, Swiss stocks are supposed to account only for a weight of just below 3%. Portfolios distorted due to a home bias are insufficiently diversified and contain unnecessary country, sector and factor risks

(PPCmetrics, 2020). An investment in the Swiss Market Index would imply an 80% exposure to three sectors: health, food and financial services. The home bias would only be justified if the Swiss stock market systematically generated higher returns, which was not the case for the last two decades. However, global companies dominate the Swiss stock market. The three largest Swiss companies make up over 50% of the Swiss Market Index, but generate most of their sales abroad. This implies that a pension fund is globally exposed by holding these domestic stocks. The home bias seems even more present in real estate investments. A potential explanation is that foreign investments are challenging within this investment category. The capital intensity of direct investments, the illiquid market, the high transaction costs, and complex tax aspects may explain the investment behaviour observed in practice (EY, 2019).

A further international diversification would imply an increase of currency risk. These may be eliminated using derivatives to hedge this exposure to foreign currencies. Swiss pension funds currently only hedge about one third of their foreign currency exposed assets. Even though a trend towards increasing hedging of the currency risk can be observed, it is still uncommon for smaller Swiss pension funds to make use of financial derivative securities (Swisscanto, 2019). Swiss pension funds also appear to exhibit the lowest usage of derivatives among European pension funds (Badaoi et al., 2014). The limited use of derivatives may be a potential explanation why Swiss pension funds seem to have relatively large exposure to currency risk. The effectiveness and importance of hedging is debated in the literature. Froot et al. (1993) argue that in the long-term exchange rates diverge to their expected rate based on nominal interest rates, while Perold and Schulman (1998) argue that that hedging reduces risk without affecting the returns. UBS (2013) published a study, in which they investigate the benefits of hedging for Swiss pension funds. They conclude that hedging for shares depends on the trade-off between risk and return and only recommend hedging for predefined cashflows such as fixed-income securities.

6 Data

This chapter is aimed to introduce the data used in this study. It primarily represents different asset classes in which Swiss pension funds are typically invested in (see previous Chapter 5). The same asset classes are considered for this study. We seek to analyse how differently structured portfolios perform during a period of low interest rates. Therefore, a sufficiently long sample is required that comprises returns during a low interest rate environment. For this reason, we extend the current period of low interest rates by adjusting the prices of the individual securities accordingly. Therefore, we use a theoretical asset pricing approach that is described in the second part of this chapter. As this is an important feature of our analysis, we finally provide a detailed descriptive overview on the data before and after the interest rate adjustment.

6.1 Data Choice

We choose nine different asset classes in which a Swiss pension scheme can invest in throughout the investment period. Subject to this list are government bonds, stocks and real estate, of which each is divided into domestic and foreign markets, as well as alternative assets including commodities, private equity and hedge funds. The selection is based on supporting literature discussed in Chapters 4 and 5.

The Swiss pension regulator distinguishes between domestic and foreign investments in their asset allocation restrictions for government bond, real estate and stocks (see Chapter 3.1) due to their exposure to corresponding local currency and economy. Therefore, these asset classes are split between Swiss and foreign markets in this study. In contrast, these arguments cannot be applied on the alternative asset classes, apart from real estate. Commodities are a homogeneous good, which implies similar prices across market places and sellers. Hedge funds and private equity are not bound to a particular country exposure due to their wide investment opportunities resulting in diversification of country risk. We do not include corporate bonds, as relevant characteristic appear not very different to government bonds (Hoevenaars et al., 2008). DeMiguel et al. (2009) state that for an optimal portfolio to outperform a naïve $\frac{1}{N}$ portfolio, a large sample size is required that is increasing with the number of assets included in the problem. Therefore, we want to keep the dimension of the market-timing portfolio choice problem as small as possible. Furthermore, this study assumes for simplicity that the hypothetical pension fund does not hedge its currency risk. As mentioned in previous Chapter 5, the use of derivatives is not widespread in the Swiss pension industry. Therefore, Swiss pension funds may be exposed to considerable currency risk. The assumption of zero currency-hedging may thus be not unrealistically far from industry practice.

In the following paragraphs, we introduce the collected data sample for each asset class. An overview of the chosen dataset is provided in Table 1. All time-series contain data points starting from January 2000 with monthly frequency. All asset classes are proxied by indices such that they are subject to diversification and eliminate unsystematic risk. We chose a monthly data frequency as daily values may exhibit substantial noise and yearly data points would decrease the number of observations and explanatory power of the results substantially. The data has been retrieved either from the Thomson Reuters's Datastream or Bloomberg.

Table 1: Data Source

Asset Class	Abbreviation	Data Source
Equity CH	ST CH	Swiss Performance Index
Equity Int	ST Int	MSCI World Index
Government Bond CH	GB CH	SW Total Over 10Y Domestic Gov Index
Government Bond Int	GB Int	iBoxx Sovereigns 10Y+ Index
Real Estate CH	RE CH	SXI Real Estate Selected Funds NAV Index
Real Estate Int	RE Int	MSCI World Real Estate Index
Commodities	CM	Bloomberg-Commodity Index
Hedge Fund	HF	Credit Suisse Hedge Fund Index
Private Equity	PE	S&P Listed Private Equity Index
Risk-free rate	r_f	SW Gov BM Bid Yield 3-Month
Liability Discount Rate	r_{10y}	SW Gov BM Bid Yield 10-Year
Equity Market	ST M	MSCI ACWI Index
Bond Market	BD M	Bloomberg Barclays Global-Aggregate Index
USDCHF	USDCHF	Datastream USDCHF

Pensions funds' domestic investments in stocks [ST CH] is represented by the Swiss Performance Index [SPI]. The SPI is the overall market index for the Swiss equity market. It contains most of the equity securities traded on the SIX Swiss Exchange of companies domiciled in Switzerland or the Principality of Liechtenstein. Equity securities with a free float of less than 20% and investment companies are not included in the SPI. The SPI is free-float-adjusted, which means that the market capitalisation is adjusted for the respective fixed holdings, and only the tradable part of the shares is taken into account. We use the SPI total returns that include potential dividend payments to capture the stock's total revenue stream.

The MSCI World Index denotes foreign stock asset allocations [ST Int]. The index comprises stocks of over 1,650 large and mid-cap companies from 23 developed countries. Similar to the SPI, stocks in the MSCI World Index are weighted based on the free-float market capitalisation. In this way, the MSCI World Index tracks approximately 85% of the market capitalisation and is one of the world's most important stock indices. For our analysis, the MSCI World Gross Total Return Index is used that includes the performance of the containing shares as well as corresponding distributed dividends.

The asset class of domestic government bond investments [GB CH] is represented by the Switzerland Total Over 10 Years Domestic Government Index. The index seeks to track the performance of debt issued by Swiss Government denominated in CHF with a maturity of 10 or more years. As mentioned previously, pension funds tend to be long-term buy-and-hold investors with preference for risk-free, long-term and stable revenue streams that are typically provided by government bonds. For the purpose of immunising interest rate risk of pension liabilities and in order to match durations of assets and liabilities, the duration of available fixed income assets should ideally be close to the duration of pension liabilities. This is why we chose a government bond index that includes long-maturity bonds only. Similar to the stock indexes, the total return price index is collected such that coupon payments are comprised as well. Similarly, the international government bond investments performance [GB Int] is tracked by the iBoxx Sovereigns 10Y+ Total Return Index, denoted in US dollars.

The SXI Real Estate Selected Funds NAV Index proxies the performance of domestic real estate investments [RE CH]. It is a net asset value weighted index and tracks the performance of the ten largest Swiss real estate funds. It is the only available Swiss real estate index with data since 2000. Real estate funds may not be an optimal proxy for the performance of Swiss real estate assets, especially not for direct investments. Real Estate Investment Trust [REIT] funds may be more appropriate as they must meet specific requirements. To qualify as a REIT, it must distribute at least 90% of taxable income to its shareholders and obtain at least 75% of its gross income from real estate related sources such as property rent. Real estate funds are not bound to these restrictions but typically invest in REITs and real estate-related stocks. This reduces the transparency of their income sources. Nonetheless, we consider them as a sufficient proxy for indirect real estate investments of pension funds.

International real estate investments [RE Int] are represented by the MSCI World Real Estate Total Return Index. The index is a free float-adjusted market capitalisation index that consists of large and mid-cap equity across 23 developed market countries comprising 106 constituents. All securities in the index are classified in the Real Estate Sector and consist only of REITs. It should be mentioned that the index does carry a high country-specific risk exposure, with approximately 66% of the United States. However, it is commonly used as a benchmark for performance and risk of international real estate funds.

As mentioned in Chapter 4 above, commodities may provide good diversification capabilities as the asset class reportedly exhibit low correlation with other equity and fixed income assets. The investment performance of commodity asset class [CM] is measured by the Bloomberg-Commodity Index denoted in US dollars. The goal is to provide liquidity and a diversified benchmark for commodity investments with a broad exposure for which individual commodities or commodity sectors do not dominate.

In the early 2000s, investment in hedge funds [HF] have become popular among investors, including pension funds, for further diversification and return generating capabilities (Brown & Kaplan, 2019). In our analysis, the Credit Suisse Hedge Fund Index proxies the potential generated returns of hedge funds investments. It is an asset-weighted hedge fund index, which only includes funds instead of separate accounts. Approximately 9,000 funds are tracked of which each fund must have a minimum of 50 million US dollars under management, a 12-month track record and audited financial statements. Furthermore, the index reflects the performance of all hedge funds net of performance fees and expenses.

Private equity is the ninth and last asset class included in our study. Its performance is proxied by the S&P Listed Private Equity Index [PE] denoted in US dollars. It measures the total return of listed private equity companies traded on developed-market exchanges that meet specific requirements in terms of size, liquidity, and business activity. Its constituents are weighted according to their float-adjusted market capitalisation and are subject to specific diversification requirements.

Prices of indices denominated in foreign currencies have to be converted to its corresponding Swiss Franc value as Swiss pension fund investments are exposed to currency risk. All international indexes are unhedged and denoted in US dollars, which implies that other foreign currencies and corresponding market risks of the constituents are already included in the US dollar valuation.

The Thomson Reuters Switzerland Government Benchmark Bid Yield 3-Month serves as an approximation for the Swiss Franc risk-free rate. Furthermore, the long-maturity interest rate, used for modelling the pension liabilities, is represented by the 10-year Thomson Reuters Switzerland Government Benchmark Bid Yield. The methodology of the CAPM return estimation requires further data points as a benchmark for the stock market and bond market returns. The stock market return is proxied by the MSCI ACWI Total Return Index, which represent the performance of a defined set of large- and mid-cap stocks across developed and emerging markets. Bond market returns are represented by the Bloomberg Barclays Global-Aggregate Total Return Index measuring the performance of the global investment-grade, fixed-rate bond markets.

6.2 Interest Rate Adjustment

Starting with the financial crisis in 2008, many central banks worldwide took a series of extraordinary measures to keep the banking sector afloat and to avert a potential economic depression. In March 2009, the SNB set the target interest rate for Switzerland to be located in between the interval of 0% and -0.75% (Swiss National Bank, 2013). Because the Swiss Franc has been regarded as a safe haven currency during the financial and euro crisis, the SNB was forced in 2014 to further decrease the interest rate to an unprecedented negative rate of -0.75%, ahead of all other countries. The overnight bank deposit rate has since remained on this level until the day of writing this thesis. As a result, the sample size of a low interest rate period would be approximately ten years or 120 months. However, for an estimation window length of 60 months, this sample would be considerably short to provide meaningful insights into the performance of the proposed strategies. DeMiguel et al. (2009) have shown that an estimation window should be about 3000 months for a portfolio of 25 assets for a sample-based mean-variance portfolio to outperform a naïve $\frac{1}{N}$ benchmark. To mitigate this issue and to improve the explanatory power of results, we adjust the prices of securities throughout the entire sample to a common level of negative short-term interest rates.

In light of this rather unique adjustment approach, we initially considered and evaluated several potential techniques. Each method presents its advantages and disadvantages and result in different implications on the magnitude of the adjustment.

One method may be the empirical estimation of the interest rate sensitivity of each asset class via regressions. This method implies the assumption of a linear dependency of price changes to changes in interest rates. There have been several studies in this area with a tendency of finding a negative relationship between stock returns and the change of interest rates (Alam & Uddin, 2009; Andries et al., 2014; Ang & Bekaert, 2006). However, these regression on asset classes in our sample sometimes resulted in large positive and statistically significant coefficients. This may be due to issues in causality. Causality describes the relationship between two events, in which one affects the other. Although the interest rate can affect the realised return, returns may also affect the interest rates. This was observed during the global financial crisis when the interest rates have been lowered to support the struggling economy.

As mentioned in Chapter 4, the bond duration concept may also be transferred into non-fixed income classes to establish a corresponding price sensitivity to interest rate changes. This requires estimating the duration of equity using, for example, the dividend discount model. While fundamental data for certain indices used in this study are not published, Leibowitz (1995) proposes an alternative approach to estimate the equity duration based on the correlation between stocks and the bond market. However, estimations for equity durations in our sample appear highly volatile, including a substantial period of statistically insignificant results. Thus, the empirical approaches appear to produce rather extreme price adjustments for (large) changes in interest rates.

Besides the empirical approaches, we consider a theoretical approach for which the implications of changing interest rates are defined with clear tractability. Interesting is the asset pricing theory whose central motive is to determine the price or value of a security with claims to uncertain payments. Within the risk-neutral pricing approach of asset pricing theories, the state preference theory appears as an appropriate approach for this study's requirements. The state preference theory can be used to price every kind of security, delivers a clear dependency on the risk-free rate and has a strong theoretical foundation. In the following section, we introduce the theory and state all the calculations and assumptions made for the adjustment of asset prices to a common level of interest rates.

The state-preference theory [SPT] presents an analytical basis for the understanding of the economic structure of capital market models. It is based on the subjective expected utility theory and was introduced by Arrow (1953) and further detailed by Debreu (1959). Hirshleifer (1965; 1966) contributed to the popularization of the Arrow-Debreu theory by applying it to several basic finance problems. The central question of asset pricing theory is how individuals allocate limited resources across a price system based on the valuation of risky assets. Hirshleifer (1966) asserts that the state preference approach resolves securities into distributions of contingent income claims defined over a set of all possible states for a specific period. Different states can command different prices for securities as their valuation is depending on the investor's preferences.

In the SPT framework, the consumer has a choice of different commodity bundles, which may be state- and time dependent. The following axioms are imposed to model the preferences of the decision maker, not to be mistaken with choices. Choices are an act, while preferences are a state of mind. A crucial assumption of the state-preference theory is the completeness of the market. It implies that every possible payoff structure exists. That is, every state is connected to an asset return. Formally speaking, this means that an Arrow-Debreu security can be created for every state by construction of a corresponding portfolio. Furthermore, the ordering axiom of transitivity is assumed for the preference structure of an individual investor. It describes consistent preferences over options. This means, if option A is preferred over option B and option B is favoured over option C, option A must also be chosen over option C. If consumers do violate transitivity in their preference structure, an arbitrage opportunity would exist. The last assumed ordering axiom is continuity, ruling out jumps of an individual's preferences. In mathematical terms, it describes that if point A on a preference curve is favoured over point B, also points close to A need to be preferred over points close to B. When preferences among such objects satisfy these ordering axioms, they are represented by an ordinal utility function. The state-preference framework allows preferences to be modelled with the fundamental principle of rationality, the no-arbitrage argument. This is an axiom that applies to groups as well as to individuals, solidly unifying the theory of rational choice across market participants choices and competitive markets (Nau, 2011).

In the state preference theory framework based on the work of Arrow(1953), Debreu(1959) and HirshleiferHirshleifer1965, Hirshleifer1966 only two points in time exist: Today (t_0) and the end of the period (t_1). Portfolio optimisation can only occur in t_0. The uncertainty in this framework is characterized by exclusive future states that can occur at time t_1 defined in the finite set $\omega = (w_1, ..., w_s)$ with cardinality S. The investor might know the different probabilities of the states, but he does not know which one is going to occur. Securities can, therefore, be a set of possible payoffs, each occurring in a mutually exclusive state of nature. Mathematically speaking, they can be represented as a vector of state-contingent claims. Securities then assign a payoff to every possible state w_s:

$$\underline{X_a} = \begin{pmatrix} X_a(w_1) \\ \vdots \\ X_a(w_s) \end{pmatrix} \tag{6.1}$$

An important concept to be introduced is Arrow-Debreu-Securities [ADS]. These securities have a payoff of 1 in state "s" and 0 in all other states. Specifically, ADS "s" denotes the vector of the following cashflows:

$$e_s = \begin{pmatrix} w_1 \\ \vdots \\ w_s \\ \vdots \\ w_k \end{pmatrix} = \begin{pmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{pmatrix} \tag{6.2}$$

This concept allows for the intuitive decomposition of every payoff into a linear combination of ADS. Let p_s be the price of an ABS in t_0 with a payoff of 1 if state "s" occurs. If a portfolio is composed with the sum of all possible ABS, a cashflow of 1 is guaranteed. The price of the portfolio defines the risk-free rate, R_f, and is defined as:

$$\sum_{s=1}^{k} p_s = \frac{1}{R_f} \tag{6.3}$$

Now we consider a multi-cashflow asset, a, with payoff X_{sa} in state "s". In the absence of arbitrage, the price of this security must equal:

$$P_a = \sum_{s=1}^{k} p_s X_{sa} \tag{6.4}$$

As a next step, the concept of a stochastic discount factor [SDF], also known as the pricing kernel, is introduced. The existence of SDFs can be proven theoretically provided the requirements of the law of one price and no-arbitrage are fulfilled (Tirimba, 2014). This variable is part of the function of possible future payoffs that define the current price of a security. The SDF represents an adjustment for systematic sources of risk, market prices of risk and the risk-free rate. The SDFs can also be implied by specific economic models, in which they reflect investor preferences. We estimate the SDFs using the consumption-based asset pricing models, expressed as:

$$m_s = \frac{\beta U'(C_{t+1})}{U'(C_t)} \tag{6.5}$$

Where β is enclosed in a boundary of $0 \leq \ \beta = \frac{1}{1+\theta} \leq 1$ and represents the discount factor for preferences with θ as the corresponding rate of discount. C_t corresponds to the consumption in time t and M_{t+1} the SDF for the next period. Furthermore, the SDF in the state preference theory is defined as $m_s \equiv p_s/\pi_s$, which translates to the division of price of the Arrow-Debreu security for the state "s" by the probability that state "s" occurs. This definition can be used to modify equation 6.4:

$$\begin{aligned} P_a &= \sum_{s=1}^{k} \pi_s \frac{p_s}{\pi_s} X_{sa} \\ &= \sum_{s=1}^{k} \pi_s m_s X_{sa} \\ &= E\left[m X_a\right] \end{aligned} \tag{6.6}$$

Another essential part of asset pricing is the concept of risk-neutral probabilities. These are probabilities of potential future outcomes adjusted for risk, which then can be used to compute expected asset values. These theoretical risk-neutral probabilities differ from actual physical probabilities. The benefit of the risk-neutral pricing approach is that they can be used to price every asset based on its expected payoff, as the expected values of each security do not need to be adjusted for the securities' individual risk profile. Risk-neutral probabilities may therefore be seen as the decision maker's marginal betting rates on events, also known as state prices. The risk-neutral probability of state "s" does also represent the price for the Arrow-Debreu security for state "s", where a rational decision maker would be indifferent between buying or selling. Furthermore, in equilibrium, a universal agreement on asset prices is necessary for the no-arbitrage assumption to hold.

The risk-neutral probabilities are defined as $\widehat{\pi}_s \equiv p_s R_f$ resulting from the multiplication of the price of the elementary security with the risk-free rate. Equation 6.6 can be rewritten as:

$$\begin{aligned} P_a &= \sum_{s=1}^{k} p_s X_{sa} \\ &= \frac{1}{R_f} \sum_{s=1}^{k} p_s R_f X_{sa} \\ &= \frac{1}{R_f} \sum_{s=1}^{k} \hat{\pi}_s X_{sa} \end{aligned} \tag{6.7}$$

Furthermore, the risk-neutral probabilities can also be rewritten since $m_s \equiv \frac{p_s}{\pi_s}$ and $R_f = 1/E\left[m\right]$:

$$\begin{aligned} \hat{\pi}_s &= R_f m_s \pi_s \\ &= \frac{m_s}{E\left[m\right]} \pi_s \end{aligned} \tag{6.8}$$

In comparison to the previous stochastic discount factor approach, the newly derived formula uses modified probabilities of the cashflows for each different state instead of discounting the cashflows by a different discount factors.

As the equation is now dependent on the risk-free rate, the formula can be used to adjust the prices of the defined asset classes used in this study. However, a few assumptions are necessary to derive the required paramaters for the formula. In the following section, the chosen method for the adjustment of asset prices will be explained in further detail.

As mentioned previously, the stochastic factor can be estimated based on a decision maker's utility curve. The power utility, also known as CRRA utility, is often used in applied theory and empirical work because of its tractability and appealing implications, e.g. stationary risk premia (Wakker, 2008). The power utility $U(C_t)$ is given by:

$$U\left(C_t\right) = \frac{C_t^{1-\sigma} - 1}{1 - \sigma} \tag{6.9}$$

Where C_t denotes the consumption in time t and σ the risk aversion of the holding investor. While the utility curve does not need to hold for a single investor, we assume that it represents the preferences of the market that includes all its participants. Substituting (6.9) in (6.5), the stochastic discount factor for the state "s" is expressed as:

$$m_{t+1,s} = \beta \left(\frac{C_{t+1,s}}{C_t} \right)^{-\sigma} \tag{6.10}$$

An SDF estimation for each state "s" in time t can be achieved by estimating the preference discount factor β, future consumption C_{t+1}, and the risk aversion σ. However, before this step, we describe how the states have been defined for the individual asset classes by estimating the "true" probability density of each asset class.

In this study, we use the kernel density estimation, also known as the Parzen-Rosenblatt window method, to estimate the "true" distribution. It is a statistical, non-parametric method used to predict the probability density function (Parzen, 1962; Rosenblatt, 1956). The data smoothing method is based on a finite data sample size in which the mean and the variance of an infinite population are not known. The main advantage of a non-parametric approach is that no assumption regarding the probability distribution must be made, which may result in a more accurate prediction of outliers in comparison to the parametric approach. However, the lack of power and the magnitude of the discrepancy between the assumptions of a parametric approach and the infinite distribution in comparison to the estimation errors of the non-parametric approach are its main concerns (Zambom & Dias, 2012). The kernel density estimation has been applied to each asset class based on the obtained sample size consisting of monthly returns for the whole period. Given the estimation of the “true” distributions, we can define a finite amount of states with their respective probabilities and expected return values across all asset classes.

Remember that β is defined as $0 \leq \beta = \frac{1}{1+\theta} \leq 1$ and represents the discount factor for preferences with θ as the corresponding discount rate. Based on previous studies we assume that the discount factor for preferences β is 0.96 with a corresponding discount rate of 4.16% (Ahmed et al., 2012; Epstein & Zin, 1989; Ogaki & Reinhart, 1998). For simplicity reasons, this study assumes that β is constant over time. As a next step, we estimate the consumption in time $t+1$ for each state by making it only dependent of the market return. Yu (2012), Poterba (2000) and Maki and Karen (2001) examined the correlation between the household consumption expenditure and the stock market development. They state that the final consumption expenditure growth correlates with the market return with a coefficient of approxiamtly 0.15. Piazessi and al. (2007) argue that consumption-based asset pricing should be based consumption expenditure as it represents the characteristics of financial consumption model the closest. However, the market return is not the only factor that influences the consumption growth. Other factors may include inflation, interest rate, employment, wages as well as subjective factors. The annual growth in Switzerland over the last 30 years ranged from -0.5% to 3.5%, with an average of 1.48%. Based on the previously mentioned literature, we assume that all the other drivers for consumption growth remain stable over time and account for a growth of 0.9%, while only the market return for state “s” increases or decreases the consumption. Note, that the intercept has been adjusted to account for the average positive drift of the market return. With consumption in $t = 1$ being 1, the consumption in time $t+1$ is defined as:

$$C_{t+1,s} = 1.009 + 0.15 r_{m,s} \tag{6.11}$$

This implies that the states between an asset class and the market return are connected to each other, meaning that both the specific asset class and the market do have the same states.

Lastly, the risk aversion needs to be estimated. As all the parameters for the SDF should fit the data of each asset class, we calculate the risk aversion implicitly to match the price. Conine et al. (2017) state that the relative risk aversion of an average market investor should be in a range from 1 to 10, while most common findings for share indexes range from 2 to 5. The retrieved risk aversion (σ) can be seen in Table 2.

Table 2: Implicit Risk Aversion (σ)

Asset Class	Risk Avers.
ST CH	2.70
ST Int	2.63
GB CH	1.32
GB Int	1.66
RE CH	0.98
RE Int	0.53
CM	1.87
HF	7.86
PE	0.44
ST M	2.13
BD M	0.17

Recall equations (6.7) and (6.8). Note that the risk-free rate is given by the 3-month Swiss government bond yield and that $X_{sa} = P_a\,(1 + r_{a,s})$, with $r_{a,s}$ is the return in state s for the asset class a. The credit rating of the Swiss government of Standard & Poor, Moody and Fitch is set to AAA, which represents the highest possible rating implying high creditworthiness in terms of meeting financial commitments and low risk of default. Even though government bond yields are not entirely risk-free, we assume in this study that they are, as it represents a close proxy of the "true" risk-free rate. Furthermore, the 1-month yield would have been more accurate estimate for the risk-free rate of a one month period, however, due to data availability restrictions, we opted for the 3-month yield. As all missing parameters have now been estimated, we can adjust the prices for each asset class in each time t for a newly chosen risk-free rate. To eliminate opposing price adjustments by altering the discount factor and the risk-neutral probabilities with the new risk-free rate as well as further subjective corrections to the SDF, we make one further assumption. Changes in the risk-neutral probabilities are not caused by preference alterations, effectively meaning that the SDFs change proportionally to the risk-free rate. This implies that the valuation of the intrinsic value of the asset is uncorrelated with the risk-free rate, leading to price adjustments solely in terms of time value of money. As stated in Chapter 4, interest rate changes affect stock prices not only through the discount rate of its cashflows but also the cashflows themselves. However, we assume that cashflows are not affected by interest rate changes for the respective one-month period following the price adjustment. Based on the monetary policy response lag which previous literature suggest could reach up to 4 years (Shapiro, 1986), this may be a reasonable assumption[8].

[8]The monetary policy response lag describes the duration from the implementation of the monetary policy

Based on the price adjustment method and its assumptions detailed above, prices for every asset class can be re-calculated for a common level of interest rate while still keeping the characteristic of the realised returns at the market. The target rate for the interest rate adjustment is set to -0.75% to be in line with the current three-month target yield of Swiss government bonds introduced in 2015. All asset classes are adjusted according to the Swiss government yield at the time of the adjustment, even though international assets would be exposed to their respective local interest rate from various governments. As we are interested in the asset's sensitivity to Swiss interest rates, we for simplicity assume a perfect correlation to the basket of international interest rates. This implies a parallel shift of the Swiss interest rate to the basket of international rates. We refer to the the international Fisher effect as basis for the assumption that the exchange rates will not be affected by the parallel shift. The international Fisher effect states that the expected disparity between the exchange rate of two currencies is approximately equal to the difference between their countries' nominal interest rates (I. Fisher, 1930). This assumption allows us to disregard the effects of adjusted interest rates on the exchange rate. Finally, all international assets are converted into Swiss Francs to induce the currency risk for Swiss investors. Given the assumptions detailed above, the approach of adjusting the security prices to a common level of interest rates may be regarded as relatively conservative. We purposely limit subjective inputs for this approach to ensure reliability and validity of the newly generated returns. The magnitude of the interest rate adjustment will be discussed in the following chapter. However, Figure 5 below provides a visual example of the domestic government bond adjustment. Figures of the price adjustment for the remaining asset classes can be retrieved from Appendix A.

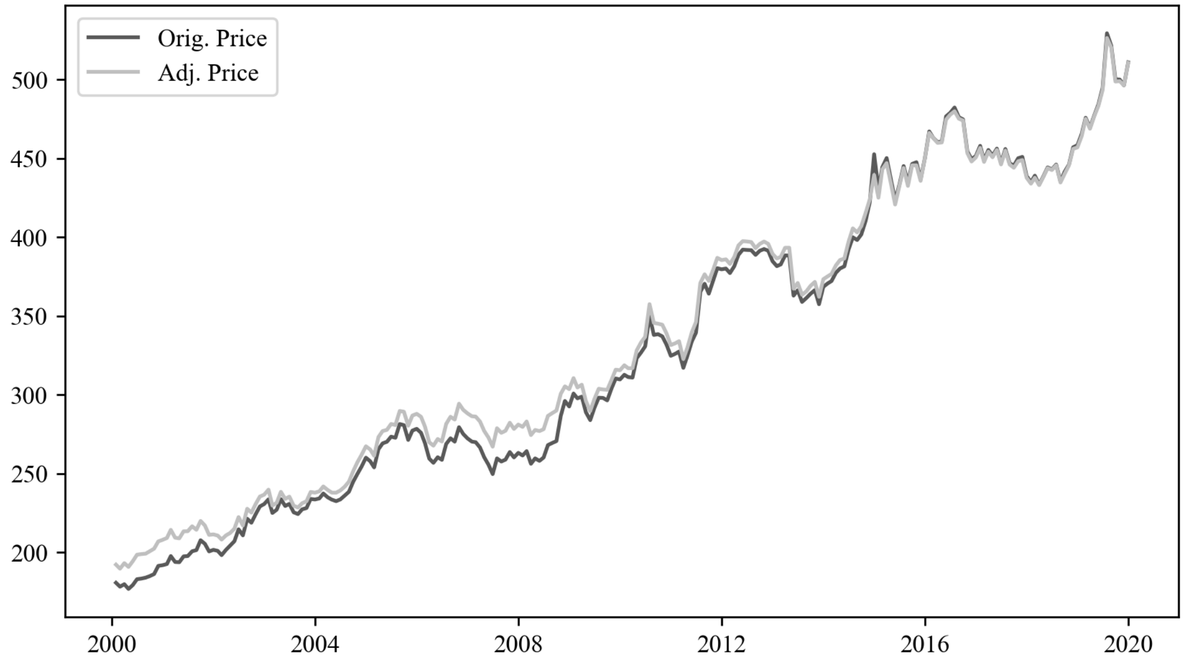
6.3 Descriptive Statistics

In the following section, we provide a brief descriptive summary on the dataset in order to gain a basic understanding of the individual asset classes and their characteristics. Furthermore, we compare the asset classes before and after their returns have been adjusted for a common interest rate level and subsequently evaluate its impact. Finally, we examine the dataset after the international asset classes have been adjusted for currency risk and exchanged to Swiss currency.

All return series are based on monthly logarithmic returns. The logarithmic returns are defined

change to its affect on the economy. Greenville (1996) argues that the phenomena may be caused through lagged credit demand effects, meaning that due to fixed debt structures companies can not profit from the new rates directly.

Figure 5: Price of Swiss Government Bonds Before and After Interest Rate Adjustment



as the natural logarithm of the securities' price at the end of month t divided by the price of the previous month $t-1$. The summary statistics includes the annualised mean, standard deviation, and Sharpe ratio as well as monthly minimal and maximal return observations. The Sharpe ratio is given by the division of the average return in excess of the risk-free rate over the standard deviation of an asset, where the annual risk-free rate is equal to -0.75%. The Sharpe ratio is a standard tool to evaluate the risk-adjusted return and measures the excess return on an investment per risk unit. This implies that the higher the Sharpe ratio of an asset class or portfolio, the more the fund compensates for the risk taken.

Furthermore, we include the skewness and excess kurtosis of the empirical return distribution in the summary statistics. The skewness measures the degree of symmetry of a distribution. A skewness of zero implies a perfectly symmetric distribution such as the normal distribution. The kurtosis measures the heaviness of the tails of a distribution relative to those of a normal distribution. The normal distribution exhibits a kurtosis of 3. We present the kurtosis in excess of this value such that the excess kurtosis of the normal distribution is zero. Thus, a positive excess kurtosis implies heavier tails and thereby a higher probability of extreme returns relative to the normal distribution and vice versa. Moreover, a positive excess kurtosis may exhibit a larger probability mass around the center relative to the normal distribution.

Table 3: Summary Statistics

Annualised mean, median, standard deviation, and Sharpe ratio as well as minimum and maximum observations expressed in monthly returns across all asset classes. Furthermore, corresponding skewness and excess kurtosis of the return distributions are provided.

	Mean	Median	Std dev	Sharpe	Min	Max	Skew	E. Kurt
ST CH	4.88%	12.64%	17.44%	0.32	-21.04%	16.74%	-1.22	0.73
ST Int	5.37%	17.35%	17.77%	0.34	-35.37%	10.37%	-2.03	7.00
GB CH	5.17%	5.28%	7.11%	0.83	-6.78%	7.35%	0.10	-1.87
GB Int	8.66%	10.89%	11.30%	0.83	-23.99%	13.33%	-2.24	13.30
RE CH	6.05%	6.27%	7.25%	0.94	-7.62%	6.12%	-0.41	-1.79
RE Int	3.61%	9.84%	18.12%	0.24	-30.00%	18.06%	-1.25	2.50
CM	0.82%	1.44%	17.17%	0.09	-33.03%	12.29%	-1.28	4.68
PE	4.63%	16.56%	21.80%	0.25	-31.04%	29.53%	-1.08	3.26
HF	3.32%	5.08%	5.24%	0.78	-6.96%	6.00%	-1.07	1.85

The first column of Table 3 shows that the annualised return mean ranges from 0.82% to 8.66%, with the lowest value realised by the commodity asset class while Swiss government bonds exhibit the highest average return. This appears surprising, considering the downgrade in the sovereign credit rating of several Europe Union members in 2010, also known as European sovereign debt crisis. Its domestic counterpart with a mean of 5.17% supports the relatively strong average performance of government bonds. Their good performance may be attributed to the falling yields, as this leads to bond price increases due to the higher present value of their future cashflows. International governemnt bonds appear to yield even higher returns. Apart from Swiss real estate, both government bonds seem to yield the highest risk-adjusted return with a Sharpe ratio of 0.83. his seems to be the result of their good performance as well as their naturally low volatilities with annual standard deviations of 7.11% for the domestic and 11.30% for the foreign asset class, respectively. The low variability also implies a low range between the minimum and maximum values, where Swiss government bonds range between -6.78% and 7.35% and, surprisingly, foreign government bonds between -24% and 13.33%. However, these extreme returns of the foreign government bonds were realised during the turmoil of the global financial crisis with only one month between them. Additionally, international government bonds exhibit the smallest skewness of all asset classes with -2.24 and the highest excessive kurtosis with 13.30. A negative skewness suggests that the left tail of the distribution is either longer or fatter than the tail on the right side. This implies that more observations are found on the right side of the mean returns than the left side, which can be also seen by a higher median than average. Financial return time-series typically exhibit a negative skewness due to fast-paced negative price corrections and slow build-up in gaining value (Teiletche, 2015). The positive excess kurtosis, particularly for international assets, implies heavy tails that may be attributed to extreme returns during the global financial crisis and European sovereign debt crisis. The Swiss government bonds, as well as the Swiss real estate sector, are the only asset class where the skewness implies a close to symmetrical distribution and while the negative excess kurtosis implies a lower probability of extreme results.

There have been some turbulent times for the stock market since the beginning of the millennium. The data set includes two market crises, the Dot-Com bubble in 2000 and one of the greatest recessions in history, the global financial crisis from mid-2007. Furthermore, two substantial stock price corrections occurred in 2002 and 2011. On the other hand, two long-lasting bullish markets are also included in the sample, one from 2002 until the global financial crisis and the other since the last correction in 2011 until the end of the data set. Throughout the period of this study, these events generated some extreme return values for the stock market, whose effects can be observed in the summary statistics. While the stock markets show an average annualised return of 4.88% and 5.37% respectively, their corresponding median values are at 12.64% and 17.35%, showing the impact of the negative return outliers. Their existence can also be observed in the negative skewness of the asset class, driven by the long-lasting bull market and the sudden substantial corrections during the crisis. This appears to translate into a relatively low risk-adjusted return for both stock assets with Sharpe ratios just above 0.3 due to the naturally high variability of stock markets.

Domestic and foreign real estate assets performed differently over the sample period. The Swiss market shows a higher average return of 6.05% and much lower variation with a standard deviation of 6.27%, resulting in the highest risk-adjusted return for all asset classes with a Sharpe ratio of 0.94. At the beginning of the 90s, the Swiss real estate bubble burst leading Switzerland into a national financial crisis. However, since then the housing prices rose consistently, leading to a 60% increase in inflation-adjusted returns over the last two decades. On the other hand, the international real estate market exhibits a higher median with 9.84% but also the second-highest annualised standard deviation of all asset classes. This seems rather atypical for a real estate market, but these extreme results can be explained. As mentioned previously, the foreign real estate index comprises an US-American country-specific risk. Furthermore, during the American housing boom, the S&P/Case-Shiller house price index reported an approximately annual 10% price growth in inflation-adjusted terms between 2001 and 2006, before a price correction of nearly 35% occurred at the start of the global financial crisis. During these times of uncertainty, the stock prices of publicly traded REITs plummeted, leading to a loss of -30% within one month. However, the American real estate market recovered since then.

Commodities show the lowest annualised average and median returns of all asset classes, with 0.82% and 1.44%, respectively. In addition, commodities exhibit high variation with a monthly standard deviation of 17.17%. Its market is known to be volatile, and sudden market movements may appear for no particular reason. As a rule of thumb, the market may be seen as subject to a function of supply and demand, being more independent of other market factors (Chen et al., 2012). One non directly explainable instance happened in mid-2014, where the global commodity prices fell by 38% over a period of six months. Demand and supply conditions led to lower price expectations, which could not be attributed to a single factor or event. The consensus assumption is that this was caused by a multitude of industry-specific and macroeconomically factors that led to a simultaneous drop across many different commodity classes. Nevertheless, it should be mentioned that during the financial crisis commodities performed relatively well, mainly driven by the rising gold prices, before experiencing a price crash in 2010.

Private equity achieved an average return of 4.63% and the second-highest median value of 16.56%. Furthermore, in this dataset it shows the highest standard deviation of 6.29%. These results are not in line with the statement of Brown et al. (2019) as neither the returns nor the volatility outperform the international stock market. Interestingly, they exhibit the highest maximum return observation of 30%, almost double of all other asset classes.

Hedge fund assets contrast private equity with the lowest standard deviation of 5.24%. Even though the annualised average return of 3.32% is rather low, the Sharpe ratio of 0.78 is relatively high. These results are rather surprising considering that the asset class is known for high risk exposure and heavy usage of leverage. Hedge funds are popular among investors due to their promised low correlation with the market and their high expected returns. However, the participation in a fund requires high fee payments, which could be partially a reason for their low average annualised returns. Furthermore, the index tracks 9'000 different hedge funds with ten investment strategy subcategories, which, paired with the low market correlation, may result in a highly diversified index with a low systematic risk exposure.

Table 4: Summary Statistics in CHF after Interest Rate Adjustment

Annualized mean, median, standard deviation and Sharpe ratio as well as minimum and maximum observations expressed in monthly returns across all asset classes. Furthermore, corresponding skewness and excess kurtosis of the return distribution are provided. All asset classes marked with * have been converted from US dollars to Swiss Francs.

	Mean	Median	Std dev	Sharpe	Min	Max	Skew	E. Kurt
ST CH	4.75%	12.55%	17.62%	0.31	-21.75%	16.42%	-1.25	0.75
ST Int*	2.64%	10.95%	20.14%	0.17	-31.09%	14.89%	-1.46	2.03
GB CH	4.90%	5.77%	6.84%	0.83	-6.84%	6.89%	-0.06	-2.11
GB Int*	5.89%	10.83%	13.82%	0.48	-19.71%	12.71%	-1.10	2.29
RE CH	5.78%	5.99%	7.21%	0.91	-7.52%	6.10%	-0.34	-1.82
RE Int*	0.87%	6.19%	18.27%	0.09	-25.73%	21.94%	-0.81	0.84
CM*	-1.91%	-1.45%	17.95%	-0.06	-28.76%	13.91%	-1.21	2.64
PE*	1.90%	11.81%	24.36%	0.11	-27.27%	33.41%	-0.59	0.74
HF*	0.59%	2.72%	11.08%	0.12	-15.66%	11.80%	-0.60	0.48

Table A.13 in the appendix shows the summary statistics after the the returns have been adjusted to an interest rate level of -0.75%. As shown in Figure 5 at the end of Chapter 6.2, the prices of the indexes representing the asset classes are generally adjusted upwards as returns are largely adjusted for lower interest rates. In the following paragraphs, we refer to the delta as the difference of a statistical value after to before the interest rate adjustment has been made. The delta of the annualised average returns are negative and have a rather small magnitude ranging from -0.14% to -0.27%. The standard deviation increases for most asset classes apart from government bonds with a delta ranging from -0.27% to 0.31%. The increase in the standard deviation may be attributed to extreme returns which get relatively more weight after the adjustment. Yield shifts play a major role for price adjustments of government bonds. However, as the interest rate adjustment is based on the 3-month yield, the price modification partially covered the bond price development and therefore decreasing the standard deviation. The Sharpe ratio decreases for all asset classes with a delta ranging from -0.01 to -0.65. The most effected asset class by the interest rate adjustment is hedge funds with the highest change in variance and risk-adjusted return, due to their previously small standard deviation and average monthly return.

Table 4 shows the summary statistics after the interest rate adjustment as well as the exchange of all asset classes into Swiss Francs. One can observe that the conversion to Swiss Francs leads

Figure 6: USD/CHF Exchange Rate over Time

to a decrease of -2.73% in average annualised returns for all international asset classes. This is the result of the Swiss Franc largely appreciating against the US Dollar over the past 15 years. Figure 6 displays the exchange rate USD/CHF throughout the sample period. The substantial appreciation of the Swiss Franc can partially be attributed to the European debt crisis and the monetary policy of the US Federal Reserve. The European debt crisis caused investors to seek safe haven in the Swiss franc. Moreover, the recent loose monetary policy of the US also led to a relative depreciation of the US dollar. The conversion into Swiss Francs led to a higher standard deviation for all international asset classes with a delta ranging from 0.78% to 5.84%. As exchange rates are relatively volatile and show a low short-term correlation with the market (Bodart & Reding, 1999), their inclusion naturally leads to higher volatility. In some instances, even new outliers have been generated. For example, in September 2011, the SNB introduced a minimum exchange rate of CHF 1.20 per Euro as a stabilisation measurement, which increased the returns of all international asset in this month by 13%. As a result, the maximal and minimal return observations of private equity doubled. Furthermore, the minimal values of many other international asset classes have increased exactly by 4.27%, implying that the most significant value loss occurred in the same month. Due to the lower average returns and volatility, the Sharpe ratio decreased substantially for all international asset classes with a delta ranging from

-3.98% to -18.92%. Lastly, it seems the international return distributions became more aligned with a normal distribution as both skewness and excess kurtosis converge closer to zero.

Table A.14 and A.15 in Appendix A show the variance-covariance and correlation matrix, respectively, for each of the asset classes after the adjustment for interest rates and conversion into Swiss Francs. In line with literature, commodity assets seem to exhibit good risk diversification capabilities due to its low correlation with other asset classes. This is particularly true in combination with Swiss government bonds. Nonetheless, Swiss real estate and Swiss government bonds seem to add even better risk diversification potential. While domestic government bonds exhibit negative correlation in particular with the stock asset classes, Swiss real estate exhibits low correlation with hedge funds and Swiss government bonds. On the other hand, international real estate and private equity appear to be less attractive for risk diversification purposes. Both exhibit relatively high correlations with the remaining asset classes, in particular with stocks. Based on both, return variability and risk diversification capabilities, Swiss government bonds as well as Swiss real estate seem to be attractive candidates for a (conservative) mean-variance investor due to their low covariances with other asset classes.

In Chapter 7 we want to estimate the first and second central moment of the return time series. Therefore, it may be insightful to assess the correlation of the returns with their lagged observations within the same time series. This characteristic is also known as autocorrelation and may provide further information on the degree of serial dependency of the return distribution. A return series is regarded as independent if the returns are uncorrelated for all lags. We plot the autocorrelations of returns and squared returns for lags of up to 24 months across all asset classes. Corresponding Figures are found in Appendix A. We find that returns series are generally not significantly autocorrelated for any lags. One exception, however, is private equity which appears to exhibit significant positive correlation for a lag of 1 month at a significance level of 1% followed by insignificant correlations for the remaining lags. While autocorrelations of returns are often insignificantly different from zero, squared returns as a proxy of their variability tend to exhibit correlations with their lagged observations (Mandelbrot, 1967). This phenomenon is commonly known as volatility clustering expressed by significant autocorrelations that are geometrically decaying for increasing lags and may range from a few minutes to several weeks (Cont, 2007). In our sample, however, this appears to be true for private equity only. While also Swiss stocks and international real estate exhibit some significant autocorrelations of squared returns, the pattern seems less clear. Volatility cluster for a monthly frequency in our sample appear therefore less pronounced.

7 Methodology

In this chapter, we derive a model to describe the pension's liabilities. Further, we describe how the regulatory minimum interest requirement is implemented. As pension funds are liability-driven investors, we argue for a fund ratio optimising approach that is structured in a way such that assets are primarily allocated relative to the development of liabilities. Following the description of the market-timing strategy, we define the return dynamics of assets and liabilities that are a necessary condition if the pension managers assume to be able to time the market. We opt here for a forward-looking theoretical approach. The subsequent section is dedicated to the asset allocation strategy mitigating the pension scheme's interest rate risk by matching the duration of its assets and liabilities. Finally, we derive the naive fixed weight and buy-and-hold portfolios.

7.1 Pension Liabilities

We model the fair value of typical pension liability and its return dynamics according to the present value of a constant maturity index-linked bond based on the log-linear transformation described by Campbell and Viceira (2002). Assuming an ex-ante determined liability duration D_L and a given long-maturity nominal interest rate r_{10y} liability returns r_L are given by:

$$r_{L,t+1} = \frac{1}{12} r_{10y,t+1} - D_L \left(r_{10y,t+1} - r_{10y,t} \right) \tag{7.1}$$

Where r_{10y} is the 10-year Swiss government bond yield to reflect the liability's long-maturity characteristics. At the same time, we assume the duration of the liabilities to be 16 years which is a reasonable average value according to the Swiss Pension Accounting Survey of KPMG (2019)[9]. The liability discount rate is market based to ensure the pension liabilities reflect a corresponding market value. As discussed in Chapter 3.1, this contrasts regulatory liabilities for reporting purposes which are valued using a flat discount rate. Liabilities are adjusted in accordance to the method introduced in Chapter 6.2 in the same way as the remaining assets to ensure consistency of its properties relative to the assets.

[9] While a 15-year or even 16-year bond yield may be more appropriate to better reflect the liability's maturity, we choose the one available to us that is closest to this maturity

By modelling liabilities in terms of a long-term nominal bond, interest rate risk is the only risk-factor faced by the pensions fund. We explicitly do not account for inflation risk[10] and non-market related risks such as longevity, ageing and other changes in Swiss demographics. Thus, it is implicitly assumed that the characteristics of the pension scheme, the distribution of retirees and contributors remain constant over time. Moreover, we assume that monthly contribution inflows equal capital outflows. That is, premium payments and pension payments offset each other such that the asset management aspect can be analysed without bias.

7.2 BVG Minimum Interest Rate

Swiss pension schemes have to pay a minimum interest rate that is accredited to a contributor's savings account. The current minimum interest rate r_{min} is set to 1% by the regulator. Furthermore, pensions can decide to distribute additional returns based on their past long-term performance which they frequently make use of for competitional and reputational reasons. Further details are explained in Chapter 3.1.

If the funding level of a pension's liabilities falls below the regulatory threshold of 90%, the regulator allows to decrease the minimum interest paid to 0.5% (BVG §65d, 2013). Hence, the return distributed to pensioners r_{dist} is a function of the past fund performance $r_{p,t}$, the current funding ratio FR_t, and the prevailing minimum interest rate r_{min}:

$$r_{dist,t+1} = \left\{ \begin{array}{rl} r_{min} + PR * max(r_{p,t} - r_{min}, 0) & if\ FR_t \geq 1 \\ r_{min} & if\ 1 > FR_t \geq 0.9 \\ r_{min} - 0.005 & if\ FR_t < 0.9 \end{array} \right\} \tag{7.2}$$

Where PR denotes the pay-out ratio of the minimum interest exceeding returns and $r_{p,t}$ denotes the weighted average performance of the pension funds past 5-years. We choose PR=30% and

$$r_{p,t} = 0.75\bar{r}_{p,t-1} + 0.25\bar{r}_{p,t-2,t-5} \tag{7.3}$$

[10] A natural choice to accommodate inflation risk of liabilities would be inflation-linked bonds. However, markets for inflation indexed bonds are little in size relative to liabilities of pension funds. Thus, the availability of assets limits the ability to fully hedge liabilities. With inflation as the main reason why markets are assumed to be incomplete (Hoevenaars et al., 2008), we decided to exclude this risk-factor from our analysis.

Here, $\bar{r}_{p,t-1}$ is the average fund performance of the past year while $\bar{r}_{p,t-2,t-5}$ denotes the average return of past years two to five. The weights are chosen such that the distributed returns in our model approximately mimic the empirical average interest paid by the Swiss pension schemes.

To model the increased obligations that arise by paying the minimal interest as well as the additionally distributed returns, we add the total distributed returns r_{dist} to the liability returns of the subsequent period. Hence, (7.1) becomes:

$$r_{L,t+1} = \frac{1}{12} r_{10y,t+1} - D_L \left(r_{10y,t+1} - r_{10y,t} \right) + \frac{1}{12} r_{dist,t+1} \tag{7.4}$$

The liability return can thus be seen as a function of a change of its discount rate, denoted by the first two terms, and the interest paid on the contributors' accounts indicated by the last term. The progression of the liability model is thereby not only dependent on changes in the long-term interest rate, but also on the past performance of the corresponding allocation strategy that is described in the following sections.

7.3 Market-Timing

7.3.1 Model

The fundamental objective of asset-liability management is to choose assets in such a way that future liabilities can also be funded in case market conditions change. Thus, in contrast to an asset-only perspective, the performance of assets must be measured relative to the development of liabilities as a benchmark. Hence, a natural criterion for the portfolio choice of a pension fund is its funding ratio. Following Leibowitz et al. (1994), we base the optimal portfolio decision on the return of the funding ratio. The funding ratio F_t at time t is defined as the present value of assets A_t over the present value of liabilities L_t. Accordingly, the logarithmic return of the funding ratio $r_{F,t}$ equals the log-return of assets $r_{A,t}$ minus the log-return of liabilities $r_{L,t}$:

$$\begin{gathered} F_t = \frac{A_t}{L_t} \\ r_{F,t} = r_{A,t} - r_{L,t} \end{gathered} \tag{7.5}$$

Hence, the pension liabilities may also be considered a short position asset in the pension's portfolio. Both asset and liability returns are logarithmic and have been adjusted according to the method introduced in Section 6.2 above. All log-returns of the individual assets are in excess of the short-term interest rate to which level they have been adjusted to beforehand. These excess returns of the single assets as well as of the pension liability are combined in a vector x_t:

$$x_t = \begin{pmatrix} x_{A,t} \\ x_{L,t} \end{pmatrix} \tag{7.6}$$

Like Campbell and Viceira (2002) we relate the individual asset log-returns x_t to the portfolio log-return $r_{A,t}$ by using a first-order Taylor approximation, assuming that the relevant time series are jointly normally distributed[11]:

$$r_{A,t+1} = w'_{A,t}\left(x_{A,t+1} + \frac{1}{2}\sigma^2_{A,t}\right) - \frac{1}{2}w'_{A,t}\Sigma_{AA,t}w_{A,t} \tag{7.7}$$

Where $w_{A,t}$ denotes the vector for portfolio weights of the assets and Σ_{AA} the covariance matrix of the assets with σ^2_A as a vector of its diagonal elements. We explicitly do not include the option to invest in the so-called "risk-free" asset, as it is not truly risk-free in an ALM setting. This is discussed in more detail in Chapter 3.2.

Similar to van Binsbergen and Brandt (2011) as well as Hoevenaars et al. (2008), we assume the hypothetical pension manager exhibits CRRA preferences with regard to the funding ratio. Thus, the pension manager seeks to maximise her utility with:

$$\underset{w_{A,t}}{max}\; U_t\left(F_{t+1}\right) = \underset{w_{A,t}}{max}\; E_t\left[\frac{F_{t+1}^{1-\gamma}}{1-\gamma}\right], \quad \gamma > 0, \quad \gamma \neq 1 \tag{7.8}$$

This ensures that the pension manager exhibits a risk aversion that is constant and independent

[11] As discussed in Chapter 6.3, the time series in this study often exhibit fatter tails and higher peaks relative to the normal distribution. This is not unusual for financial return times series (Campbell et al., 1997). Tu and Zhou (2004) introduced an approach to incorporate uncertainty in the data generation process to account for fat tails in the return distribution. However, they find that loss due to ignorance of fat tails are small and for mean—variance investors the normality assumption works well.

from the current funding level[12]. Here, γ denotes the relative risk aversion coefficient. The maximization problem can then be described according to mean-variance portfolios such as in Campbell et al. (2003; 2002). To include the short position in liabilities into the ALM setting we use (7.1) and substitute in (7.3) to get the funding ratio return similarly to Hoevenaars et al. (2008):

$$r_{F,t+1} = w'_{A,t}\left(x_{A,t+1} + \frac{1}{2}\sigma^2_{A,t}\right) - x_{L,t+1} - \frac{1}{2}w'_{A,t}\Sigma_{AA,t}w_{A,t} \tag{7.9}$$

The mean on the funding ratio $\mu_{F,t}$ as well as its variance $\sigma^2_{F,t}$ can then be expressed as follows:

$$\mu_{F,t} = E_t\left[r_{F,t+1}\right] = w'_{A,t}\left(\mu_{A,t} + \frac{1}{2}\sigma^2_{A,t}\right) - \mu_{L,t} - \frac{1}{2}w'_{A,t}\Sigma_{AA,t}w_{A,t}, \tag{7.10}$$

$$\sigma^2_{F,t} = Var_t\left[r_{F,t+1}\right] = \sigma^2_L - 2w'_{A,t}\sigma_{AL,t} + w'_{A,t}\Sigma_{AA,t}w_{A,t} \tag{7.11}$$

Here $\mu_{A,t}$ and $\mu_{L,t}$ are vectors of the expected returns at time t for the individual assets and liabilities, respectively. While Σ_{AA}, σ_L and σ_{AL} denote elements of the total variance-covariance matrix Σ_{AL} that includes all assets as well as the liabilities:

$$\Sigma_{AL} = \begin{pmatrix} \Sigma_{AA} & \sigma_{AL} \\ \sigma_{AL} & \sigma^2_L \end{pmatrix} \tag{7.12}$$

Thus, the middle term of (7.11) represents the assets' contribution to liability hedging, while the latter part constitutes the impact of assets on the variability of the funding ratio return. Note that even for perfect correlation of assets and liabilities (7.11) cannot become negative as a result of the second algebraic identity. Σ_{AL} is estimated based on equally weighted observations of past returns throughout a rolling estimation window of 60 months. Thereby, we assume a stable variance and covariance structure such that estimation errors are homoscedastic. We thus, neglect potential volatility clusters that may lead to inefficient variance estimations. However, as detailed in Chapter 6.3, the presence of volatility cluster in our sample seems limited.

[12]This is true since the relative risk aversion: $RRA\left(FR_t\right) = \frac{-FR_t\ U''(FR_t)}{U'(FR_t)} = \gamma$

Assuming excess returns are normally distributed, the optimisation of the return on the funding ratio can then be expressed in the typical form of a mean-variance maximisation problem. Within the ALM framework, the variance of the funding ratio $\sigma^2_{F,t}$ can be regarded as the mismatch risk between assets and liabilities (Hoevenaars et al., 2008).

$$\begin{aligned} \underset{\{w_{A,t}\}}{max} & :\mu_{F,t} + \frac{1}{2}(1-\gamma)\,\sigma^2_{F,t} \\ s.t. & \;\; 1'w_{A,t} = 1, \\ & \;\; 0 \leq w_{A,t} \end{aligned} \tag{7.13}$$

Where 1 is a vector of ones with length equal to the number of assets N. The maximisation problem is numerically solved for monthly optimal portfolio weights using sequential least squared programming on a period-per-period basis. While portfolio weights and subsequent returns on assets are updated periodically, we neglect for simplicity any transaction cost, taxes and other frictions that might arise throughout frequent trading of securities. The performance of a market-timing portfolio as well as other portfolios that require frequent rebalancing may therefore be upwards biased relative to, for example, a buy-and-hold portfolio.

7.3.2 Additional Constraints

In addition to the short-sell constraints, specific asset classes are subject to individual constraints on portfolio weights. The total weight of stocks must be at a maximum of 50% of the portfolio. Similarly, the total weight of real estate assets cannot amount to more than 30% of the portfolio, of which real estate that is not located in Switzerland can be at most 10%. Other alternative assets, which in this study include commodities, private equity, and hedge funds, are capped to a total weight of 15% of the pensions' portfolio. Bonds are not restricted and can be allocated up to 100% of the portfolio. Further details are described in Chapter 3.1 Swiss Pension Regulatory Framework.

We also consider an ex-ante risk constraint that limits the chance for the funding ratio to fall below a specified funding level. A natural choice is the so-called Value-at-Risk [VaR] measure. For a pre-determined time horizon, it allows for an assertion of the maximum loss relative to a benchmark for a given probability. In an ALM framework, liabilities are an obvious choice for this benchmark. Thus, similar to van Binsbergen et al. (2011), we can specify an upper limit for the probability of the funding level to fall below a certain threshold. We set this threshold to 0.9 from which the Swiss pension regulator requires to take further actions to increase funding (see Chapter 3.1 for details). As we assume $r_{A,t}$ and $r_{L,t}$ to be normally distributed, their difference, which we define as the return of the funding ratio $r_{F,t}$, is also normally distributed. We can then specify the probability of the funding ratio to fall below the regulatory threshold by:

$$P_t\left(F_{t+1} \leq 0.9\right) = \Phi\left(\frac{FS_t - \mu_{F,t}}{\sqrt{\sigma^2_{F,t}}}\right) \tag{7.14}$$

Where $\mu_{F,t}$ and $\sigma^2_{F,t}$ are the conditional mean and variance of the funding ratio return in $t+1$ defined above and Φ describes the function of the cumulative normal distribution. The maximum shortfall FS_t denotes the distance of the funding ratio in t to the funding threshold given by the regulator i.e., the funding ratio return in t+1 that would lead to a drop of the funding level to 90%:

$$FS_t = \ln\left(\frac{0.9}{F_t}\right) \tag{7.15}$$

The probability of falling below this threshold can then be bound to an upper limit δ. We impose this constraint on a period-per-period basis. Thus, portfolio weights $w_{A,t}$ are chosen such that at the end of the investment horizon $t+1$ the conditional probability of the funding ratio to fall below the regulatory threshold remains below δ. We choose δ to be equal to 0.01. The out-of-sample probability of realising funding ratios below the regulatory threshold is likely to be different to δ. Therefore, we provide a back-test of the corresponding realised probabilities to evaluate the deviations from our distributional assumptions in the subsequent chapter.

However, if the funding ratio is below the threshold funding ratio of 0.9 for some periods, FS_t becomes positive, and the VaR constraint is impractical to hold. In-sample, this is true, by definition, in δ percent of all periods. If the funding ratio at the beginning of a period is below the regulatory threshold, the VaR constraint described above is adjusted such that the probability of a further decrease of the funding ratio is set to be below δ percent. This means the fund manager is facing the same constraint as if appropriate measures would have been undertaken to keep the funding level at the threshold of 90%.

As we study pension liabilities from a market-based perspective, the funding ratio in this study may be seen as an economic measure of the pension's financial stability as opposed to a regulatory based funding reporting. Liabilities of Swiss pensions are discounted using a technical discount rate for regulatory purposes, as discussed in Chapter 3.1. As these technical discount rates are typically smoother than actual market-based discount rates, reported funding ratios tend to be upwards biased relative to their marked-to-market value. A drop of the funding ratio below the regulatory threshold is thereby more likely for an economic funding measure that is considered here than a drop of the reported funding from a regulatory perspective. The imposed VaR constraint can thus be seen as more conservative than restrictions that would be based on regulatory measures.

7.4 Return Dynamics

We consider for main asset classes that are split into nine individual assets a pension plan can invest in. Thus, including the liability returns, we have a total of 10 return series for which expected returns need to be estimated. We acknowledge that this makes the dimension of the optimisation problem relatively large giving rise to potentially large estimation errors. From a practitioner's point of view, however, this seems to be an applicable size of asset classes a pension manager may want to consider.

7.4.1 Error Sensitivity and Models of Expected Return Estimation

Scholars of similar asset allocation problems, most notably Hoevenaars et al. (2008), van Binsbergen and Brandt (2011) as well as Campbell and Viceira (2003), have used state variables to model expected returns by applying vector-autoregressions. In particular, they utilised the often documented predictive capabilities of short-term interest rates, yield spreads and dividend yields, for example in Brandt and Santa-Clara (2006) as well as Campbell and Viceira (2003; 2005).

However, in Ang and Bekaert's (2006) study on stock return predictability, they express substantial concerns on the forecasting capabilities of these state variables. They find little evidence for return predictability of the dividend yield. On the other hand, they find the short-term interest rate to be the primary source for predictive power. However, this is only true for short horizons. They conclude that these finding might affect the asset allocation literature that "often has taken the predictive power of the dividend yield in a univariate regression as a stylized fact". Other studies find results that confirm this finding. Campbell and Yogo (2006) have developed a novel inference methodology within the framework of linear regression. They also conclude a substantially weakened forecasting power of dividend yields while they find the return predictivity of the short-term rate to be robust. A detailed discussion about return predictability is found in Chapter 4.

Another issue in the portfolio choice literature is the widely documented sensitivity of portfolio weights to little variations of expected return estimates. Kan and Zhou (2007) demonstrate analytically that the out-of-sample performance of optimal portfolio choice decisions can be very poor under parameter uncertainty. Generally, with an increasing number of assets included in the portfolio, the potential for weak out-of-sample performance and unreliable asset allocation outcomes increases even more. With an equally weighted portfolio, DeMiguel et al. (2009) show that out-of-sample optimal portfolio choice models may not outperform naive $\frac{1}{N}$ portfolios.

Many proposals have been made to overcome these shortcomings in return estimation. Jorion (1986) has suggested a Bayesian prior referred to as Bayes-Stein estimator that shrinks the sample means towards a common value: the mean of the minimum variance portfolio. By means of "shrinking" the mean, the estimation risk is statistically lowered in a natural way. Purely based on statistical arguments, however, shrinkage estimators ignore the risk-return trade-off that might help estimate expected returns. Black and Litterman (1990) propose to combine the view of active investors with the market equilibrium by a weighted average. Their idea is that the expected returns are theoretically consistent with the market equilibrium, with the explicit exception that the manager seeks to contribute her own view. While Black and Litterman are using the International Capital Asset Pricing Model[13] developed by Adler and Dumas (1983), Jorion (1991) considers the traditional Capital Asset Pricing Model [CAPM] introduced by Sharpe (1990) and Lintner (1965) to estimate the mean for portfolio choice. He compares three classes of estimators based on the estimation errors they produce as well as the Sharpe-ratio of the estimated optimal portfolio: the classic sample mean estimator, the Bayes-Stein shrinkage

[13]In contrast to the traditional CAPM, the international CAPM includes a basket of foreign currency as a second risk factor to incorporate exposure to currency in the estimation of expected returns.

estimator and the CAPM based estimator. Even though shrinkage estimators showed substantial improvement relative to historical means, the best performing estimator is found to be based on the Sharpe-Lintner CAPM.

7.4.2 The CAPM as a Mean Estimator

In Chapter 7.3, one variable has not been defined yet: the mean of assets and liabilities μ_A and μ_L, respectively. As described above, the estimation of expected returns is not trivial. Estimation errors can severely influence the outcome of the portfolio optimisation. Moreover, the predictability of returns from state variables is controversial where the short rate appears to be a promising exception. As time-series in this study are adjusted to deterministic interest rates, however, an empirical estimation based on historic short-term rates is ruled out. Instead, we opt for a more theoretical forward-looking approach that various scholars (see previous Section 7.4.1 above), as well as practitioners in one form or another, rely on: the capital asset pricing model.

Expected excess returns are estimated based on the Sharpe-Lintner CAPM. This model is based on the central assumption of market equilibrium. The concept is that generally, all investors hold some fraction of the market portfolio and the remainder in a risk-free asset. Hence, if the market equilibrium assumption holds, i.e. expected returns equilibrate the demand and supply for assets, then expected excess returns are proportional to the covariance of excess returns on the assets and the market portfolio. The market risk premium is the return on the market portfolio in excess of the risk-free asset. The essential insight of the CAPM is that, given the market equilibrium, the risk premium of any asset is the market risk-premium scaled by its sensitivity to the market portfolio. This sensitivity is commonly also termed as "systematic risk" due to its non-diversifiable nature.

Hence, the CAPM estimation model reduces expected excess returns to be solely a function of systematic risk and the market risk premium. If all returns are defined to be excess returns, the expected return on assets can be described as:

$$\begin{gathered}\mu_{AL,t} = E\left[r_{AL,t+1}\right] = \beta_{AL,t} E\left[r_M\right] \\ \beta_{AL,t} = \frac{Cov\left[r_{AL}, r_m\right]}{Var\left[r_M\right]}\end{gathered} \tag{7.16}$$

Where $\beta_{AL,t}$ is the rolling covariance of the excess returns on the relevant asset or liability and the market portfolio scaled by the variance of the latter. Moreover, r_m denotes the expected returns on an equally weighted equity and bond market portfolio to account for the securities' exposure to both markets. For the former, we use the MSCI All Country World Index weighted by market capitalisation as a proxy while the latter is proxied by the Bloomberg Barclays Global-Aggregate Index measuring the total return of global investment-grade bonds.

One can observe that the CAPM provides a cross-sectional relationship between assets and thereby explaining the risk-return trade-off. In doing so, we implicitly assume that $\beta_{A,t}$ captures all cross-sectional variations of assets' excess returns and that the intercept is zero. Another assumption is that the risk premium on the market portfolio must be positive. We ensure the non-negativity of the expected market return by using Merton's (1980) simple technique to estimate the market return:

$$E\left[r_m\right] = max(\mu_m, 0) \tag{7.17}$$

Where μ_m is the historical average excess return on the market portfolio using the same window length as for the rolling beta estimation.

We estimate the expected excess returns of the liabilities under the market equilibrium hypothesis. Thereby, we implicitly pretend that pension liabilities are tradable on the market. For simplicity, the liability asset is modelled like a nominal bond on in which the pension scheme holds a short position. Hence, for the purpose of this study, the assumption of tradable liabilities seems not too far-fetched in order to remain within the market equilibrium assumption setting.

7.4.3 Bayes-Stein as a Mean Estimator

To assess the robustness of the market-timing strategy in the previous section, we additionally estimate the excess returns of assets and liabilities by applying the aforementioned Bayes-Stein method developed by Jorion (1986). As discussed earlier, if and to which extent expected returns can be predicted is uncertain. An often cited and widely used method is a so-called Bayesian shrinkage method. In contrast to the CAPM estimator, a Bayesian shrinkage estimator is a purely statistical method based on historical means. It aims to statistically reduce estimation risk by 'shrinking' the sample means to a joint value. The consensus view is that this approach may be more efficient than a simple average of past returns as aggregating information that is potentially also contained in the cross-section provides a better estimation of expected returns (Jorion, 1991). For example, assets with high historical returns relative to their peers are likely to contain comparatively more positive estimation errors, and therefore, future returns might perform less well.

One example is the Bayes-Stein estimator has initially been developed by James and Stein (1961). This estimator is the so-called empirical Bayes because the shrinkage factor is derived directly from data. In an out-of-sample portfolio choice setting, Jorion (1991) has shown that the Bayes-Stein estimator outperforms the simple sample mean substantially.

We construct the Bayes-Stein estimator in accordance to Jorion (1986)and shrink the sample means towards the minimum-variance portfolio:

$$\begin{aligned} \mu_{AL,t} = E\left[r_{AL,t+1}\right] = \left(1 - w_t\right)\bar{\mu}_{AL,t} + w_t \mu_{0,t} 1, \\ w_t = \frac{\lambda_t}{\lambda_t + T}, \\ \mu_{0,t} = \frac{1' \Sigma_{AL,t}^{-1} \bar{\mu}_{AL,t}}{1' \Sigma_{AL.t}^{-1} 1}, \\ \lambda_t = (\frac{\left(N+2\right)\left(T-1\right)}{\left(\bar{\mu}_{AL,t} - \mu_{0,t} 1\right)' \Sigma_{AL,t}^{-1} \left(\bar{\mu}_{AL,t} - \mu_{0,t} 1\right)\left(T - N - 2\right)} \end{aligned} \tag{7.18}$$

Where Σ_{AL}^{-1} is the inverse of the covariance matrix of assets and liabilities, N and T are the number of assets and sample-size, respectively, and 1 is again a vector of ones with length N. While $\bar{\mu}_{AL,t}$ denotes a vector of the sample-means of asset and liabilities across the estimation window, $\mu_{0,t}$ represents the cross-sectional estimated return of the minimum-variance variance portfolio.

7.5 Immunisation

Contrary to an asset allocation strategy in which the manager assumes to be able to time the market, the duration matching method seeks to minimise – or at best eliminate – the mismatch risk between assets and liabilities in case interest rates change. Thus, unlike the market-timing strategy, the emphasis is not on utilising the upside potential by maximising an estimated risk-return trade-off. Instead, the main objective of duration matching is to minimise the downside risk in terms of the deviation of assets from liabilities.

The appealing feature of this method is that it is almost assumption-free. While a mean-variance analysis is naturally exposed to estimation risk of return and risk-parameters, a duration matching approach only requires the durations of the assets and the pension liability. The sensitivity of stocks with regard to interest rate changes is not stable over time and is therefore unreliable for liability hedging purposes. Consequently, an asset allocation strategy based on durations can only include fixed-income securities for which interest rate sensitivities can be calculated. The duration matching method in this study, therefore, includes long-term government bonds only. In Chapter 4, we discuss findings of the stock's interest rate sensitivity in more detail.

Generally, to derive a bond's interest rate sensitivity, one needs to know the particular underlying interest rate, by which its cash-flows are discounted. In our analysis, the investor can choose between two long-maturity government bond indices, a domestic Swiss government bond index and a US-Dollar denominated international basket of long-term government bonds. The latter is adjusted for the USD/CHF exchange rate exposure. Further, durations and convexities of the international bond index are based on durations and convexities of its underlying constituents that have exposure to interest rates of various countries. As defined previously in Chapter 6.2, we further assume a perfect correlation of the Swiss interest rates to the basket of international interest rates.

Using their convexity properties (i.e. the second-order derivative of the bond prices with regard to the interest rate), we adjust the durations of both bond indices in order to correspond to the relevant adjusted interest rate according to Chapter 6.2:

$$D^{*}_{A,t} = D_{A,t} - \frac{1}{2} C_{A,t} \left(r^{*} - r_{s,t} \right) \tag{7.19}$$

Where $D^{*}_{A,t}$ is the asset's duration adjusted for interest rate r^{*} while $D_{A,t}$, $C_{A,t}$, and $r_{s,t}$ are the unadjusted duration, convexity and Swiss 3-months treasury rate, prevailing at time t, respectively.

Durations of assets and liabilities can then be matched by minimising the mismatch between the portfolio duration and the duration of the pension liability. The portfolio duration of total assets $D^*_{A,t}$ can be derived by the weighted sum of individual bond durations $D^*_{B,t}$ and their portfolio weights $w_{B,t}$:

$$D^*_{A,t} = D^*_{B,t} w_{B,t} \tag{7.20}$$

Where $D^*_{B,t}$ and $w_{B,t}$ are both vectors only assigned to the fixed-income assets.

The risk-mitigating duration matching approach becomes then a simple minimisation problem of the form:

$$\begin{aligned} \underset{\{w_{B,t}\}}{min} &: \left| D^*_{A,t} - D_L \right| \\ s.t. \;\; & 1' w_{B,t} = 1, \\ & 0 \leq w_{B,t} \end{aligned} \tag{7.21}$$

Here, $|x|$ denotes the absolute value of x and the liability duration D_L is assumed to be constant over time to ensure the minimum of the function is where asset and liability duration match. As in Section 7.3, we impose short-sale constraints on the asset weights such that bond weights sum to one. Commonly, an immunisation strategy would additionally require the present value of assets and liabilities to be equal in $t = 0$. However, we also consider a pension scheme that is initially underfunded and seeks to limit its downside risk by immunising the portfolio when liabilities have already increased above the asset value.

In matching only the duration of assets and liabilities, we ignore the convexity property of interest rate sensitivity and implicitly assume only small potential changes in interest rates. For a more comprehensive elimination of interest rate risk, the respective convexities would have to be matched as well[14]. However, as there are only two bond assets available to invest in, a full immunisation is often not achievable. Even in the case of duration matching, the liability

[14] To be precise, the convexity of assets would have to be greater than that of liabilities to prevent the duration gap to become negative when interest rates change.

duration is for some points of time t higher than the maximum portfolio duration. This makes it impossible to match the liability duration in some cases entirely. However, this issue is not so far from reality as long-maturity bonds that perfectly match the liabilities are often not easily available or relatively expensive. As discussed in Chapter 3.2, this is particularly true during low interest rate periods.

7.6 Buy-and-Hold and Fix-Mix

We refer to the buy-and-hold and fix-mix strategies as naïve allocation because they require relatively few assumptions. Both are, in essence, ex-ante determined portfolios that require an initial setup by choosing an appropriate weighting of the assets at the beginning of the investment horizon.

For the fix-mix approach, theses portfolio weights are kept constant during the entire investment horizon. This requires continuous (i.e. periodic) rebalancing of the securities. At the end of each period $t+1$, appreciated assets are sold, and depreciated assets are purchased until the initial portfolio mix is restored. Thus, it may, to some extent, also be seen as a buy low – sell high strategy. Here, we also neglect any transaction cost or taxes that might occur by rebalancing the portfolio.

Initial portfolio weights $w_{A,0}$ are chosen by applying the optimisation procedure described in Section 7.3.1 once at the beginning of the investment horizon. Thus, the initial setup of the market-timing portfolio and the naïve portfolios is the same, allowing for a direct comparison of the strategies' performance. Using the log-linear approximation of (7.3), the fix-mix portfolio return $r_{FM,t}$ is then:

$$r_{FM,t+1} = w'_{A,0}\left(x_{A,t+1} + \frac{1}{2}\sigma^2_{A,t}\right) - \frac{1}{2}w'_{A,0}\Sigma_{AA,t}w_{A,0} \tag{7.22}$$

The portfolio returns of the buy-and-hold approach are derived in a similar manner. The portfolio is purchased based on the initial optimisation and then held until the end of the investment horizon. Here, the weights are not constant over time. Instead, they deviate from the initial target rate conditional on the previous development of the assets. The buy-and-hold portfolio returns $r_{BH,t}$ can then be denoted as:

$$r_{BH,t+1} = w'_{A,t}\left(x_{A,t+1} + \frac{1}{2}\sigma^2_{A,t}\right) - \frac{1}{2}w'_{A,t}\Sigma_{AA,t}w_{A,t} \tag{7.23}$$

Here, $w_{A,t}$ is only dependent on prior performance of the individual assets and the initially chosen weights $w_{A,0}$. Thus, the weighting of these assets floats relatively freely and may exceed the maximum allocation allowed by the regulator. We then intervene and sell the assets whose relative portfolio weights exceed the regulatory maximum value in favour of Swiss or international government bonds depending on the nature of the asset sold. There are no regulatory constraints on the allocation towards government bonds. This approach allows to comply with the regulatory guidelines. However, it also makes the buy-and-hold strategy less risky ceteris paribus.

8 Results

8.1 Estimation

In this section, we present estimation results that are mainly related to the market-timing method. In Chapter 7 above, we proposed two techniques to estimate expected returns: a Bayes-Stein shrinkage approach in which the simple means of the individual assets are shrunk towards the mean of the minimum-variance portfolio and a CAPM estimation that is based on the systematic risk of the assets relative to the global market portfolio.

Table 5: Return Estimation Errors

Mean squared estimation error [MSE] in per mille across all assets, including the pension liabilities [LB] for the simple mean, Bayes-Stein and CAPM estimation procedures. The total column shows the sum of MSEs across assets.

	ST CH	ST Int	GB CH	GB Int	RE CH	RE Int	CM	PE	HF	LB	**Total**
Mean	1.94	2.92	0.43	1.71	0.45	3.06	2.87	5.19	1.08	0.71	**20.35**
Bayes-Stein	1.88	2.85	0.43	1.70	0.46	2.97	2.85	5.06	1.06	0.70	**19.96**
CAPM	1.81	2.78	0.45	1.69	0.47	2.94	2.86	4.96	1.05	0.72	**19.73**

We evaluate the performance of the prediction methods based on the average squared deviation of predicted returns relative to the realised returns over time. This is done for all assets and the liabilities, allowing for a global cross-evaluation of the two estimation techniques. We also include the simple mean estimate for benchmark purposes.

Overall, the CAPM estimator appears to predict returns slightly better than a Bayes-Stein estimation and even more so compared to the simple mean.[15] On a more granular basis, however, the CAPM forecasts are marginally outperformed for the Swiss government bond and liability returns as well as Swiss real estates. The Bayes-Stein estimator appears to capture some information from the cross-section and predicts returns better than the simple mean. However, this is not true for the Swiss real estate index.

The global results across all assets in our sample confirm the findings of Jorion (1991), who suggests the CAPM to be the superior predictor relative to both, the Bayes-Stein shrinkage

[15] We estimate the explanatory power of the CAPM using the two-step regression approach proposed by Fama and MacBeth (1973). Although the CAPM outperforms the simple mean and Bayes-Stein predictors in our sample in terms of MSE, it seems it cannot explain the risk-return trade-off on a statistically significant basis. We find both, the intercept and slope of the security market line to be positive albeit insignificant.

and simple mean approaches[16]. We move forward using the CAPM as default return predictor. Nonetheless, to analyse the sensitivity of the market-timing strategy towards different forecasting models, we refer to corresponding results on occasion.

Estimations of the second central moment of the asset's return distributions may provide additional insights on how assets may be allocated in an optimal portfolio. Like in Campbell and Viceira (2005), we assume homoscedastic returns, i.e. return variability is independent of time, and estimate return variance on equally weighted observations. Thereby, empirical evidence for volatility clusters of financial return time-series is neglected.

With few exceptions, however, the estimated variability of asset returns (plotted in the right half of Figure 7) appears to be relatively stable over time, implying the unconditional variance estimation may not be unreasonable. Along the entire investment horizon of 15 years, only private equity returns appear to diverge substantially more than three standard deviations. Assets that are exposed to currency risk naturally show higher levels of volatility and exhibit jumps as a result of the unpeg of the Swiss Franc to the Euro. As discussed earlier in Chapter 6.3, Swiss real estate returns appear to be substantially more stable and less volatile than its international counterpart.

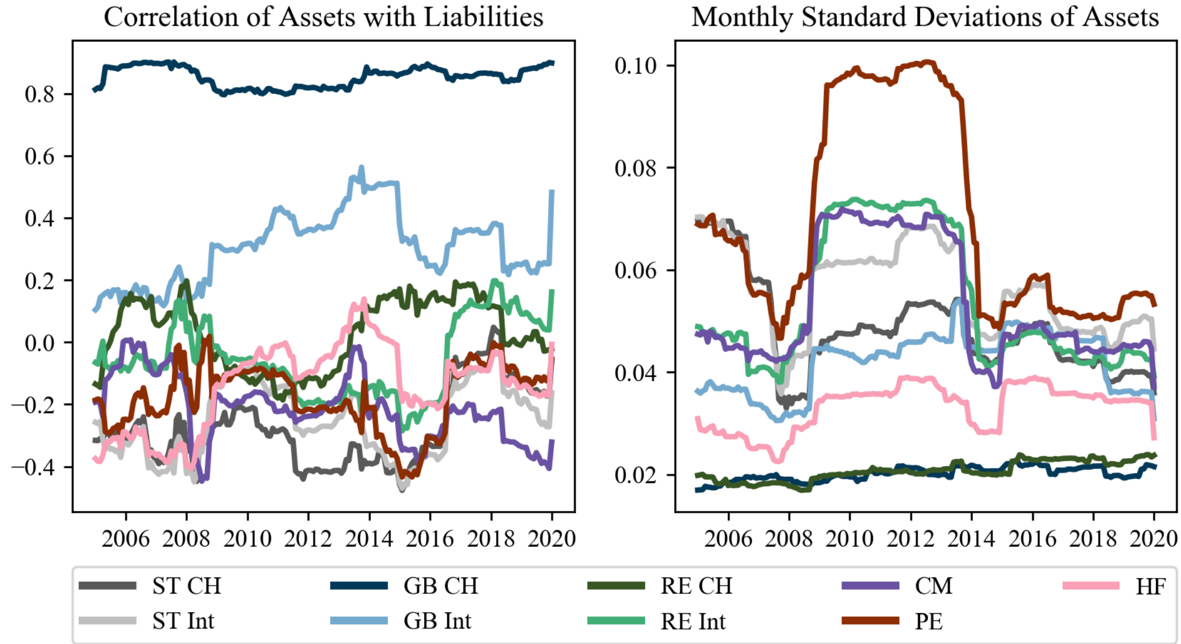
After determining the model of pension liabilities in previous Chapter 7.1, the liability-hedging capabilities of the asset classes can be estimated. Besides expected returns and their variability, this is an essential characteristic for an ALM investor who wants to allocate assets that best match their liabilities to ensure stable funding.

Also, the correlation estimates of the assets with the pension liabilities (plotted in the left half of Figure 7) seem for most assets relatively stable over time. As expected, government bonds have the best liability-hedging potential. However, while Swiss bonds exhibit an almost constant correlation of approximately 0.8, international bonds hedging capabilities are markedly lower, varying from 0.15 to almost 0.6. This is of no surprise, as international government bonds comprise various countries and thereby exhibit additional risk that mainly stems from country-specific currencies and yields. The correlation of Swiss real estate and liabilities varies around zero while most other asset classes almost always exhibit a negative correlation coefficient.

[16]Interestingly, the pattern of estimation errors over time is not very different for the CAPM and Bayes-Stein estimators. Only the magnitude of estimation errors appears to be slightly smaller for the CAPM method.

Figure 7: Estimations of Asset and Liability Correlation and of Asset Variability

Pearson correlation coefficients of asset classes with liabilities (left) and monthly standard deviations of assets (right) over time.



Thus, based on their low volatility and relative high liability-hedging potential, we expect a substantial allocation of Swiss government bonds and real estate in the optimal portfolio.

8.2 Asset Allocation

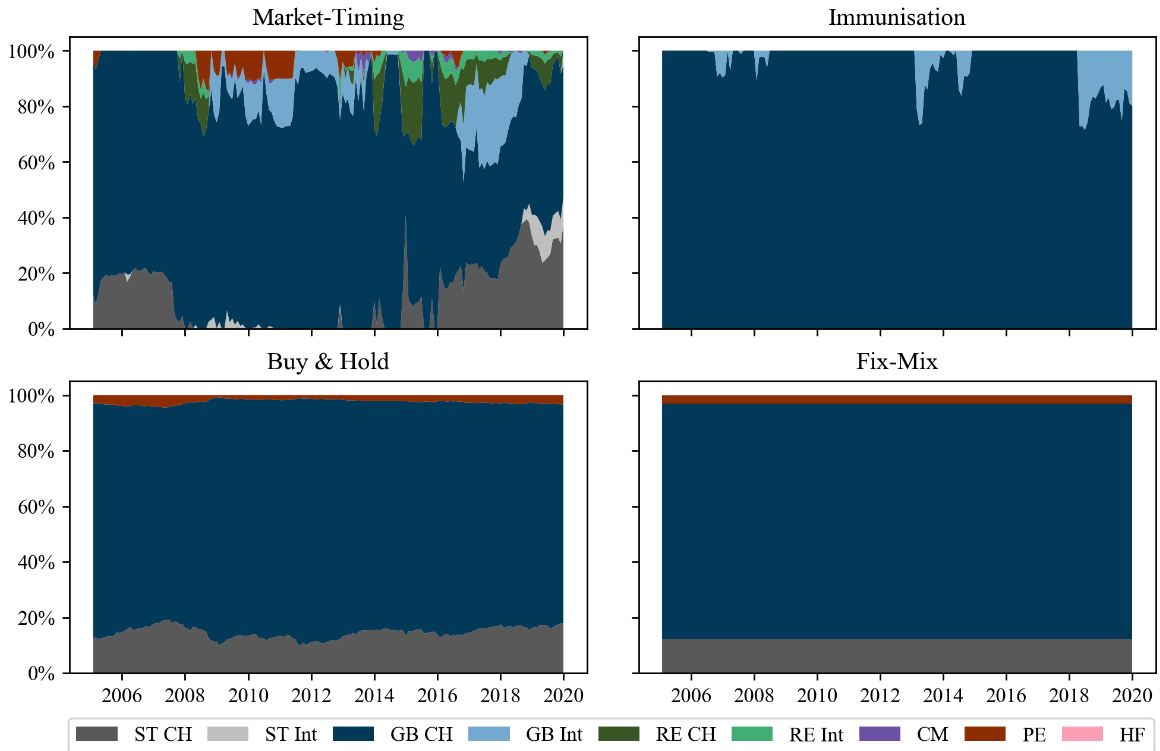
To understand the performance of the four proposed strategies, it may be helpful to consider how assets are distributed in each portfolio, respectively. While the allocation of the immunisation portfolio only depends on the duration level of the two government bond assets, the asset allocation of the buy-and-hold, as well as the fixed-mix strategy, is conditional on their initial weights. The initial portfolio composition for these strategies, in turn, is derived from a single-period optimisation in $t = 0$ that is in line with the market-timing approach. Therefore, the buy-and-hold, the fix-mix, as well as the market-timing portfolio, are identical at the beginning of the investment horizon.

The optimal portfolio depends on the relative risk aversion of the pension scheme as well as the initial level of funding. We choose to set $\gamma = 10$ as a default moderate degree of risk aversion.

Also, by default, the pension starts fully funded at a funding ratio of FR=1. In addition, we evaluate how allocated assets and performance of the strategies change if these default values vary. Thus, we also consider a riskier as well as a conservative pension manger with a relative risk aversion of $\gamma = 5$ and $\gamma = 15$, respectively. As we are in a state of low interest rates where the liability market value may already have risen above that of the assets, we also consider that the pension fund might begin underfunded. Hence, on occasion, we additionally evaluate the strategies if the pension is initially underfunded ($FR = 0.95$), yet still above the regulatory threshold of 90%, as well as a start from a relatively comfortable funding level where $FR = 1.1$.

Assessing how assets are allocated for each respective strategy allows us to evaluate the contribution of the individual asset classes to the portfolio and to get an initial sense of its riskiness. A portfolio composition over time may by interesting mainly for the market-timing approach relative to the three remaining strategies that are not time-dependent. Comparing the market-timing model that tries to capture time-varying risk premia subject to a funding risk constraint with naïve allocations that lack these features may already give first insights.

Figure 8: Cumulative Portfolio Composition Across Allocation Strategies over Time



For the default case with moderate risk aversion and full funding, the asset allocation is widely dominated by domestic government bonds with 84.9% and 12.1% Swiss stocks in $t = 0$. With 3.0%, private equity is the only asset class included in the initial optimal portfolio that is exposed to currency risk. The immunisation or duration matching portfolio is dominated by Swiss bonds as well. This is the result of the practical reason that Swiss governments bonds often exhibit a larger duration than its international counterpart. Moreover, with some exceptions, the liability duration is higher than both. This is often the case in practice as long-duration bonds tend to be considerably expensive, especially during low interest rates. See Chapters 3.2 and 5 for discussion on this issue.

For the buy-and-hold strategy, equity allocation was growing to a peak of almost 20% of the total portfolio in autumn 2007 but falls to 10.0% in early 2009 as a consequence of the financial crisis. The market-timing strategy, on the other hand, already starts divesting from stocks by late 2007. This is largely credited to the value-at-risk constraint that takes into account the increased volatility and a sharp decline of the funding level during that time. Instead, the market-timing investor increasingly invested in real estate, international government bonds and to a marginal amount into commodities. Hedge Funds are at no time included in the optimal portfolio even though they exhibit relatively low variance. This seems to be the result of their low return and diversification potential.

Table 6: Market-Timing Asset Allocation for Different Levels of Risk Aversion

Average asset allocation (in % of the total portfolio) of the market-timing strategy for different levels of relative risk aversion [RRA (γ)] and initially fully funded liabilities.

RRA (γ)	ST CH	ST Int	GB CH	GB Int	RE CH	RE Int	CM	PE
Risky (5)	21.1%	3.6%	51.5%	9.3%	7.0%	3.7%	0.6%	3.3%
Moderate (10)	11.0%	1.0%	72.7%	6.8%	4.3%	1.5%	0.4%	2.3%
Conservative (15)	7.2%	1.0%	81.4%	5.6%	1.9%	0.9%	0.4%	1.5%

While a moderate market-timing investor would on average allocate 12.0% to stocks, 79.5% to government bonds and 8.5% towards real estate and alternatives, these preferences naturally change for varying levels of risk aversions. A risky investor would with 24.7% more than double its allocation to stocks and at the same time increase her exposure towards real estate (10.7%) and alternatives (3.9%) of which the largest part comes from private equity. A pension manager with relative high risk-aversion, on the other hand, would only allocate 8.2% towards stocks while 87.0% of her portfolio is comprised of government bonds. Real estate and alternative assets only make up only 4.7%. As expected, domestic government bonds play a substantial role in the market timing portfolio across all levels of risk aversion. This is due to its low variability, high liability-hedging potential, and its good risk-diversification capabilities as a result of its low correlation particularly with stocks. International assets appear to contribute considerably less towards the total portfolio than its Swiss counterparts, due to the exposure to currency risk. This is also true for international government bonds for which the average portfolio allocation is reduced with increased risk aversion.

A risk-taking pension manager that simply buys and holds the portfolio, or regularly rebalances towards the initial weights, seems to invest a larger share in risky assets than if she would time the market. Her portfolio composition includes 25.9% Swiss stocks, 45.2% domestic government bonds, 24.9% real estate of which more than two-thirds are Swiss and 4.2% in private equity at the beginning of the investment period. In contrast, a conservative investor only invests 5.1% in Swiss stocks, 91.6% towards domestic government bonds and 3.3% in private equity. Thus, also a conservative investor that chooses to allocate assets naively appears considerably more conservative than if she chose to time the market. This is primarily due to the fact that the initial portfolio weights of the buy-and-hold and fix-mix strategies are determined only once at $t = 0$ while the market timing composition changes over time allowing for a regression towards a mean that is naturally less extreme. The immunisation portfolio does not depend on an investor's risk preference and is thereby unaffected by varying levels of risk aversion.

The effect on the portfolio allocation is less clear if the funding levels at the beginning of the investment period are varied. Beside the default case of fully funded pension liabilities, we also consider funding levels of 95% and 110%. This means that a drop of the funding ratio towards the regulatory threshold of 90% is more or less likely and the VaR-constraint may be attained more or less quickly. Thus, a pension manager facing a comfortable funding level of 110% might be able to freely optimise her portfolio while an optimal allocation might be restricted if the funding level at the beginning is close to the regulatory threshold.

A pension scheme that starts on a funding ratio of 1.1 is in a more favourable position if its assets are declining unexpectedly in case of a recession or market crash. This extra cushion allows for an optimal portfolio without the risk of facing the additional VaR constraint for an extended period of time, ceteris paribus. Hence, the pension fund can on average allocate more assets to

Table 7: Market-Timing Asset Allocation for Different Levels of Initial Funding

Average asset allocation (in % of the total portfolio) of the market-timing strategy for different levels of initial funding and a moderate level of risk aversion.

Initial Funding	ST CH	ST Int	GB CH	GB Int	RE CH	RE Int	CM	PE
95%	13.6%	1.5%	70.6%	4.7%	3.7%	2.9%	0.4%	2.7%
100%	11.0%	1.0%	72.7%	6.8%	4.3%	1.5%	0.4%	2.3%
110%	12.0%	1.3%	68.2%	6.4%	6.1%	2.0%	0.4%	3.7%

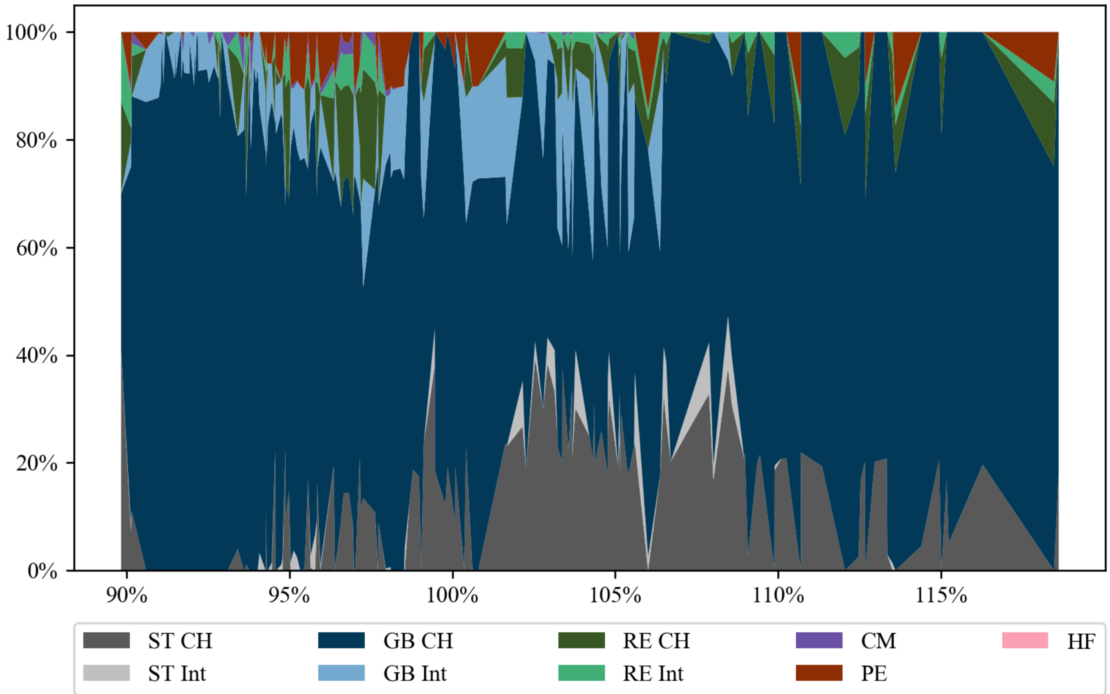
riskier investments than a pension without this additional buffer. Relative to the default case of only 100% funding of the liabilities, our model allocates 1.3% more in stocks, 2.3% more in real estate and an additional 1.4% in private equity. Therefore, for the market-timing investor, an extra funding of 10% has only minor effects on the average asset allocation over time. If the pension scheme starts with underfunded liabilities that are close to the regulatory threshold, however, the VaR risk constraint exhibits adverse effects. The probability of falling below the funding threshold is now higher. Depending on the investor's risk preference, the model increases the exposure to stocks substantially in case the funding level falls below 90%. Less risk-averse managers prefer high expected returns over low future volatility. As a consequence, the VaR constraint may lead to an increase in risky assets to break out of the 90% funding level (see Figure 9 below) if the investor exhibits risky ($\gamma = 5$) or moderate ($\gamma = 10$) relative risk aversion. This explains why the model allocates an additional 4.2% of risky assets if liabilities are initially underfunded.

Plotting the allocation of assets of the market-timing strategy on the monthly funding ratio shows the effect of the VaR constraint on the portfolio composition. For a funding ratio decreasing from a level of approximately 1.02 and approaching the regulatory threshold of 0.9, a larger share of bonds is allocated, and the portfolio becomes less risky. However, for funding ratios very close to 0.9 and beyond, allocation to stocks and real estate increases sharply leading to an overall riskier portfolio. This appears to be the consequence of the VaR constraint requiring zero loss in the tail given the funding level falls below the regulatory threshold, which may be easier to reach by increasing expected portfolio return than limiting its variance.

Initial compositions of the fix-mix and buy-and-hold portfolios do not change if an extra cushion of 10% is added to the assets at the beginning of the investment horizon. The reason is that the portfolio is already optimal if the funding level is at 100%, and thus, the VaR constraint is

Figure 9: Cumulative Portfolio Composition Sorted by Funding Level

Cumulative asset allocation of the default market-timing strategy sorted by realised funding ratios in t.



not affected. However, if the initial funding level is decreased to 95%, both portfolios become more conservative as allocation to stocks declines by 1.4%. Again, the allocation of immunisation portfolio does not depend on the initial funding ratio and thereby does not change. Portfolio compositions over time for all four strategies in every combination of relative risk aversion and initial funding ratio are attached in Appendix B.

8.3 Performance

After getting a general understanding of how assets are allocated for each respective strategy and varying premises, a pension manager is naturally interested in how these strategies perform. We measure and compare the performance of the four strategies using different key metrics to evaluate which approach may be best suitable, given a low interest rate environment. Besides performance indicators that are typically used in an asset-only setting, from an ALM perspective, an evaluation of the strategies relative to the development of the pension liabilities as a benchmark is essential. Hence, we assess not only the risk-return trade-off that results from the allocation of assets but also the risk that the market value of assets falls below that of the liabilities. As in the previous section, we analyse the performance of the four strategies by assuming different levels of risk preferences and initial funding.

Considering only the return on assets generated, we compare the four strategies based on their risk-return profile to get an initial idea of the return distribution. That is, we evaluate the annualised mean and standard deviation of excess returns generated as well as the Sharpe ratio for the corresponding strategies.

Table 8: Strategy Performance for Different Levels of Risk Aversion

Annualised mean, standard deviation and Sharpe Ratio across different levels of risk aversion [RRA(γ)] and initial funding of 100% for all four strategies throughout the entire investment horizon

	Market-Timing			**Imm.**	**Buy-and-Hold**			**Fix-Mix**		
RRA (γ)	5	10	15		5	10	15	5	10	15
Mean (%)	6.80	6.40	5.97	5.04	6.21	5.56	5.30	6.58	5.78	5.47
Std Dev (%)	7.63	6.69	6.48	7.38	6.50	5.96	6.41	6.50	6.01	6.41
Sharpe	0.89	0.96	0.92	0.68	0.95	0.93	0.83	1.01	0.96	0.85

The immunisation strategy appears to perform the worst among all strategies if only asset returns are considered. It exhibits the lowest average return and interestingly, one of the largest return variations. This may be attributable to the lack of diversification of the duration matching approach due to its sole allocation to fixed-income securities. The market-timing strategy generally seems to provide the highest returns among the strategies regardless of the pension manager's level of risk aversion. However, for a risk-affine investor, the return volatility is proportionally more increasing than the average return generated. On the other hand, a conservative investor exhibits a relatively greater decrease in average returns than their variability that results in a drop of the Sharpe ratio for both risky and conservative investors. The buy-and-hold and fix-mix strategy both profit from a riskier portfolio composition in t=0 that result in substantially higher mean returns compared to their moderate and conservative counterparts. Interestingly, the volatility of returns of both naïve allocation strategies is higher if the risk aversion increases from $\gamma = 10$ to $\gamma = 15$ while returns generated are lower on average. Thus, both strategies are inferior relative to the market-timing strategy for high levels of risk aversion. However, due to their substantially lower return variability for $\gamma = 5$, the buy-and-hold and fix-mix strategy appear to outperform the market-timing approach in terms of risk-return trade-off. Overall, the market-timing approach appears relatively riskier and performs well if risk aversion is high while in particular, the fix-mix strategy performs well when risk aversion is low.

Table 9: Strategy Performance for Different Levels of Initial Funding

Annualised mean, standard deviation and Sharpe Ratio across different levels of initial funding and relative risk aversion of 10 for market-timing, buy-and-hold as well as fix-mix strategy throughout the entire investment horizon.

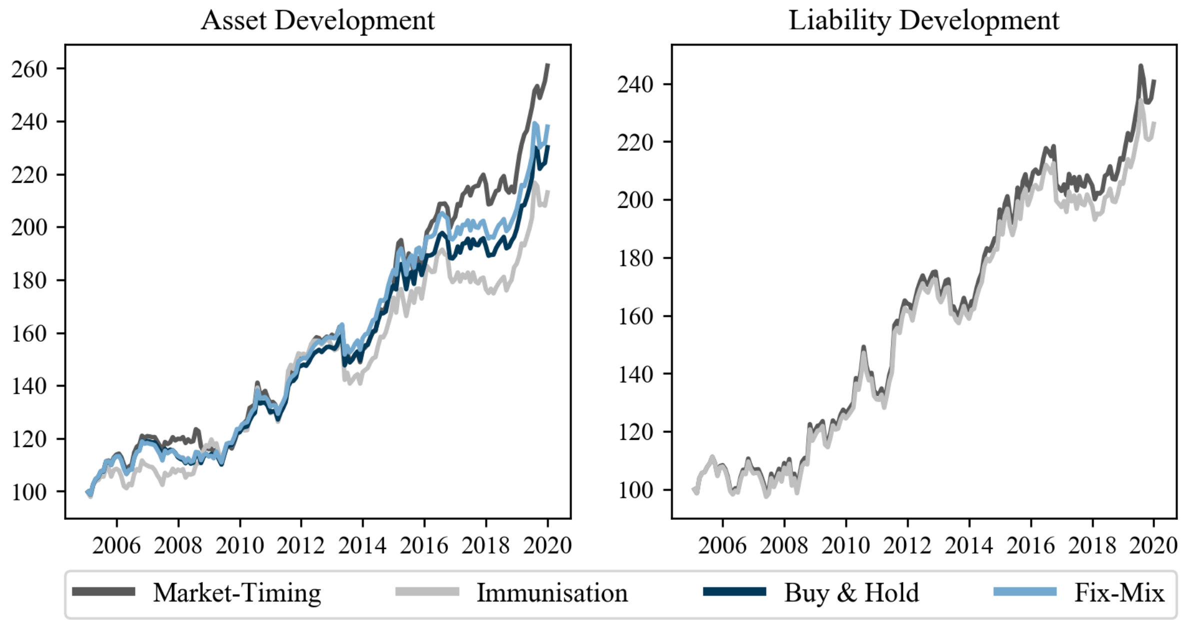
	Market-Timing		**Buy-and-Hold**		**Fix-Mix**	
Initial Funding	95%	110%	95%	110%	95%	110%
Mean (%)	5.93	6.19	5.51	5.56	5.72	5.78
Std Dev (%)	7.63	6.19	6.03	5.96	6.07	6.01
Sharpe	0.78	1.00	0.91	0.93	0.94	0.96

When initial funding is decreased, average returns decline and volatility rises across all strategies that are conditional on the funding level. Thus, if the pension fund is initially underfunded, it appears to perform relatively worse than it would otherwise. The reason is that an optimal portfolio is constrained at an earlier time if the funding ratio is closer to the regulatory threshold. As the portfolio weights for the buy-and-hold and fix-mix strategy are only chosen once at the beginning of the horizon, this effect is naturally smaller than for the market-timing approach for which the portfolio composition depends on the funding ratio periodically. If the pension scheme starts with an extra cushion for the funding of liabilities, it appears to outperform a naïve allocation in terms of the Sharpe ratio. However, a reduction of the initial funding level has a considerable negative impact on the performance of a market-timing investor as it markedly increases the volatility of returns. This effect is more (less) severe if the risk tolerance is higher (lower). Corresponding data for variations of initial funding ratios and risk aversion are found in Appendix B. Overall, the market-timing approach seems to outperform other strategies solely based on asset-returns if risk aversion and initial funding are high. The fix-mix strategy appears to work best if the level of risk aversion and initial funding are low.

We have seen in Table 8 that on average, the market-timing approach generates the highest return. This appears to be almost consistent over time. In the default case of moderate risk aversion and initial full funding, the market-timing strategy seems to outperform the other strategies most of the time in terms of asset growth. However, this is not true for low levels of risk aversion and initial funding of liabilities (corresponding Figures can be retrieved from Appendix B). In these cases, the fix-mix strategy often outperforms the market-timing strategy as well as both other strategies. Interestingly, the fix-mix strategy appears to consistently outperform the buy-and-hold strategy in every combination of risk-aversion and initial funding ratio. Furthermore, despite

Figure 10: Development of Assets and Liabilities

Development of assets (left) and liabilities (right) over time for initially fully funded liabilities and a moderate level of risk aversion. Liabilities of the buy-and-hold and fix-mix strategies lie between the ones of market-timing and immunisation strategies and have therefore been omitted for simplicity reasons.



a relatively well-performing period from late 2008 until late 2012 in which the 10-year Swiss government bond yield fell by 3%, the immunisation approach is over the long run outperformed in every case.

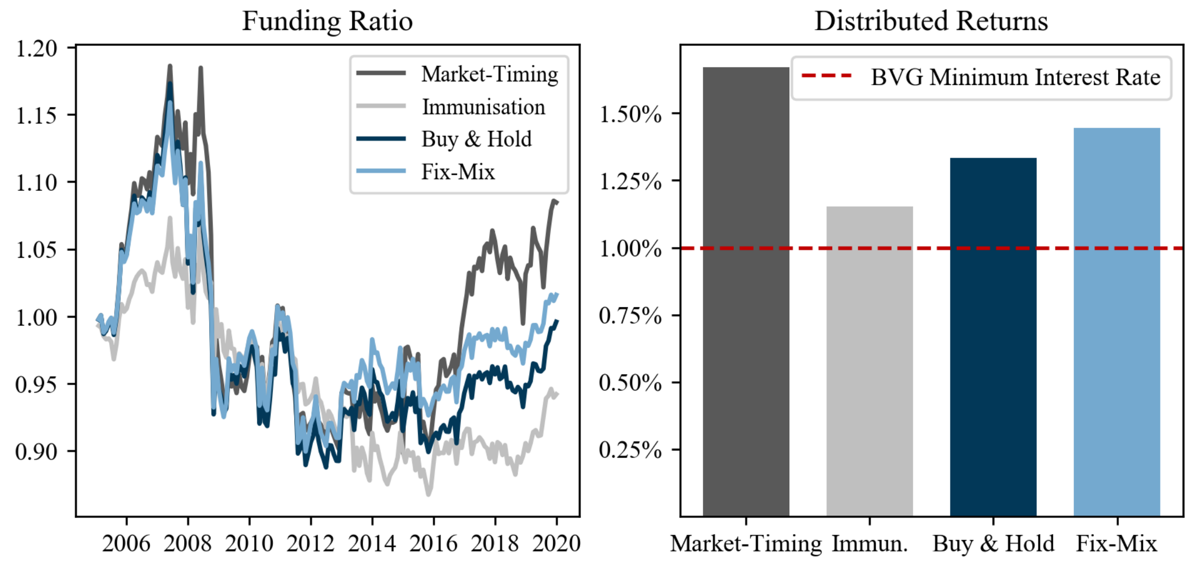
Pension liabilities differ among strategies by the amount of returns that have been distributed back to pensioners. Increased distributed returns transferred to pensioners also lead to enlarged future liabilities form a pension's perspective. Therefore, the pension liabilities depend not only on the discount rate, which is common for all strategies but also on the strategy's ability to generate additional returns on assets. The right-hand side of Figure 10 implies that changes in the discount rate have more substantial effects on the development of pension liabilities than the additional returns distributed.

However, the returns distributed to pensioners are a good indicator of how well the respective strategy performs. As distributed returns are a function of historical returns and current funding ratio, it takes both into account: funding risk as well as past financial gains. As higher distributed returns also lead to an increase in future liabilities, a well-performing strategy may exhibit higher liabilities than a less successful strategy. Thus, the liabilities of a market-timing investor are larger due to its better performance than the liabilities of an immunising investor, which can be seen in Figure 10. Although the divergence of liabilities, due to distributed returns, seems small, it may have a substantial impact on the funding level. Therefore, a comparative interpretation of the funding ratio has to be done with care, the degree of distributed returns should also always be considered.

Nevertheless, the liability funding level is an essential key metric from an ALM perspective which is why we place emphasis on the analysis of the funding ratio. For this purpose, we additionally assess the risk of a drop in the funding level that a pension fund may face. This risk is measured by the maximum drawdown [MDD] of the assets relative to the liabilities. The MDD denotes by how much the funding ratio drops from a temporary peak in the worst possible case throughout the entire investment horizon.

Figure 11: Funding Ratios and Distributed Returns

Development of the funding ratio over time for the four strategies (left) and average annual distributed returns across the investment period (right) for the default case of initially fully funded liabilities and a moderate level of risk aversion.



So far, only the performance of assets has been considered in isolation of the development of liabilities. However, sufficient funding has to be ensured for each point in time at best. For this purpose, it may be helpful to take a closer look at how the individual strategies are able to provide funding for the pension liabilities over time. The left-hand side of Figure 11 shows a funding ratio that, after a short drop, increases substantially between 2006 and mid 2007 for each strategy. While the liability funding level for an immunised portfolio increases just above 105%, the other three strategies reach a level between 115% and 120%. This is mainly attributable to the absence of equity allocation in the immunisation portfolio. However, the very same seems to cause a substantial drop in funding ratios for the stock allocating strategies towards a ratio of just below 0.95 after the financial crisis in 2008. A further drop in funding following the bear market in 2011 ends just above the regulatory threshold of 0.9. While the decline of the funding ratio continues for the immunised portfolio, the naïve allocation strategies recover to a level of approximately 1.0, and the market-timing portfolio reaches a level just below 1.1 at the end of the investment period. The immunised portfolio recovers late to a funding ratio of 0.95.

The right side of Figure 11 reveals the reason for the divergence of pension liabilities among the four strategies. On average, the market-timing investor paid an additional annual interest of 1.67% as a result of their high returns on assets relative to the other portfolio strategies. On the other hand, the immunisation approach only provides an interest of 1.15%, slightly above the minimum interest rate required by the regulator. With 1.33% and 1.45%, respectively, the buy-and-hold and fix-mix portfolios distribute higher returns than the immunising portfolio, yet less than the market-timing portfolio.

It becomes apparent that a market-timing investor often provides the highest funding even though she distributes the highest amount of returns to pensioners and therefore exhibits the largest liabilities. However, the funding level of the market-timing portfolio also appears to vary substantially. The plot of the funding ratio over time in Figure 11 indicates that the VaR constraint fails to limit the funding risk for the market-timing portfolio. The funding level drops from a peak of more than 118% in mid-2008 towards 95% in March 2009 and later to 90%, even though allocation towards stocks is reduced to zero.

During the same period, on the other hand, market-timing liabilities rise by 24% and thereby amplify the distressed situation of assets that, however, only decline by 2%. Also, the drop of the funding level in 2011 seems to stem from an increase of the liabilities by another 22% within 12 months in which assets increase by 11%. Therefore, the drop in funding levels may be the result of a larger incline in liabilities rather than a fall of asset values. This effect is intensified for strategies that performed well in preceding periods leading to high distributed returns and thereby even bigger liabilities. This can be observed from the immunisation portfolio that is designed to perform well if liabilities rise. While this is an appealing feature in that situation, there is limited upside potential for the immunising investor. In addition, a minimum return must be generated, leading to a relatively slow but consistent decline of liability funding. The decline is slow as due to relatively weak return on assets, it pays less interest to pensioners and thereby exhibits a lower value of liabilities. By March 2009, the immunisation liabilities are almost 2% and by the end of the investment period 6% lower than that of the market-timing approach. Therefore, the drop in funding ratios for the market-timing, buy-and-hold and fix-mix strategies appear to result rather from the failing to hedge a rise in pension liabilities as well as a good performance in preceding periods than from allocating risky assets. However, it is important to note that funding levels from a regulatory perspective would not drop as severely in this situation. Liabilities are not required to be marked-to-market but are discounted with a flat discount rate. Therefore, reported liabilities would commonly not exhibit high growth rates as found in this study.

At the end of the investment horizon, the relative funding level of the four strategies shows the same pattern for each combination of risk aversion and initial funding ratio: the market-timing portfolio exhibits the highest funding ratio while the immunisation approach leads to the lowest. Moreover, in every case, the final funding after the 15 year-period is larger for the fixed-mix than for the buy-and-hold portfolio. Interestingly, the pattern for average distributed returns is also the same across all nine combinations of risk aversion levels and initial funding ratios: the market-timing investor pays the highest interest rates while the immunisation approach provides the lowest interest rates, in some cases even below the minimum interest rate required by the regulator. The fix-mix and buy-and-hold portfolios reside in between where the former distributes on average higher returns. However, even if funding levels exhibit the same relative pattern at the end of the investment horizon, the intertemporal variation is substantial.

As expected, distributed returns increase with the increased risk tolerance of the investor across all strategies. As Swiss pension funds compete on the amount of interest paid to pensioners, they have an incentive to reduce risk aversion for the ability to distribute higher returns. However, lower risk aversion has a direct and considerable impact on the pension's funding risk. A risky pension manager ($\gamma = 5$) faces a much larger variability of liability funding than more moderate or conservative investors across all strategies that depend on the relative risk preference.

Table 10: Distributed Returns and Funding Risk for Different Levels of Risk Aversion

Annual average distributed returns as well as maximum, minimum, mean, maximum drawdown [MDD] of the periodic funding ratio and its realised probability of being below the regulatory threshold [P(FR<0.9)] across strategies for various levels of relative risk aversion [RRA (γ)] and initially fully funded liabilities.

	Market-Timing			**Imm.**	**Buy-and-Hold**			**Fix-Mix**		
RRA (γ)	5	10	15		5	10	15	5	10	15
Dist. (%)	1.89	1.67	1.58	1.15	1.65	1.33	1.30	1.83	1.45	1.32
Max	1.33	1.19	1.14	1.08	1.32	1.17	1.13	1.30	1.16	1.12
Min	0.75	0.90	0.88	0.87	0.80	0.89	0.89	0.82	0.90	0.91
Mean	1.00	1.00	0.99	0.95	0.98	0.97	0.96	1.01	0.99	0.97
MDD (%)	43.5	24.3	22.7	19.5	39.1	24.3	21.2	37.0	22.4	19.0
P (FR<0.9) (%)	18.3	0.6	2.8	23.3	21.7	5.6	3.9	13.9	0.6	0.0

As indicated previously, the immunisation portfolio performs weakly not only in terms of distributed returns but also by means of funding pension liabilities. While the drawdown risk of the funding ratio is relatively modest, almost every fourth observation appears to be below the regulatory threshold of 0.9. The fact that most of these observations occur at the end of the investment horizon further supports the intuition of a gradual and structural decline of the immunising funding level. This is a result of the regulatory minimum interest requirement of 1.0% that leads to a consistent underperformance relative to its liability benchmark.

Funding risk appears to be substantial for market-timing investors and to a lesser – nonetheless considerable – extent for fix-mix and buy-and-hold investors. Particularly, risky investors exhibit severe drawdowns in liability funding. In the worst case, the funding ratio of a market-timing investor drops by 43.5% from a peak of 1.33 to a funding level of 75%, far below the regulatory threshold. Likewise, naïve allocation exhibits large drawdowns for risky investors. While for $\gamma = 5$, the fix-mix portfolio exhibits slightly lesser drawdown risk and lower probability of funding levels that occur below 90%, the buy-and-hold portfolio generates even more observations below the threshold than the market-timing portfolio. For market-timing investors with moderate and conservative risk aversion, the probability of realising funding ratios below 90% seems approximately in line with the VaR constraint. However, for the risky market-timing portfolio realised probabilities exceed VaR expectations by far. This may be attributed to the higher preference for risky assets and corresponding larger exposure to estimation risk and will be discussed during the subsequent chapter.

For moderate and conservative levels of risk aversion, the fix-mix strategy appears to be the least risky strategy. Both maximum drawdown and realised probability of funding levels below the regulatory threshold are lower than their market-timing and buy-and-hold counterparts. With a minimum funding ratio of 0.91, there are no observations below the threshold for a conservative fix-mix investor. Even though the MDD of the funding level is slightly higher for the market-timing than for the buy-and-hold strategy, the latter seems to exhibit a higher probability to generate observations below the 0.9 threshold. Therefore, a market-timing investor appears to recover more quickly from low funding levels than a buy-and-hold investor.

Table 11: Distributed Returns and Funding Risk for Different Initial Funding Levels

Annual average distributed returns as well as maximum, minimum, mean, maximum drawdown [MDD] of the periodic funding ratio and its realised probability of being below the regulatory threshold [P(FR<0.9)] across strategies for different levels of initial funding and a moderate level of risk aversion.

	Market-Timing		**Immunisation**		**Buy-and-Hold**		**Fix-Mix**	
Initial Funding	95%	110%	95%	110%	95%	110%	95%	110%
Dist. Return (%)	1.36	2.21	0.93	1.61	1.13	1.78	1.23	1.97
Funding Ratio:								
Max. FR	1.12	1.31	1.03	1.18	1.11	1.29	1.10	1.27
Min. FR	0.79	0.94	0.84	0.91	0.85	0.95	0.86	0.97
Mean FR	0.95	1.07	0.91	1.01	0.93	1.05	0.94	1.06
MDD of Funding (%)	29.2	27.8	18.4	22.9	23.1	25.8	21.3	24.0
P (FR<0.9) (%)	21.7	0.0	51.7	0.0	33.3	0.0	15.6	0.0

As expected, the pension manager benefits from an extra funding cushion at the beginning of the investment horizon by being able to distribute higher returns. Conversely, paid interest to pensioners is lower if the pension scheme is initially underfunded. In this case, the immunised portfolio pays even less than the BVG minimum interest rate of 1%.

Naturally, the funding risk decreases if the pension fund is provided with additional funding at the beginning. On the other hand, if the pension is initially underfunded, all portfolios become severely risky. In this situation, the immunisation strategy exhibits funding ratios that are below 0.9 more than 50% of the time. Funding levels of the fix-mix strategy, on the contrary, are only below the regulatory threshold 15.6% of the time. With the highest minimum funding ratios and lowest worst-case drawdowns, the fix-mix portfolio again proves to be the least risky strategy. Interestingly, MDD is higher for the market-timing portfolio if the pension starts with 95% funding, while MDDs of all other strategies decrease with initial funding levels. This effect appears to result from the VaR-constraint that increasing the portfolio risk if the funding ratio is close or below the regulatory threshold. The allocation towards riskier assets in combination with errors in expected return estimation then lead to substantial drawdowns in funding levels and subsequent high probability of levels below the 90% threshold.

Table 12: Performance and Funding Risk for Bayes-Stein Estimations

Performance and funding risk measures across asset allocation strategies for Bayes-Stein return estimations in the default case of moderate relative risk aversion and initially fully funded liabilities. Mean and standard deviations are annualised. The immunisation portfolio does not change but is included for reference.

	Market-Timing	**Immunisation**	**Buy-and-Hold**	**Fix-Mix**
Mean (%)	5.04	5.04	5.08	5.10
Std Dev (%)	6.99	7.38	7.13	7.13
Sharpe	0.72	0.68	0.71	0.71
Dist. (%)	1.01	1.15	1.27	1.27
Funding Ratio:				
Max	1.08	1.08	1.08	1.08
Min	0.82	0.87	0.88	0.88
Mean	0.92	0.95	0.95	0.96
MDD (%)	24.0	19.5	18.3	18.3
P (FR<0.9) (%)	42.2	22.2	4.4	3.9

The estimation of expected returns using the Bayes-Stein approach instead of the CAPM has a devastating effect on the performance of the market-timing strategy. In the first section of this chapter we described that the Bayes-Stein estimator predicts returns slightly worse than the CAPM estimator. This larger estimation error leads to a performance of the market-timing portfolio that is largely inferior relative to the other strategies. With distributed returns of 1.0%, only slightly above the regulatory minimum rate, it generates even less returns than the immunisation portfolio. Besides the lower rate of return on assets compared to the CAPM estimation, this is mainly the consequence of a markedly larger funding risk. While the maximum drawdown of the funding ratio does not change much, the probability of realising funding levels below 90% is now 42%. The probability seven-fold relative to the CAPM estimator, as the market-timing portfolio did not recover after the drop of the funding ratios in 2008 and 2011. This effect is larger (smaller) for lower (higher) relative risk aversion and indicates a large sensitivity of the market-timing portfolio, including the VaR constraint, towards return estimation errors. The change in return estimators has little effect on the relative performance of the buy-and-hold and fix-mix strategies, where the latter again outperforms the buy-and-hold strategy in terms of both, financial performance, and funding risk. Corresponding tables and figures for the Bayes-Stein estimation across all strategies and levels of risk aversion are found in Appendix B.

Thus, our results suggest an inferior performance of the immunisation portfolio across both: generated returns and funding risk. The other strategies perform better than the immunisation portfolio for all combinations of risk aversion and initial funding levels. While the market-timing strategy generates the highest returns, it also tends to be riskier. This is particularly true if risk aversion or initial funding levels are low. In these cases, the fix-mix strategy turns out to be the best performing approach. Generally, the fix-mix strategy appears to exhibit relatively low funding risk while it allows for distributing the second-highest returns following the market-timing strategy. In our sample, the fix-mix outperforms a buy-and-hold strategy in close to every aspect we consider. A pension manager may therefore either try to time the market or employ a fixed-weight strategy depending on the pension manager's risk preference and initial funding level, provided that return prediction capabilities are sufficient. If this is not the case and estimation errors are large, however, a market-timing strategy may even be outperformed by an immunisation strategy. Implications of these results are discussed during the following chapter.

9 Discussion

This chapter discusses the implications of our study's results in relation to the strategies that pension funds may consider under current pension regulations and a low interest rate environment, as outlined in Chapter 3. Further, we occasionally relate our findings to previous research as detailed in Chapter 4 and discuss the implications of our findings in relation to the research question. Finally, we present limitations and potential areas of our study that may be subject to further research.

9.1 Discussion of Results

Our results suggest it may be beneficial to add risky assets towards a pension portfolio when interest rates are low. The immunisation portfolio is based on fixed-income assets only and designed to match the pension liabilities. However, we find it is outperformed by portfolios that include risky assets in almost every case. This appears to be the immediate consequence of the regulatory requirement to pay a minimum interest rate on the contributor's saving account that is above the market rate. Therefore, a plain liability matching strategy seems not sufficient to provide both: sufficient funding and financial gains required to fulfil the minimum interest requirement. Even though the risk of significant drops in funding levels is relatively low, we find the immunisation strategy to structurally underperform its liability benchmark after the interest is paid to contributors. Although it suffices in the default case of full initial funding to cover the minimal interest of 1%, we find the funding level to decrease gradually. While this decline seems generally slower relative to the other strategies, it also provides less upside potential. In case the pension fund is initially underfunded and decides to immunise the portfolio against interest rate risk to limit further downside risk, our results show that then distributed returns are below the regulatory minimum requirement. For given combinations of the pension manager's relative risk aversion and initial funding ratios, we find the immunisation strategy as the only strategy that may not fulfil the minimum interest requirement. Generally, we find the financial performance of the immunised portfolio to be relatively poor, supporting the arguments and previous findings of Domanski et al. (2017) that a duration matching approach may be too expensive in a low interest rate environment. The inferiority of the immunised portfolio appears to be the result of this poor financial performance and limited upside potential in combination with the minimum interest requirement. Therefore, our results suggest that an immunisation strategy might be inappropriate during an environment of low interest rates where a minimum interest must be paid that is above the market rate. This regulatory requirement appears to incentivise the pension manager to take on more risk and include assets to the portfolio that do not solely consist of fixed-income securities.

Swiss government bonds also play a key role in the market-timing portfolio due to their ability to hedge the pension liabilities as well as their good risk diversification capabilities, particularly in combination with the stock asset class. The liability hedging qualities are not very surprising, as this study's liabilities have been designed to resemble interest rate risk only. Alternative assets, however, are scarcely included. As suggested by Hoevenaars et al. (2008), they do exhibit some risk-diversification potential, especially for commodity assets. However, in contrast to their findings our results suggest subpar liability-hedging and risk-return trade-off capabilities in particular for hedge-funds that are never included in the market-timing portfolio and less so for private equity. This also appears to be the result of the substantial currency risk to which international assets are exposed. Given that pension managers do not hedge this currency risk, we find the market-timing portfolio largely comprises assets that are denominated in local currency. If Swiss pensions dread to hedge their currency risk, this might be a logical consequence for their preference for domestic assets.

By default, we estimate expected returns using the CAPM because of its theoretical foundation and relatively well documented performance, see Jorion (1986; 1991). Using this rather simple approach, we find the market-timing portfolio to deliver superior financial performance relative to the immunisation approach, but also to the buy-and-hold and fix-mix portfolios. This is robust across different levels of investor's risk aversion and initial liability funding levels. It seems, the market-timing strategy is on average able to capture time-varying risk premia out of sample supporting previous findings in favour of a market-timing potential. However, even though the market-timing investor can distribute the highest returns, our results indicate that she might also face higher funding risk. As higher distributed returns lead, ceteris paribus, to increased liabilities, one might also argue that it is the (temporary) better performance that may cause a higher funding risk. With Swiss pension funds competing on the interest paid to contributors, this might indeed create incentives to take on more risk for a higher return potential. In our sample, market-timing pension managers with low relative risk aversion pay the highest interest to contributors but also face the largest risk of underfunded liabilities. However, the latter seems to be only partly the consequence of the high returns distributed.

In our study, a VaR constraint is designed to limit the funding risk. However, depending on the pension manager's risk aversion, we find the VaR constraint may increase the allocation towards risky assets if the funding ratio approaches a level close to the regulatory threshold. This appears to result from a combination of the VaR specification, the investor's risk tolerance, and the regulatory minimum interest rate requirement. In our study, the VaR explicitly takes not only the funding ratio's variability but also its expected return into account. As the results of the immunisation strategy suggest, a pure fixed-income portfolio appears to structurally underperform the liabilities and decrease the funding level. Therefore, the funding level of the market-timing manager may decrease further if the VaR constraint leads to a full divestment of risky assets. Hence, the pension manager is forced to allocate risky assets towards her portfolio, even if the VaR constraint is binding. Our results show that when funding ratios decrease, the investor initially substitutes risky assets for Swiss government bonds. However, as funding levels decline further and get near or beyond the imposed threshold, allocation to risky assets increase again. This seems close to resemble a gambling for redemption effect as discussed in Schich et al. (2011). The degree of exposure to risky assets depends on the relative risk aversion of the pension managers who face a trade-off between maximising utility and satisfying the VaR constraint. Therefore, the higher allocation towards risky assets appears to be the reason for higher funding risk in case of risk-tolerant investors and low initial funding levels.

This is not surprising, as we find return estimation errors for risky assets to be substantially larger than for near-riskless assets such as Swiss government bonds. In general, the market-timing portfolio seems to be considerably sensitive to errors in return estimation. When returns are forecasted using the CAPM estimator, a market-timing pension fund appears to generate superior returns with, depending on investor's risk preference, funding risk that is in line with VaR expectations. However, we find the performance of the market-timing portfolio to deteriorate substantially for a small increase in estimation errors. Using the Bayes-Stein estimator, the market-timing portfolio may even be outperformed by an immunised portfolio if the investor's risk tolerance is high. In line with previous literature, we find the performance of the market-timing strategy to be considerably sensitive to errors in return estimation, see for example (DeMiguel et al., 2009; Kan & Zhou, 2007). Somewhat related to the findings of DeMiguel (2009), our results indicate that a naïve allocation may be more attractive if the exposure to estimation errors is high. As detailed earlier, there is considerable doubt in the literature if returns are predictable, and even if this is true, whether this predictability is stable over time. Yet, our results suggest that a simple one-factor return estimation may deliver superior results for the market-timing investor. Therefore, considering the potential gains, a market-timing strategy may seem tempting, however, it might also give rise to large losses. We find these losses to be even larger in an ALM setting, where pension liabilities have to be funded. As our results suggest, the underfunding risk may be rather due to rising liabilities than decreasing asset values. Thus, we acknowledge that this risk might be underrepresented if liabilities are not valued at market terms.

Of course, a monthly rebalancing might be more frequent than pension funds would do in practice, amplifying the strategy's sensitivity to estimation errors. The market-timing strategy, however, is purposely designed to exhibit the very characteristic feature of investors trying to time the market: frequent portfolio adjustment to capture the time-varying risk premia of securities.

The fix-mix and buy-and-hold strategies assume constant-risk premia and are designed to benchmark the market-timing capabilities of the market-timing portfolio. In contrast to the market-timing and immunisation portfolios, the fix-mix and buy-and-hold portfolio cannot account for changes in pension liabilities. Instead, assets are chosen at the beginning of the investment period and then allocated naïvely throughout the entire period. This neglection of liabilities, however, may give rise to potentially large funding risk as intertemporal risk-management is by design ruled out. Interestingly, we find the funding risk of these naïve portfolios to be not worse than the immunised portfolio. The fix-mix strategy even appears to exhibit the lowest funding risk among all strategies, especially when a pension manager's relative risk aversion and initial funding levels are low. This may be due to the relatively large allocation to Swiss government bonds that implicitly resembles a passive liability hedging approach similar to the dedication approach described by Fabozzi (1990). Generally, the performance of both naïve allocation strategies seems to be relatively robust to changes in the assumption of investor's risk preference and initial funding. This is not very surprising, as these assumptions only affect the initial optimal weights that are chosen once at the beginning of the period. Nonetheless, we find the naïve strategies to be not generally outperformed by a market-timing portfolio, even if (or possibly because) the performance relies on a single portfolio optimisation throughout a sample period of 15 years. Our results also support previous empirical findings in favour of a constant mix portfolio composition. The fix-mix portfolio appears to outperform the buy-and-hold portfolio in terms of both financial performance and funding risk supporting the findings of Mulvey et al. (2006) and contradicting those of Hilliard and Hilliard (2018). While our finding is robust across all variations of relative risk aversion and initial funding levels, it also depends on market conditions solely observed at the beginning of the investment period. Thus, the results may vary for initial portfolio weights derived at different points of time. As we neglect transaction cost throughout our study, we also neglect an appealing feature of the buy-and-hold strategy: it only requires a rebalancing if the share of an asset class in the total portfolio exceeds a regulatory limit. Thus, the buy-and-hold portfolio may appear less attractive relative to the other strategies that require constant rebalancing.

Our results suggest that pension managers under Swiss regulation and in an environment of low interest rates may not want to immunise their liabilities against a further decline of interest rates provided that the immunisation portfolio is solely based on government bonds. Instead, the Swiss pension regulator provides incentives to allocate more risky assets by imposing a minimum interest rate that is set above the (riskless) market rate. The competition among Swiss pensions to distribute even higher returns to contributors may even intensify the appeal of high risk-tolerance. A risk-taking pension manager trying to frequently time the market, however, appears to be subject to considerable estimation risk that potentially leads to a substantial underfunding of liabilities. A fix-mix strategy appears to be an attractive alternative even though liabilities are not actively managed.

The individual strategies we propose in this study are purposely kept distinctive and might therefore appear extreme in practice. Based on our results, a combination of the market-timing and fix-mix strategy may appear attractive for Swiss pension funds facing low market interest rates. That is, a less frequent review of the optimal portfolio where the portfolio is rebalanced to its target weights between periods. Indeed, this seems not so far from industry practice, where portfolio weights are kept relatively constant over time and reassessed in periods of three to five years only (Badaoi et al., 2014; Hoevenaars et al., 2008).

9.2 Limitations & Further Research Potential

The non-existence of a sufficiently large set of low interest rate data clearly limits our study. Provided that interest rates remain on the current level, a potential sample becomes larger and therefore provides more statistical reliability as time passes. Until then, one is only left with using the rather few data available or estimating how low interest rates may have affected historical data when actual interest rates were higher. We opted for the latter option, using a theoretical one-period asset pricing approach that takes account for a single discount rate of the assets' future cashflows only. However, as discussed earlier, interest rates may affect security prices in various additional ways. Therefore, our results and implications may be regarded as conservative. To our knowledge, the approach to adjust the prices of different types of securities to a unique level of interest rates is novel for this purpose. Thus, we see further research opportunities in this area, particularly in which way different (also empirical) adjustment approaches affect the prices of securities. Of further interest may be the impact of domestic (Swiss) low interest rates on non-domestic interest rates and the corresponding attractiveness for Swiss pensions to invest in non-domestic markets.

In our study, we solely focus on interest rate risk that pension funds are facing. While this risk is substantial, especially in an environment of low interest rates, pension funds also bear other risks that may amplify our findings or lead to different results and implications drawn. By considering nominal interest rates only, we neglected inflation risk of pension liabilities. While the increase in consumer prices in Switzerland has been low in 2019[17], this inflation risk may have an additional effect on pension liabilities that might require even higher returns on assets than assumed in this study. Longevity, however, appears to be an even greater burden for Swiss pension funds. As mentioned in Chapter 3.2, the minimum conversion rate required by the regulator assumes a lower life expectancy than is commonly expected. Therefore, the present value of pension liabilities is relatively higher, causing additional financial stress for pension funds. Swisscanto (2019) estimates that pension funds would need to consistently generate a rate of return of 5% on assets, given the current level of conversion rate. A potential impact of these risks on the asset allocation strategies of Swiss pension funds may be an interesting area for further research.

The immunisation strategy in this study is based on a duration matching approach that comprises

[17] The Federal Agency for Statistics reported an increase of consumer prices of 0.4% in 2019 (Bundesamt für Statistik, 2020).

two baskets of government bonds only. While a broader range of securities may have allowed for a closer matching of durations, a limited choice of long-duration securities resembles a restriction that pension funds might also face in practice. We argue that pension funds may benefit from an allocation to non-fixed-income assets given the low level of interest rates. Thus, the performance of an immunisation strategy based on derived durations of equity assets may be an interesting subject for further research. The same is true for an allocation to higher yielding (yet lower rated) bonds or other asset classes that potentially provide long-term and stable cashflows, such as infrastructure assets.

As discussed earlier, the fix-mix and buy-and-hold portfolios depend on initial optimal weights that are derived at the beginning of the investment period only. Therefore, their relatively good performance also depends on the estimated parameters at this point of time. Thus, an assessment of the sensitivity to variations in the market conditions that are prevailing when the initial weights are derived may be insightful. This would allow to get a more robust idea on the performance of the naïve allocation strategies.

The market-timing portfolio is based on a mean-variance optimised portfolio that includes pension liabilities as a short-position asset. Assets are selected according to their estimated return generation-, risk-diversification-, and liability hedging capabilities. Therefore, the market-timing strategy naturally involves estimation risk. The motive of this study is not to find a market-timing model that is minimising estimation risk, but to explore whether a simple market-timing model can produce a better performance relative to other strategies and how sensitive this performance is to estimation errors to which the other strategies are not exposed. Nonetheless, estimation errors might be reduced by using, for example, multi-factor models for expected return estimation or GARCH-models for variance estimation to further study the sensitivity of a market-timing portfolio towards parameter uncertainty. Moreover, assets may have also been selected according to their exposure to certain risk factors such as interest rate risk. This risk-based investing approach gained interest over the past years, in particular, among pensions funds and other liability-driven investors (Badaoi et al., 2014; Broeders & Jansen, 2019). The performance of a factor investment approach relative to more traditional strategies in an environment of low interest rates and demanding regulatory requirements may be another interesting subject to further research.

We find funding risk to be rather the result of rising market values of liabilities than decreasing asset values. As Swiss pension discount their reported liabilities using a flat discount rate, they may be subject to a similar reporting bias as discussed by Andonov et al. (2017) and Binsbergen and Brandt (2011). Therefore, an analysis of liability discount rates for reporting purposes and its potential implications on a market-based funding status may also be insightful for the Swiss pension market.

Swisscanto (2019) and Hentov et al. (2018) suggest pension funds may benefit by diversifying away from domestic assets. Our findings indicate that international assets play a lesser role in within a Swiss pension's portfolio due to their exposure to currency risk. This is the consequence of the assumption that Swiss pension funds do not hedge their currency risk and the substantial appreciation of the Swiss Franc in early 2015. Nonetheless, an attractive area of research may be whether – and to which degree of currency hedging – (Swiss) pension funds may benefit from geographical diversification.

10 Conclusion

We adjust return time-series to a common negative level of interest rates and model relevant regulations for Swiss pension funds to analyse four distinctive asset allocation strategies a Swiss pension manager may consider. This study finds that a market-timing portfolio may outperform an immunisation portfolio as well as naïve buy-and-hold and fix-mix allocations out of sample. Using a simple one-factor model to estimate expected returns, the market-timing investor appears to generate superior returns. A liability-matching approach that is solely based on sovereign fixed-income assets, on the other hand, appears to structurally underperform its liability benchmark and thereby leading to high funding risk. A pension manager may therefore not want to immunise the pension liabilities against a further decline of interest rates. We argue that this may be the consequence of the regulatory requirement to pay interest on contributions that is substantially higher than the current riskless rate. We further argue that this requirement may incentivise pension managers to allocate a larger share of risky assets than they would if the level of interest rates was higher. The allocation towards risky assets appears to be dominated by stocks and real estate. Alternative assets, in particular hedge funds, are less represented. The attractiveness of geographic diversification seems limited as a consequence of in parts considerable currency risk which we assume to be not hedged by the pension manager.

As discussed above, the prediction of future returns may be challenging. Nonetheless, the potential to generate high returns might entice pension managers to try to time the market. Pension managers attempting to frequently time the market, however, appear to be exposed to considerable estimation risk that potentially leads to large funding deficits. We find this to be particularly true for risky pension managers and pension funds who are initially underfunded. A naïve allocation of assets is naturally less sensitive to estimation errors. We find a fix-mix strategy to perform particularly well, even though it does not allow for an active management of pension liabilities. Hence, even though a market-timing approach may be tempting, an infrequent portfolio adjustment to changing market conditions appears more appropriate, given that estimation risk is substantial. However, we also acknowledge that a combination of low interest rates, regulatory pressure and competition for distributed returns may ease the pension manager's risk aversion.

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A Data

Table A.13: Summary Statistics after Interest Rate Adjustment

Annualised mean, median, standard deviation and Sharpe ratio as well as minimum and maximum observations expressed in monthly returns across all asset classes after prices have been adjusted. Furthermore, corresponding skewness and excess kurtosis of the return distribution are provided.

	Mean	Median	Std dev	Sharpe	Min	Max	Skew	E. Kurt
ST CH	4.75%	12.55%	17.62%	0.31	-21.75%	16.42%	-1.25	0.75
ST Int	5.09%	16.76%	17.94%	0.33	-35.25%	10.97%	-2.02	6.66
GB CH	4.90%	5.77%	6.84%	0.83	-6.84%	6.89%	-0.06	-2.11
GB Int	8.40%	11.90%	11.13%	0.82	-23.87%	11.61%	-2.44	13.62
RE CH	5.78%	5.99%	7.21%	0.91	-7.52%	6.10%	-0.34	-1.82
RE Int	3.33%	10.21%	18.23%	0.22	-29.88%	18.28%	-1.28	2.55
CM	0.55%	1.20%	17.41%	0.07	-32.92%	12.40%	-1.27	4.19
PE	4.36%	14.14%	22.06%	0.23	-33.15%	29.75%	-1.16	3.70
HF	3.04%	3.69%	5.55%	0.68	-6.85%	7.09%	-0.90	1.76

Figure A.12: Swiss Stocks Before and After Interest Rate Adjustment

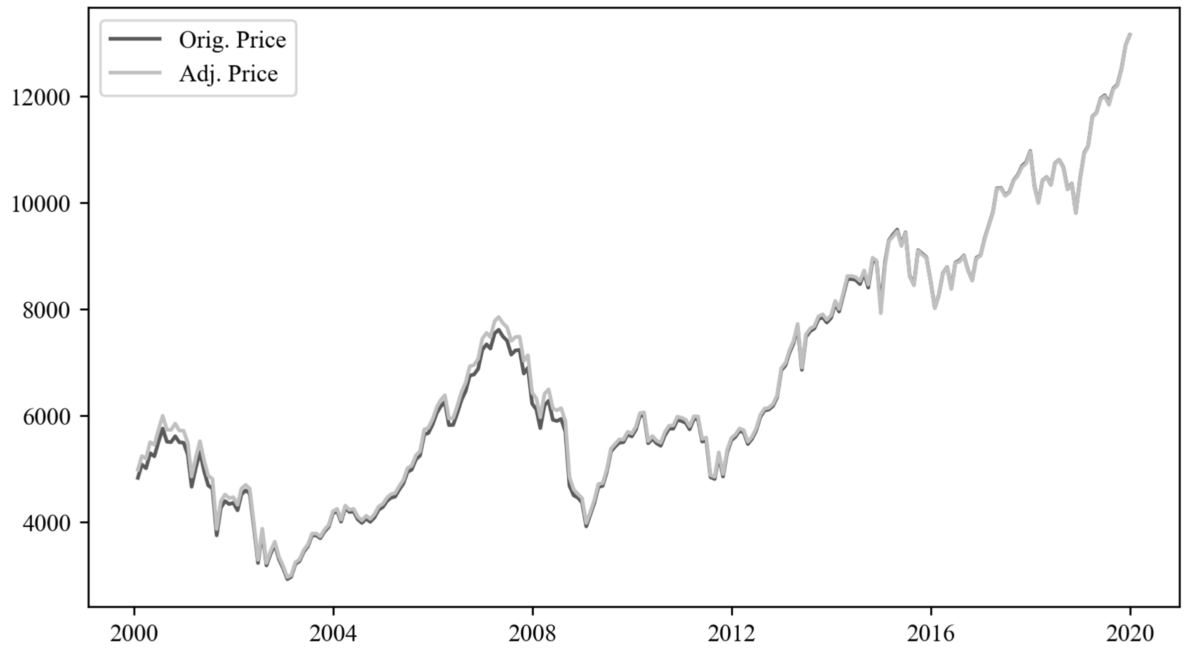


Figure A.13: International Stocks Before and After Interest Rate Adjustment and Conversion into CHF

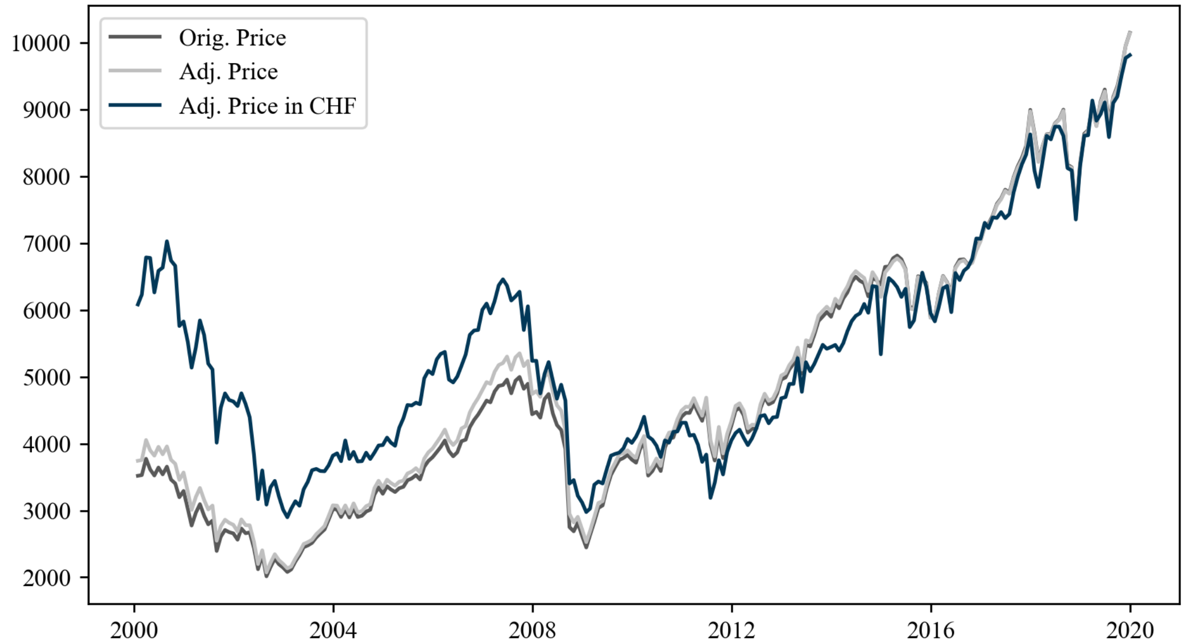


Figure A.14: International Government Bonds Before and After Interest Rate Adjustment and Conversion into CHF

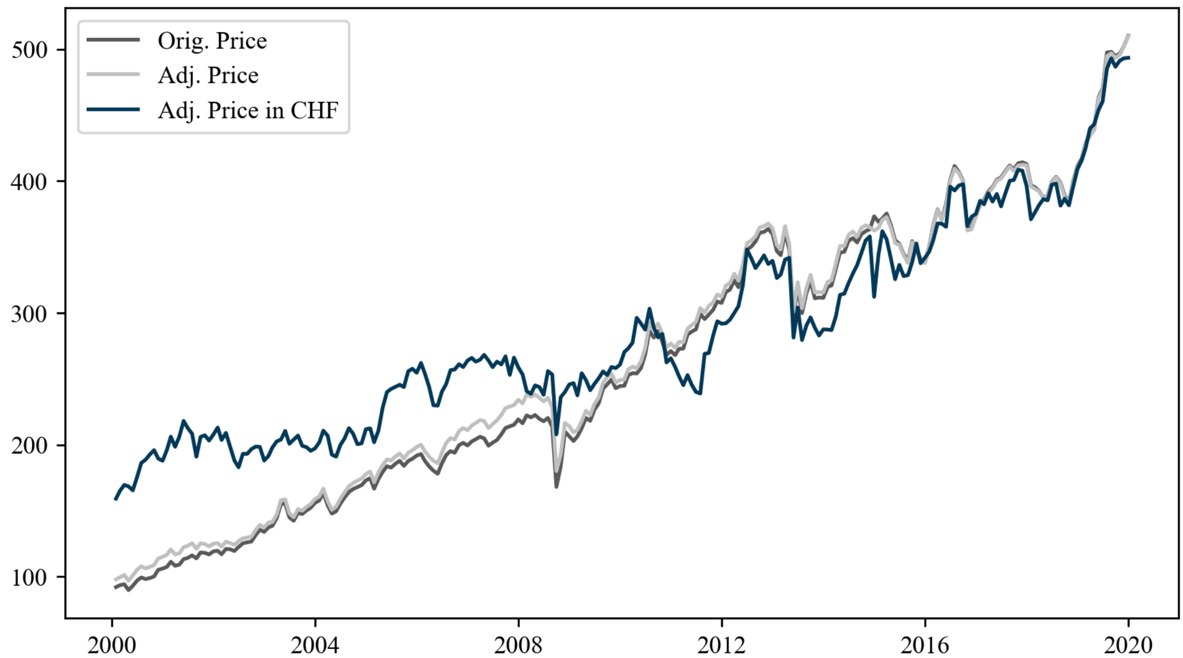


Figure A.15: Swiss Real Estate Before and After Interest Rate Adjustment

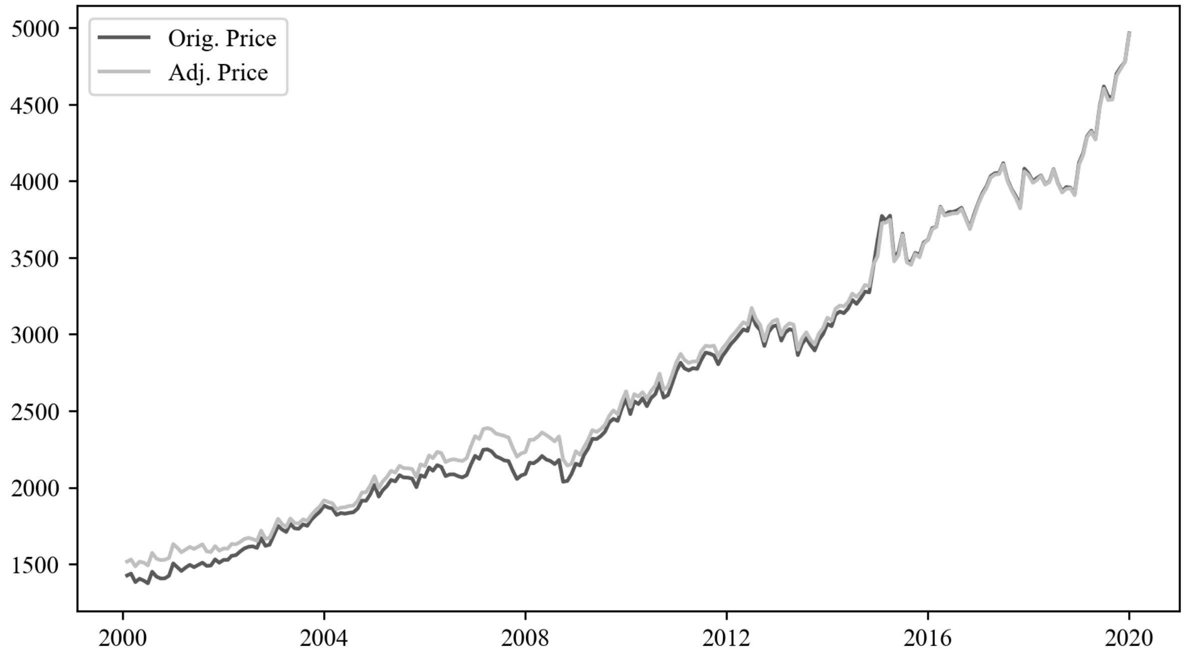


Figure A.16: International Real Estate Before and After Interest Rate Adjustment and Conversion into CHF

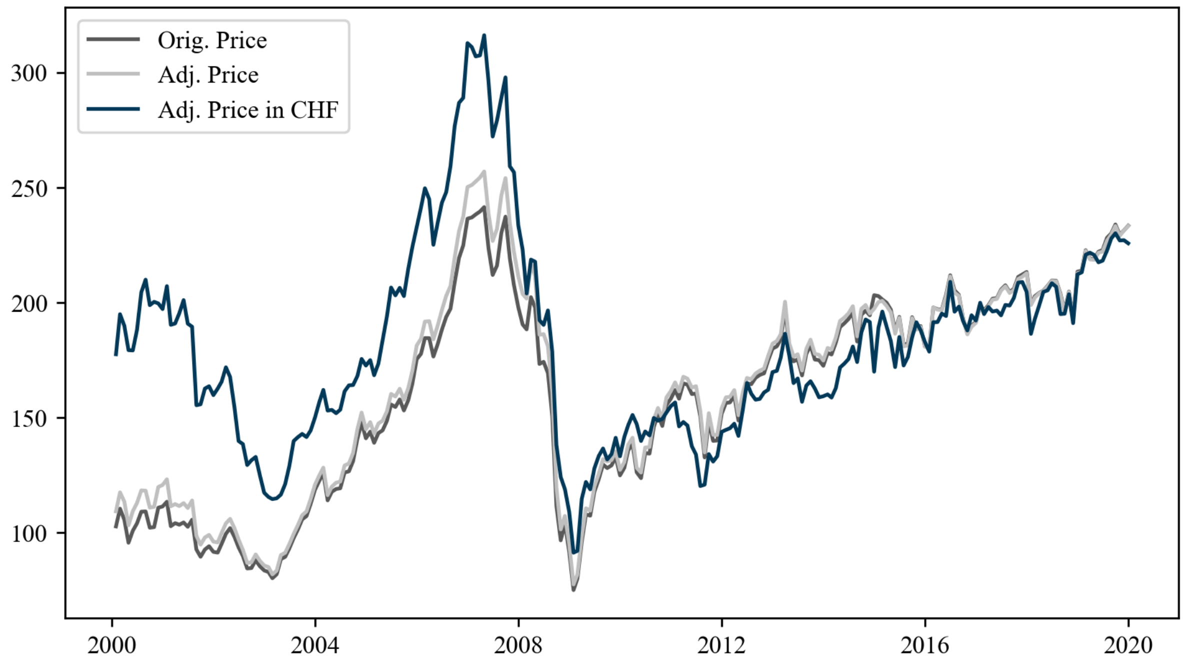


Figure A.17: Commodities Before and After Interest Rate Adjustment

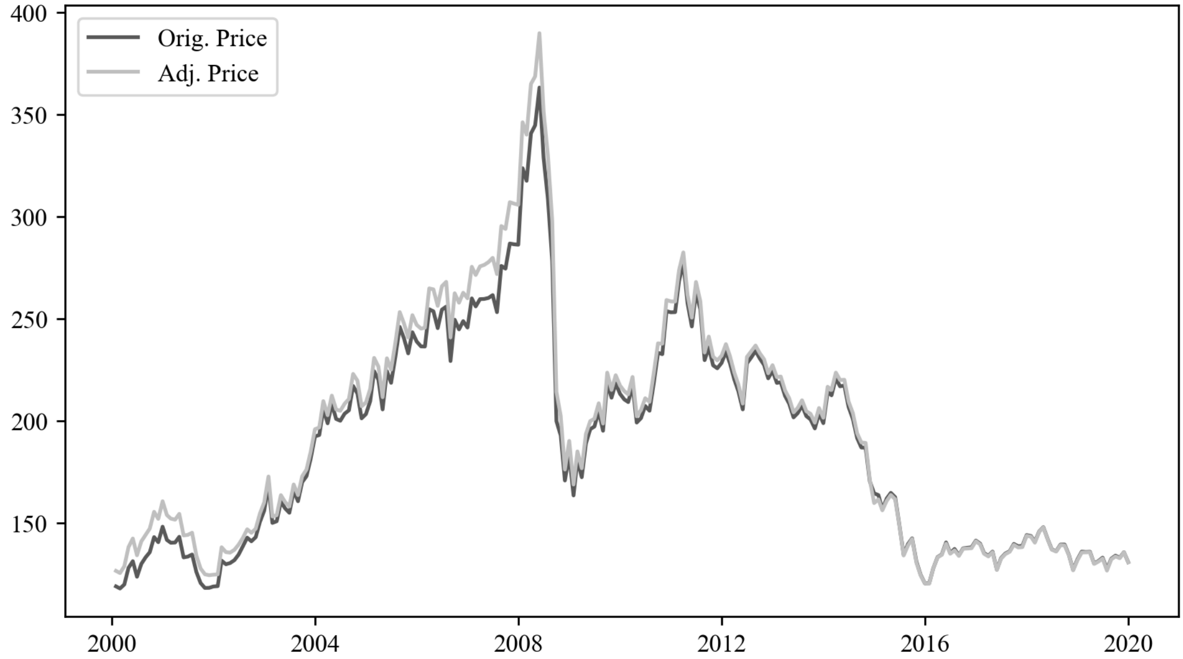


Figure A.18: Private Equity Before and After Interest Rate Adjustment and Conversion into CHF

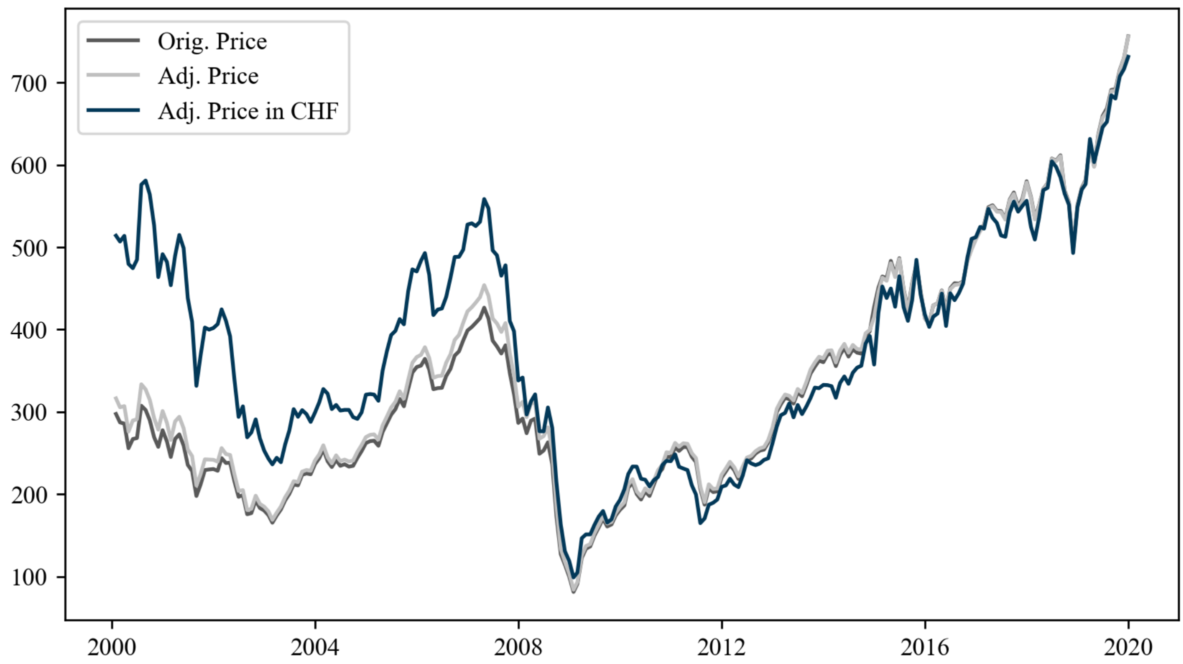


Figure A.19: Hedge Fund Before and After Interest Rate Adjustment and Conversion into CHF

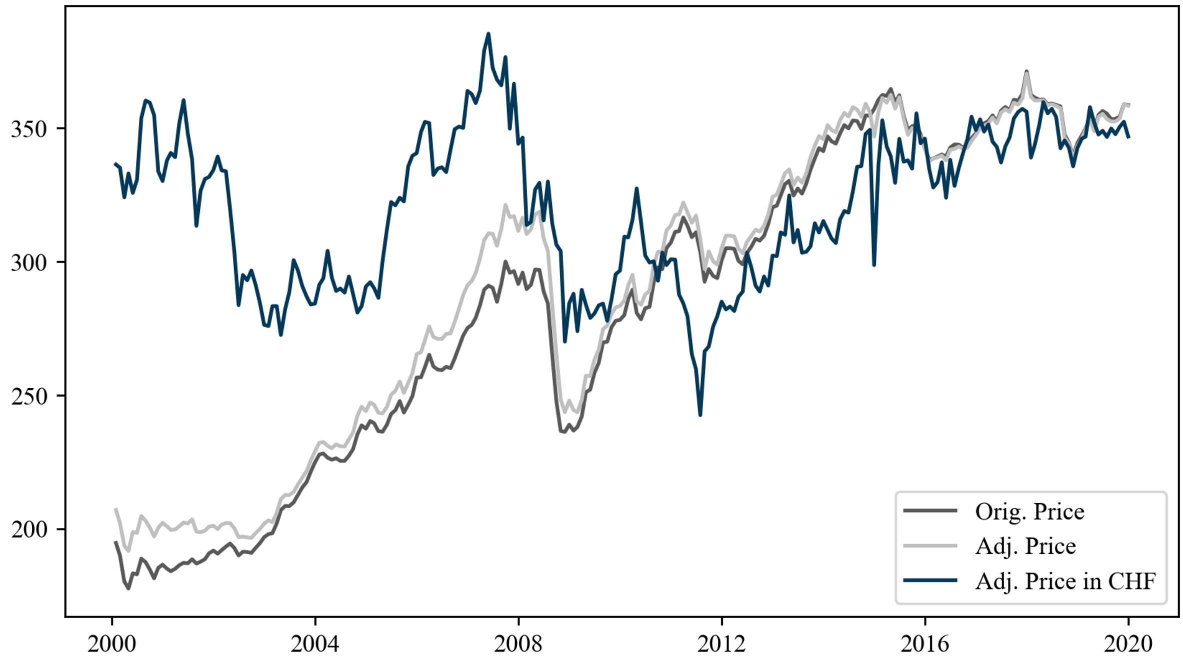


Table A.14: Variance-Covariance Matrix

	ST CH	ST Int	GB CH	GB Int	RE CH	RE Int	CM	PE	HF	ST M	BD M
ST CH	0.26%	0.26%	-0.03%	0.08%	0.03%	0.18%	0.11%	0.25%	0.08%	0.16%	0.01%
ST Int	0.26%	0.34%	-0.03%	0.12%	0.03%	0.21%	0.16%	0.31%	0.12%	0.16%	-0.01%
GB CH	-0.03%	-0.03%	0.04%	0.03%	0.00%	-0.01%	-0.03%	-0.02%	-0.01%	-0.02%	0.01%
GB Int	0.08%	0.12%	0.03%	0.16%	0.01%	0.11%	0.07%	0.12%	0.08%	0.02%	0.00%
RE CH	0.03%	0.03%	0.00%	0.01%	0.04%	0.03%	0.03%	0.03%	0.01%	0.03%	0.01%
RE Int	0.18%	0.21%	-0.01%	0.11%	0.03%	0.28%	0.10%	0.29%	0.09%	0.17%	0.01%
CM	0.11%	0.16%	-0.03%	0.07%	0.03%	0.10%	0.27%	0.16%	0.09%	0.07%	0.00%
PE	0.25%	0.31%	-0.02%	0.12%	0.03%	0.29%	0.16%	0.49%	0.15%	0.20%	-0.02%
HF	0.08%	0.12%	-0.01%	0.08%	0.01%	0.09%	0.09%	0.15%	0.10%	0.03%	-0.02%

Table A.15: Correlation Matrix

	ST CH	ST Int	GB CH	GB Int	RE CH	RE Int	CM	PE	HF
ST CH	**100.0%**	86.5%	-26.4%	38.7%	25.4%	67.2%	42.6%	69.9%	48.2%
ST Int	86.5%	**100.0%**	-26.9%	52.4%	23.5%	68.6%	53.2%	76.2%	64.5%
GB CH	-26.4%	-26.9%	**100.0%**	32.3%	3.7%	-5.9%	-24.8%	-17.7%	-11.4%
GB Int	38.7%	52.4%	32.3%	**100.0%**	16.8%	50.3%	32.4%	41.3%	63.3%
RE CH	25.4%	23.5%	3.7%	16.8%	**100.0%**	27.3%	23.9%	23.6%	9.9%
RE Int	67.2%	68.6%	-5.9%	50.3%	27.3%	**100.0%**	37.4%	79.1%	53.0%
CM	42.6%	53.2%	-24.8%	32.4%	23.9%	37.4%	**100.0%**	42.8%	51.5%
PE	69.9%	76.2%	-17.7%	41.3%	23.6%	79.1%	42.8%	**100.0%**	66.0%
HF	48.2%	64.5%	-11.4%	63.3%	9.9%	53.0%	51.5%	66.0%	**100.0%**

Figure A.20: Swiss Stocks

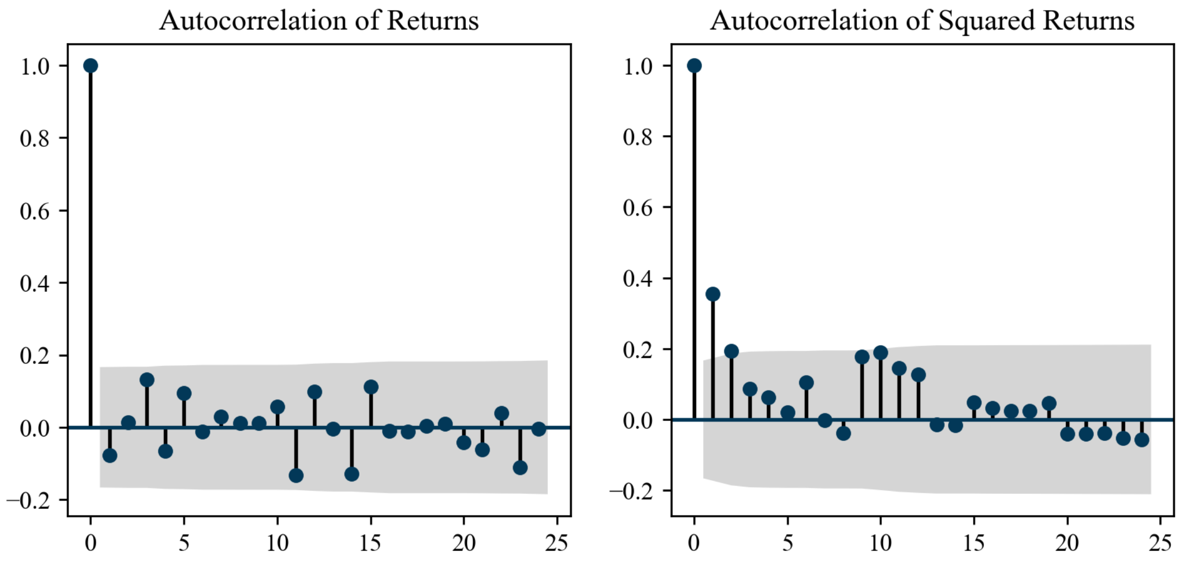


Figure A.21: International Stocks

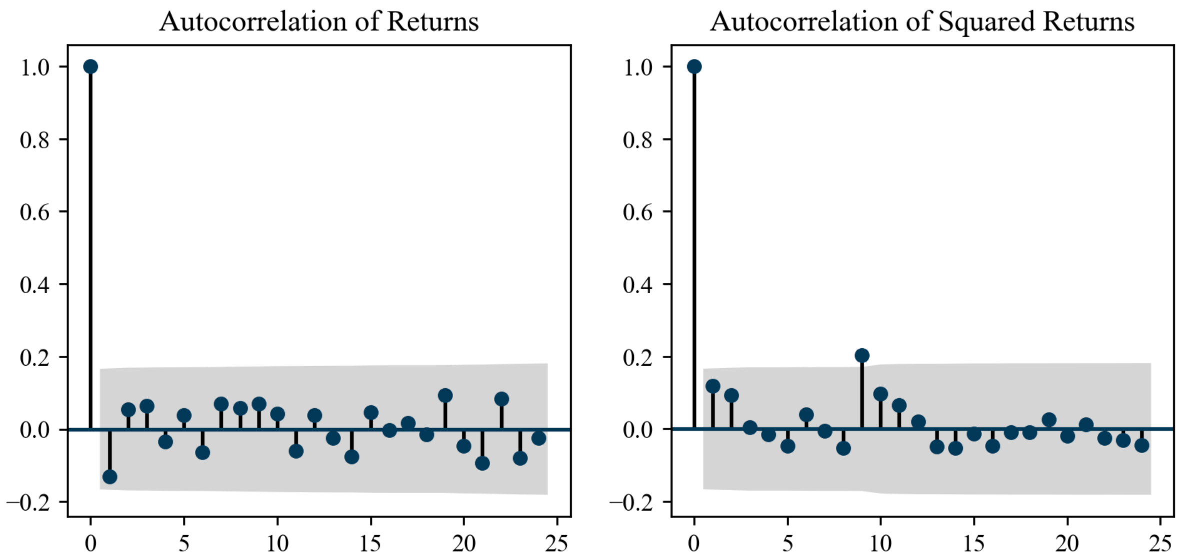


Figure A.22: Swiss Government Bonds

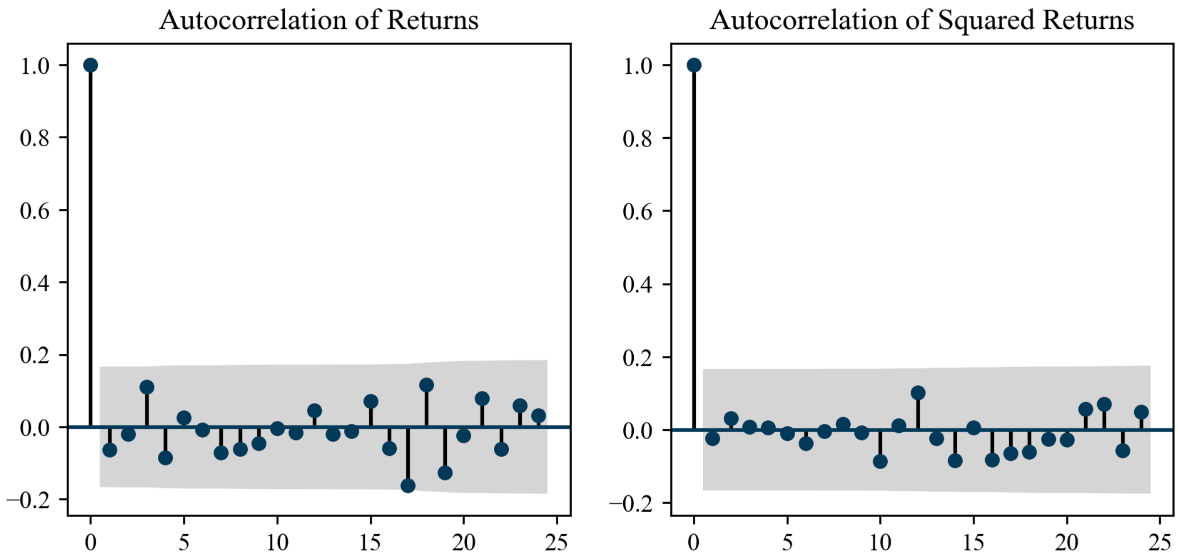


Figure A.23: International Government Bonds

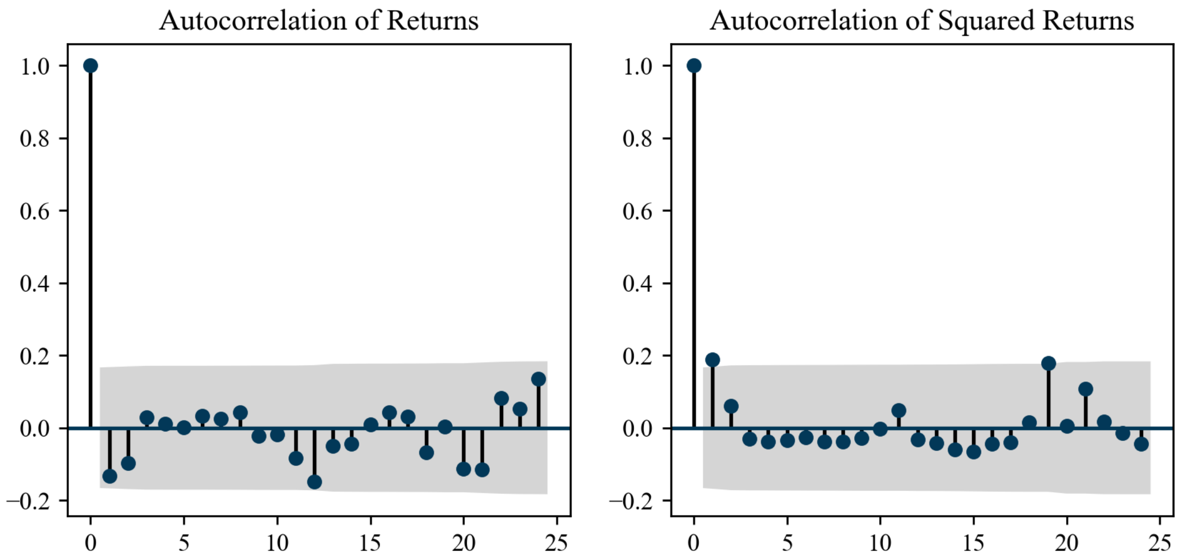


Figure A.24: Swiss Real Estate

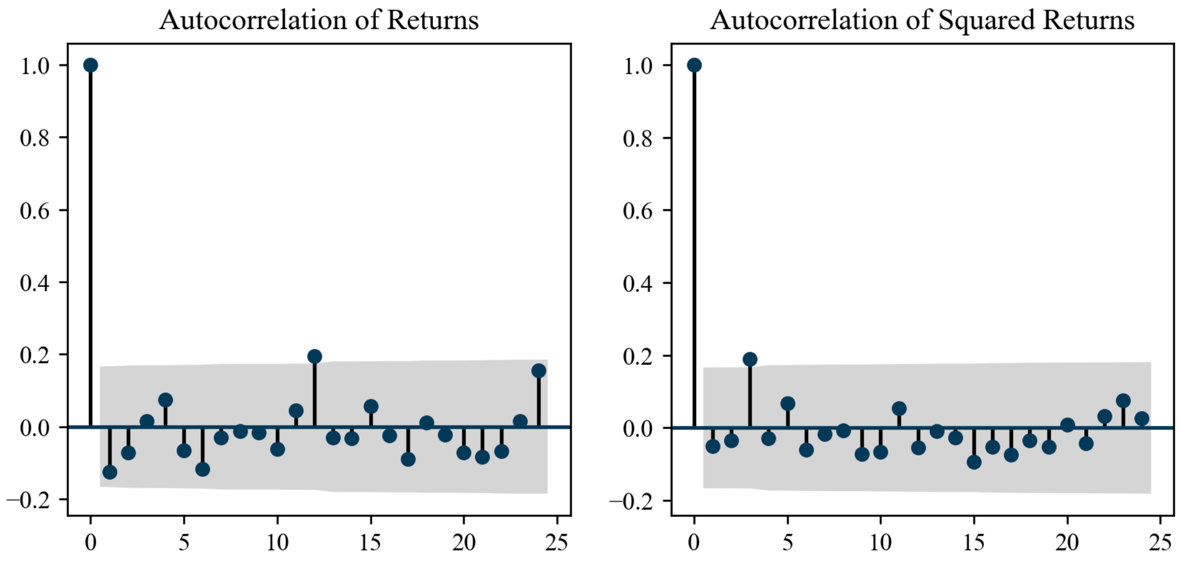


Figure A.25: International Real Estate

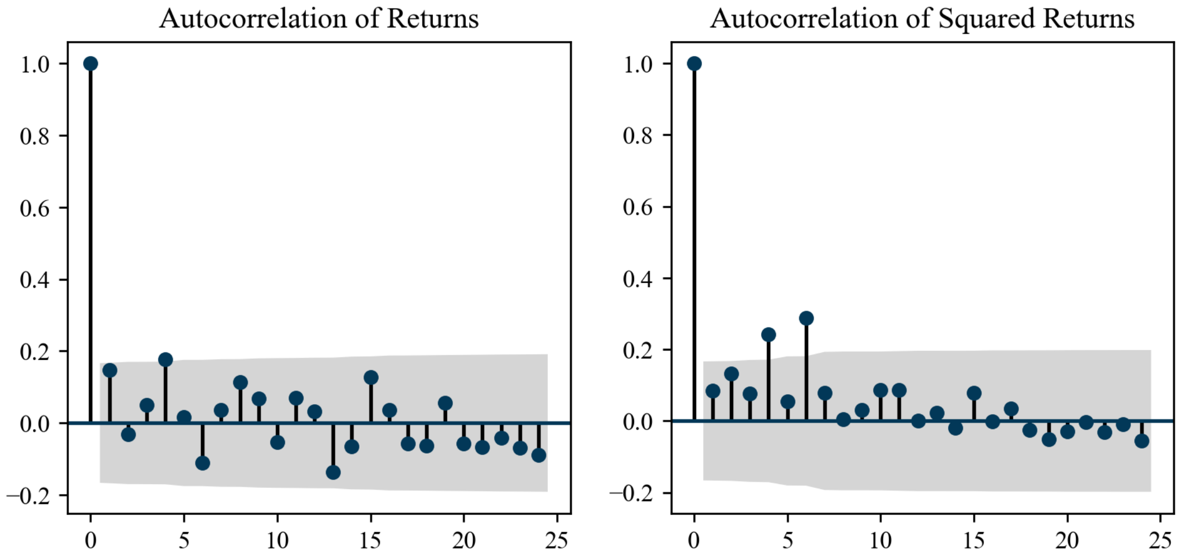
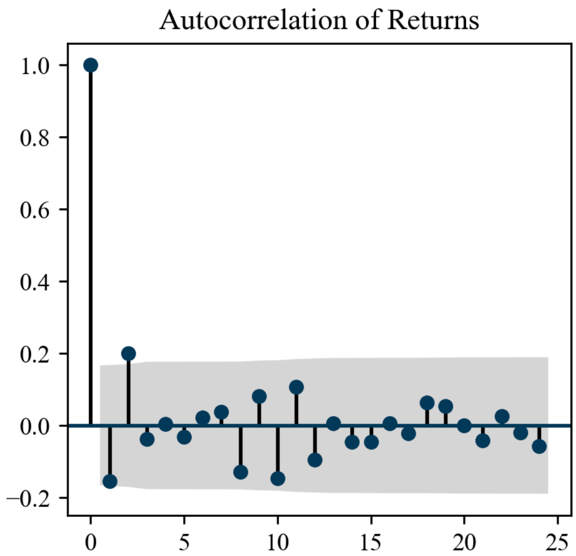


Figure A.26: Commodities



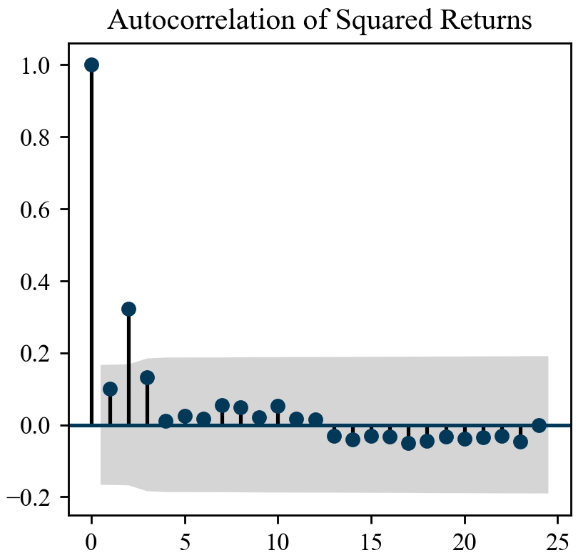
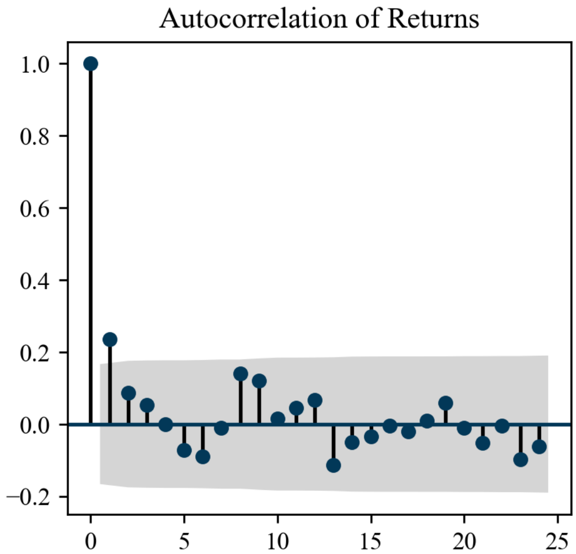


Figure A.27: Private Equity



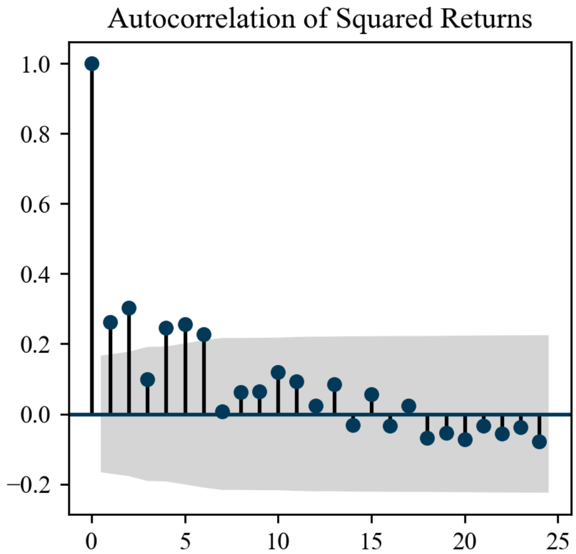
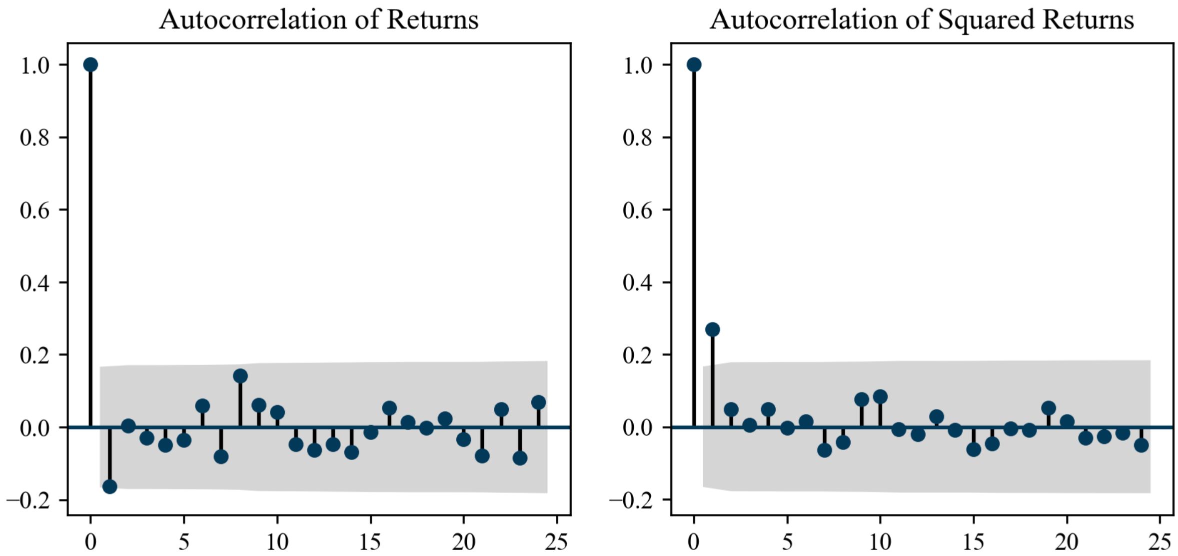


Figure A.28: Hedge Funds



B Results

Table B.16: Strategy Performance for Different Levels of Initial Funding and RRA $\gamma = 5$

	Market-Timing		**Buy-and-Hold**		**Fix-Mix**	
	95%	110%	95%	110%	95%	110%
Mean (%)	5.95	6.29	5.51	6.21	5.72	6.58
Std Dev (%)	8.72	7.82	6.02	6.50	6.07	6.50
Sharpe	0.68	0.80	0.91	0.95	0.94	1.01

Table B.17: Strategy Performance for Different Levels of Initial Funding and RRA $\gamma = 15$

	Market-Timing		**Buy-and-Hold**		**Fix-Mix**	
	95%	110%	95%	110%	95%	110%
Mean (%)	6.30	5.83	5.31	5.30	5.45	5.47
Std Dev (%)	6.31	6.29	6.41	6.41	6.43	6.41
Sharpe	1.00	0.93	0.83	0.83	0.85	0.85

Figure B.29: Cumulative Portfolio Composition Across Allocation Strategies for $\gamma = 5$ and $FR = 1.0$

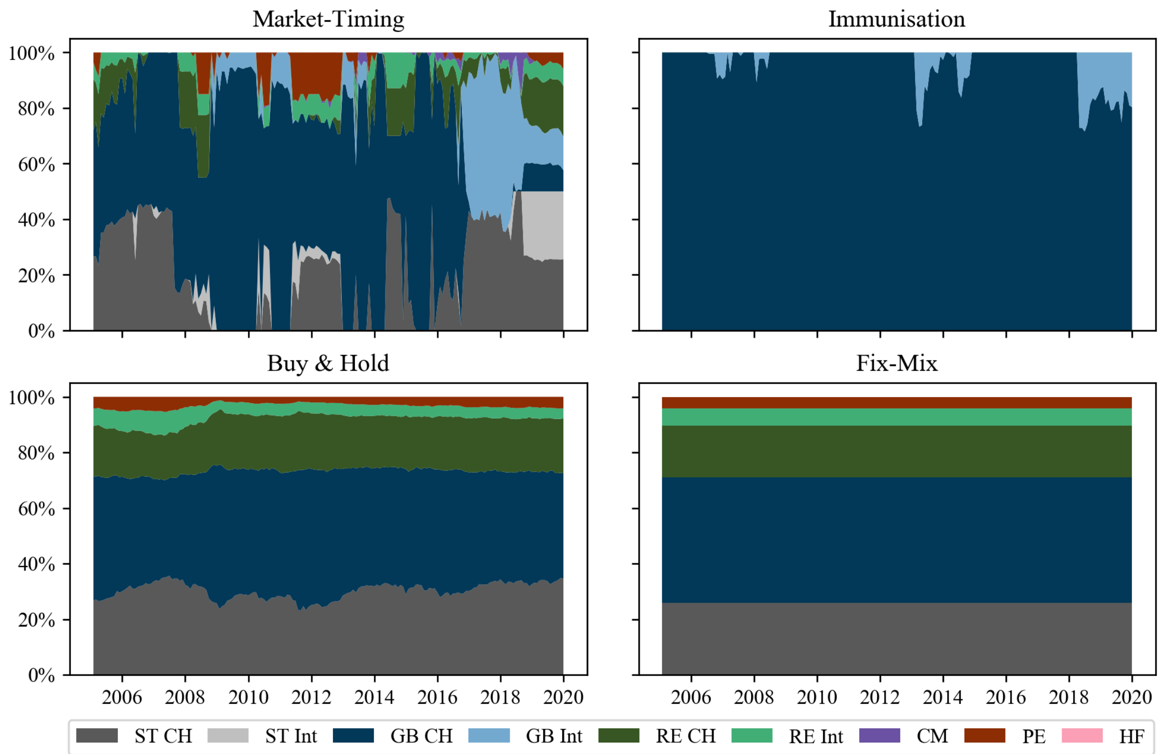


Figure B.30: Cumulative Portfolio Composition Across Allocation Strategies for $\gamma = 10$ and $FR = 0.95$

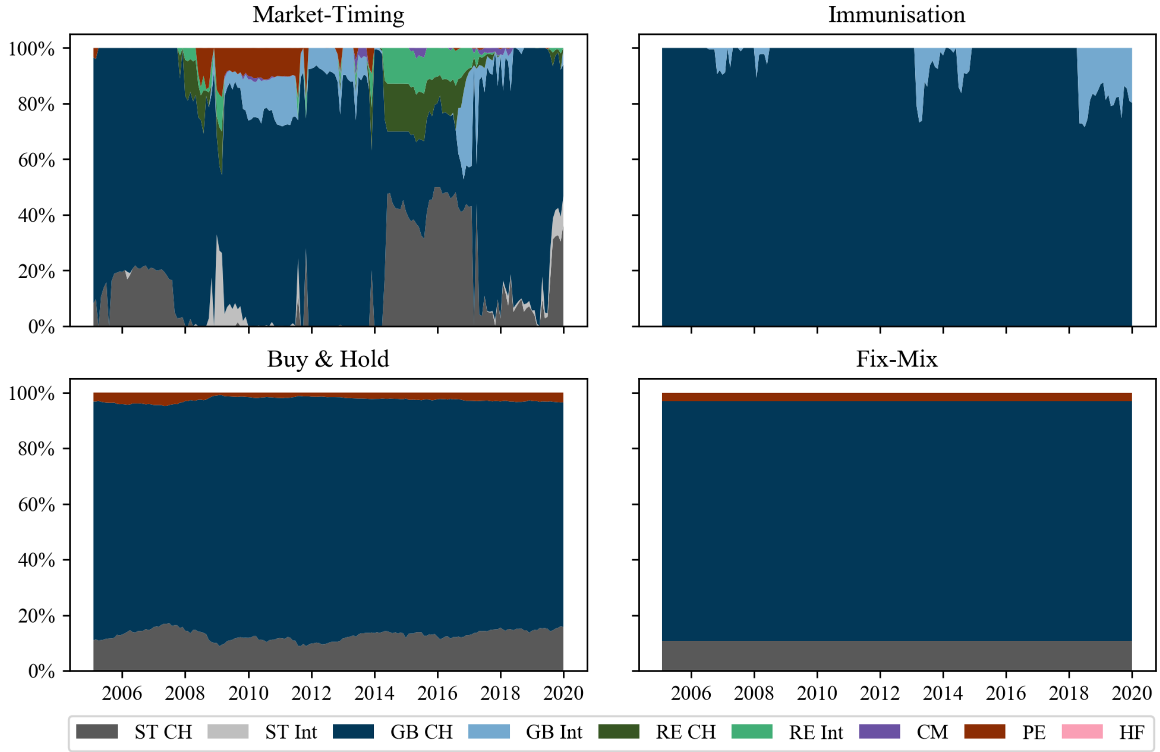


Table B.18: Performance and Funding Risk for Bayes-Stein Estimationsfor Different Levels of Risk Aversion

Performance and funding risk measures across asset allocation strategies for Bayes-Stein return estimations for different levels of relative risk aversion and initially fully funded liabilities. Mean and standard deviations are annualised. The immunisation portfolio does not change but is included for reference.

	Market-Timing			**Immunisation**	**Buy-and-Hold**			**Fix-Mix**		
	5	10	15		5	10	15	5	10	15
Mean (%)	4.37	5.04	5.20	5.04	5.16	5.08	5.06	5.22	5.10	5.06
Std Dev (%)	6.96	6.99	6.97	7.38	7.09	7.13	7.15	7.10	7.13	7.15
Sharpe	0.63	0.72	0.75	0.68	0.73	0.71	0.71	0.74	0.71	0.71
Dist. (%)	0.82	1.01	1.15	1.15	1.27	1.27	1.27	1.29	1.27	1.27
Funding Ratio:										
Max	1.11	1.08	1.07	1.08	1.08	1.08	1.08	1.09	1.08	1.08
Min	0.73	0.82	0.86	0.87	0.88	0.88	0.88	0.89	0.88	0.88
Mean	0.85	0.92	0.94	0.95	0.96	0.95	0.95	0.96	0.96	0.95
MDD (%)	33.9	24.0	19.8	19.5	18.7	18.3	18.3	18.4	18.3	18.3
P (FR<0.9) (%)	75.6	42.2	20.0	22.2	4.4	4.4	4.4	2.2	3.9	4.4

Figure B.31: Cumulative Portfolio Composition Across Allocation Strategies for $\gamma = 10$ and $FR = 1.1$

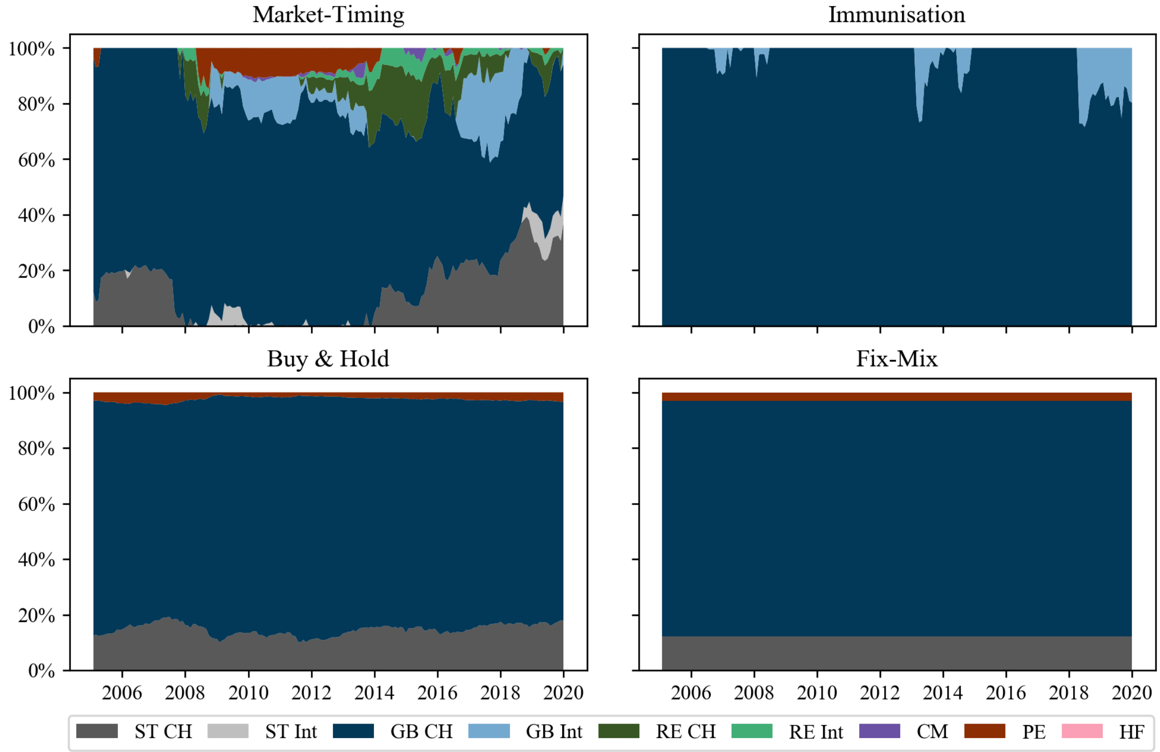


Figure B.32: Cumulative Portfolio Composition Across Allocation Strategies for $\gamma = 15$ and $FR = 1.0$

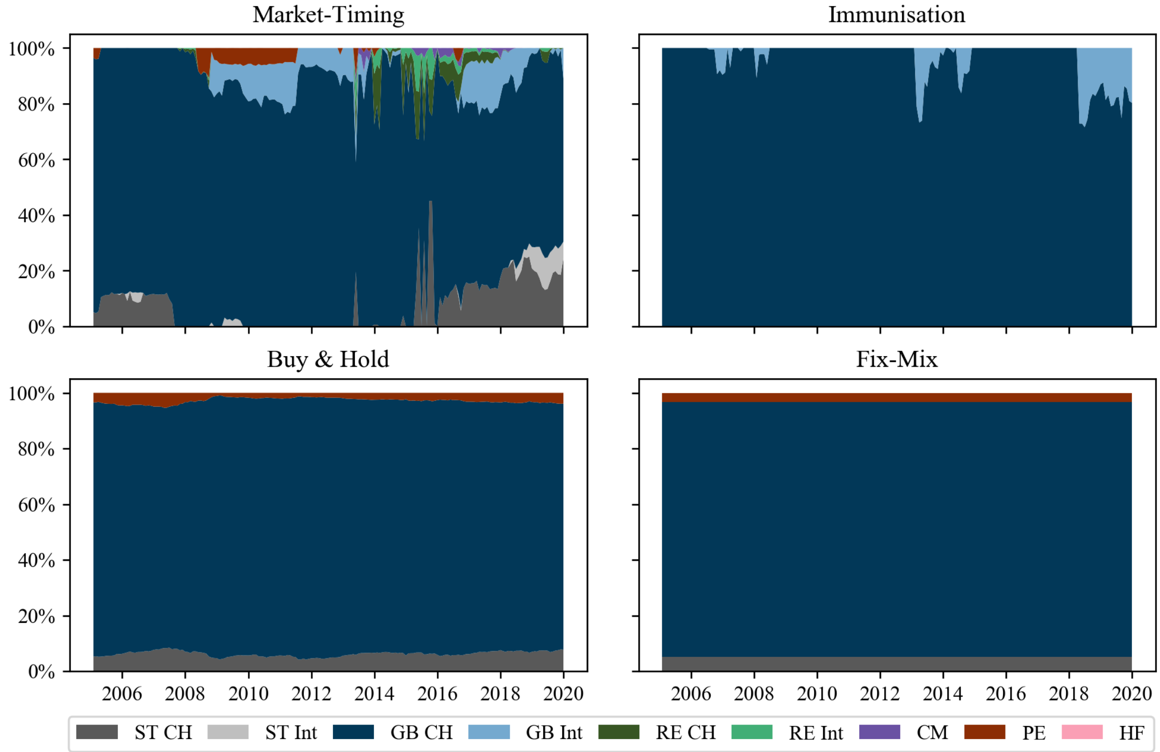


Figure B.33: Development of Assets and Liabilities for $\gamma = 5$ and $FR = 1.0$

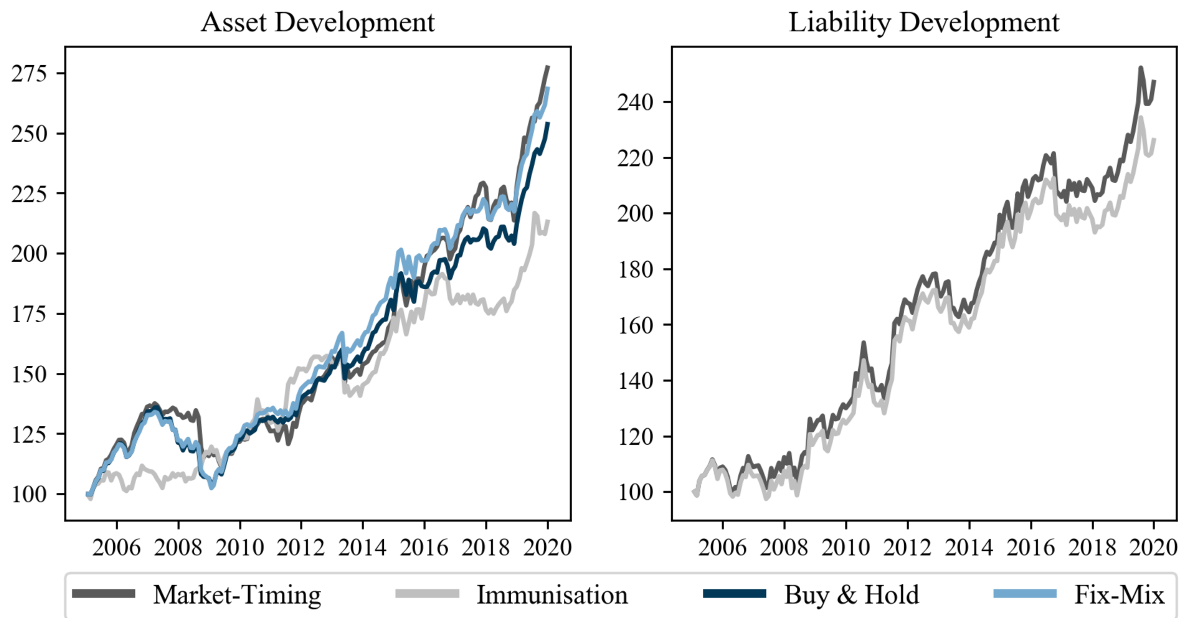


Figure B.34: Development of Assets and Liabilities for for $\gamma = 10$ and $FR = 0.95$

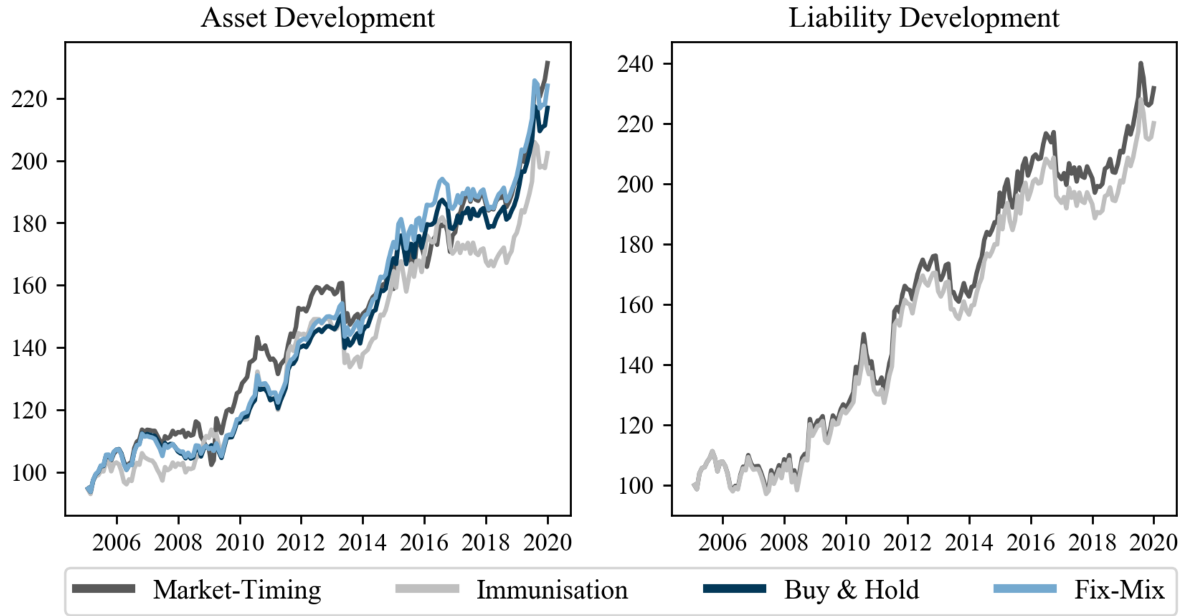


Figure B.35: Development of Assets and Liabilities for $\gamma = 10$ and $FR = 1.1$

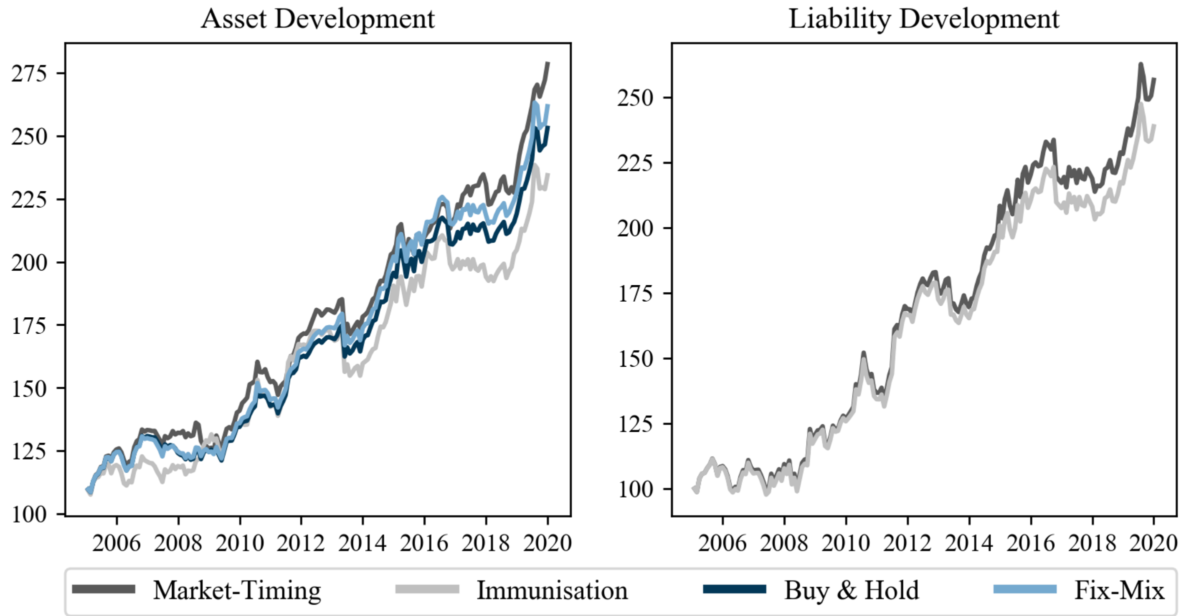


Figure B.36: Development of Assets and Liabilities for $\gamma = 15$ and $FR = 1.0$

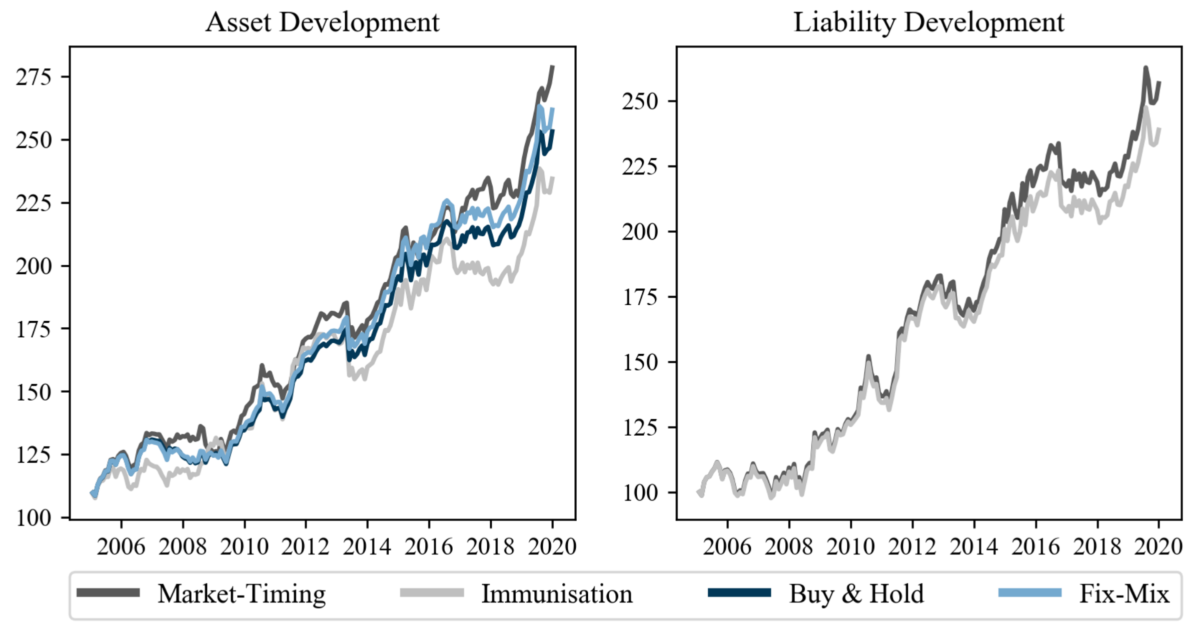


Figure B.37: Funding Ratios and Distributed Returns for $\gamma = 5$ and $FR = 1.0$

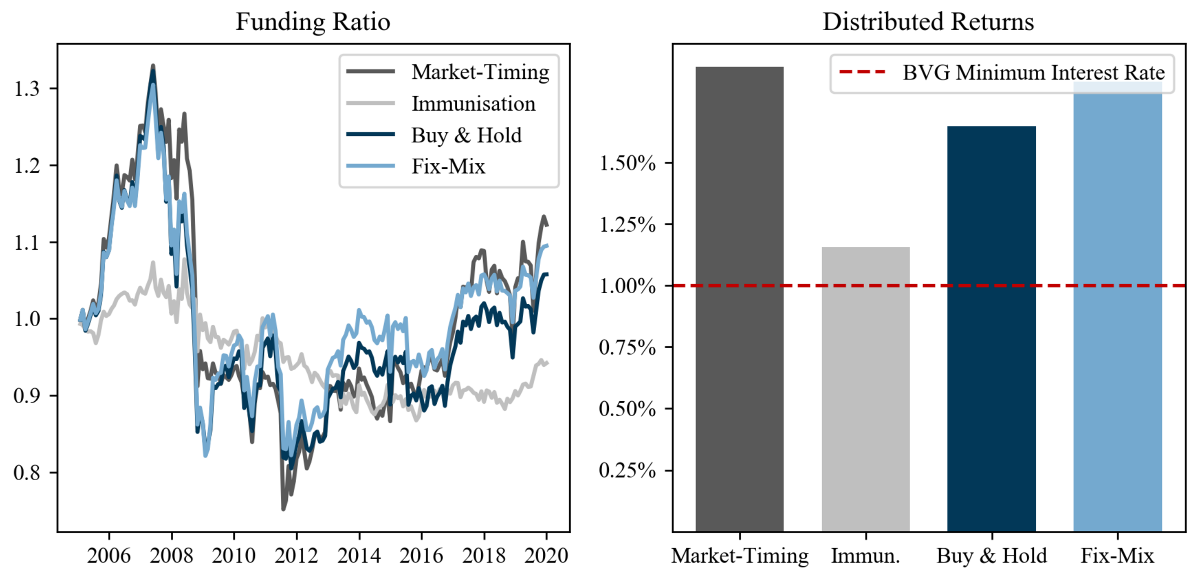


Figure B.38: Funding Ratios and Distributed Returns for $\gamma = 10$ and $FR = 0.95$

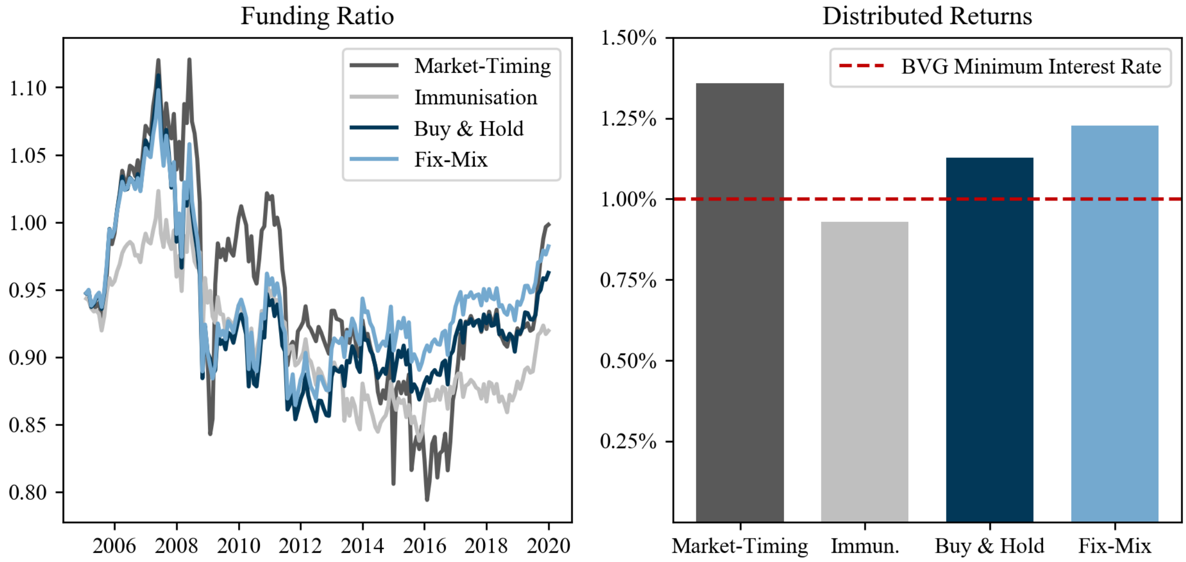


Figure B.39: Funding Ratios and Distributed Returns for $\gamma = 5$ and $FR = 1.0$

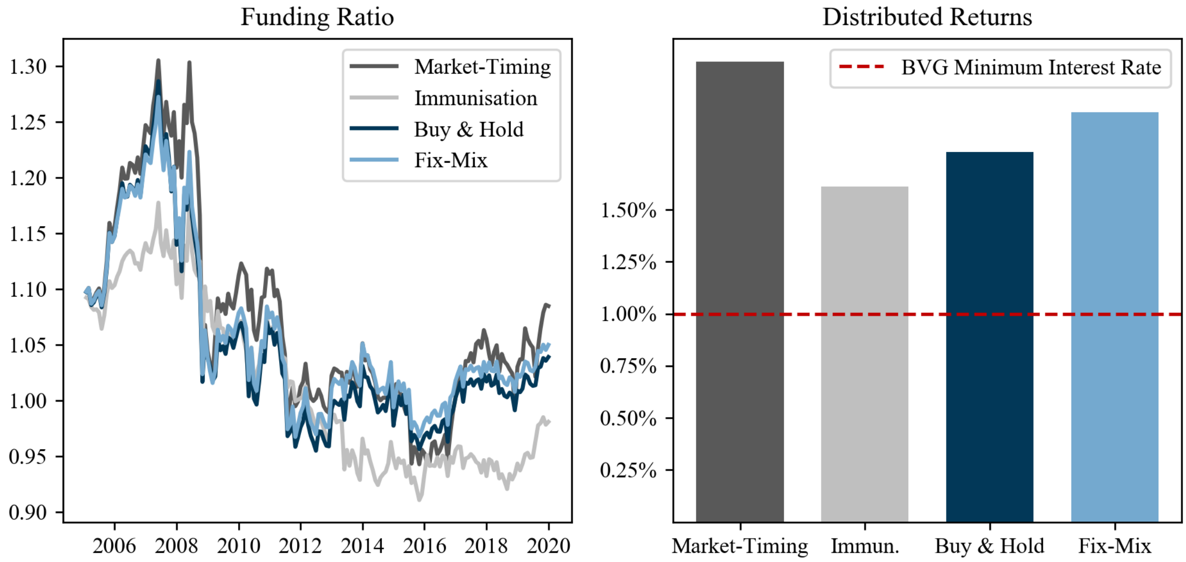


Figure B.40: Funding Ratios and Distributed Returns for $\gamma = 15$ and $FR = 1.0$

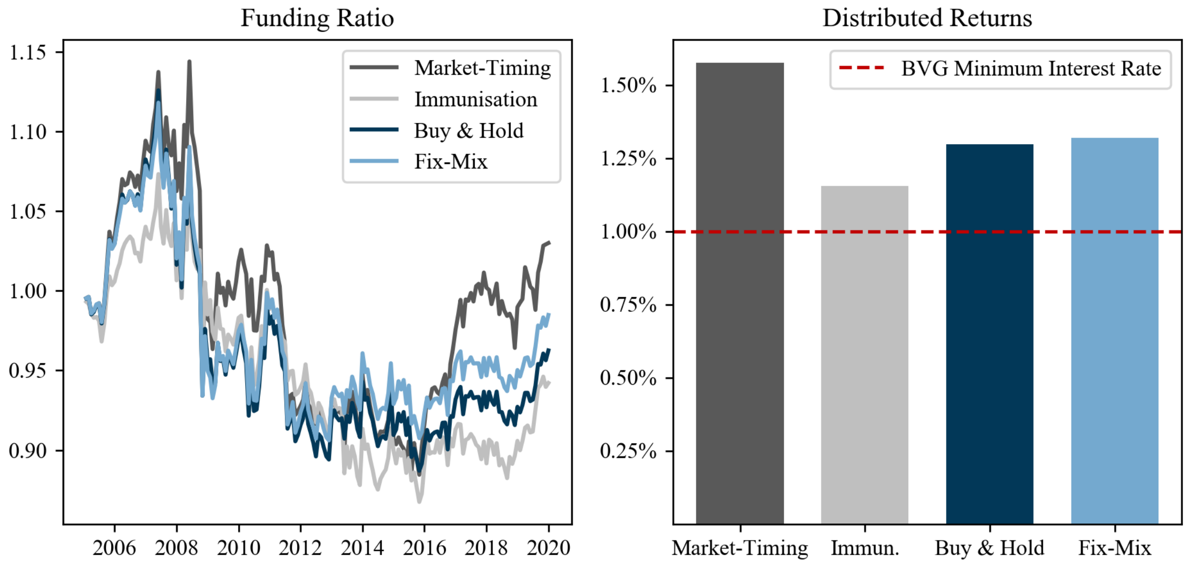


Figure B.41: Cumulative Portfolio Composition Across Allocation Strategies for Bayes Stein Estimations for $\gamma = 5$ and $FR = 1.0$

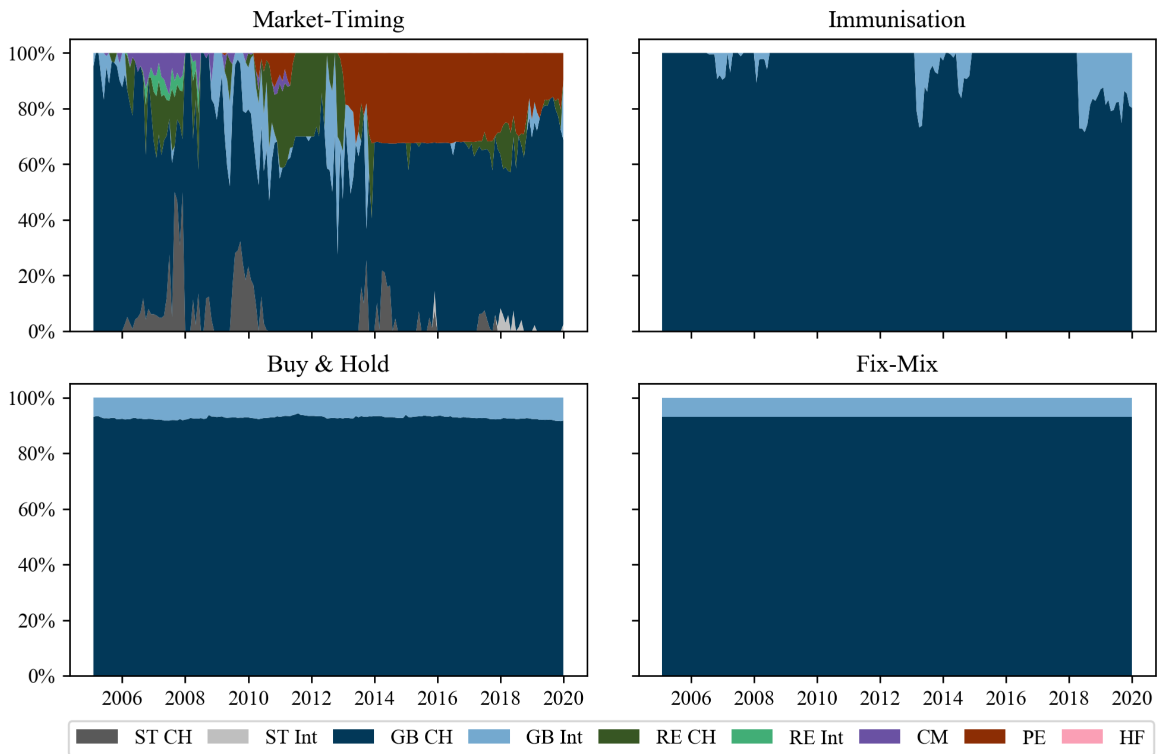


Figure B.42: Cumulative Portfolio Composition Across Allocation Strategies for Bayes Stein Estimations for $\gamma = 10$ and $FR = 1.0$

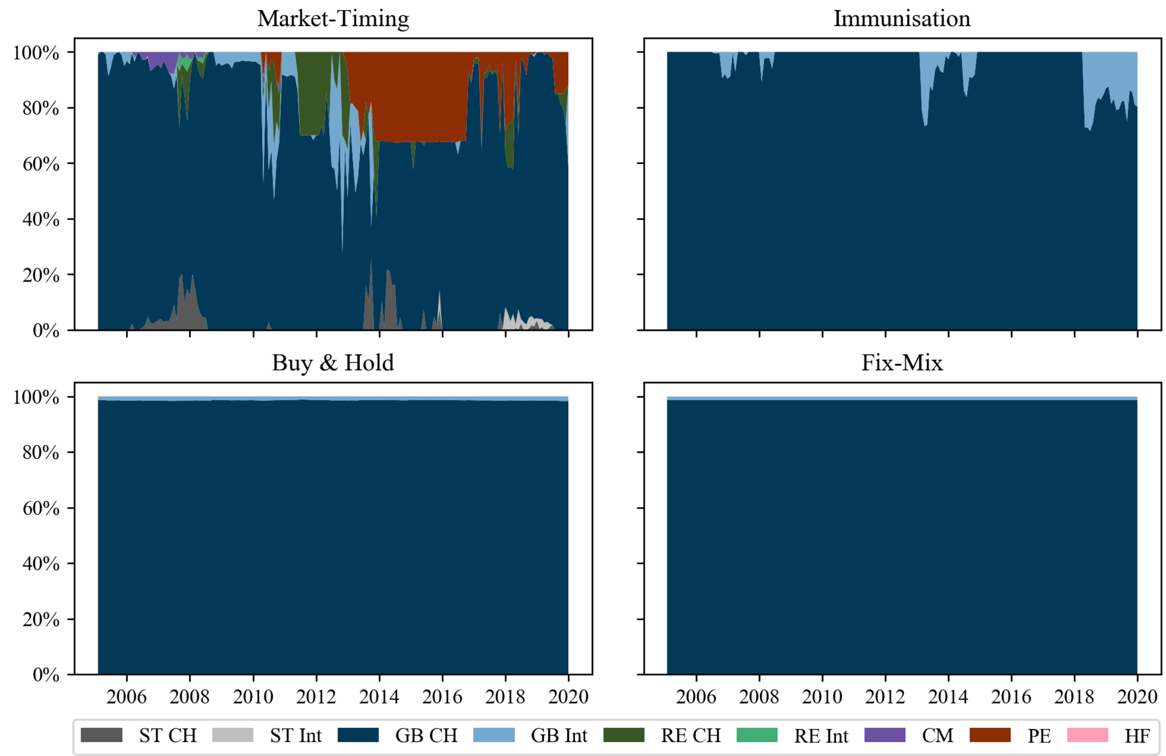


Figure B.43: Cumulative Portfolio Composition Across Allocation Strategies for Bayes Stein Estimations for $\gamma = 15$ and $FR = 1.0$

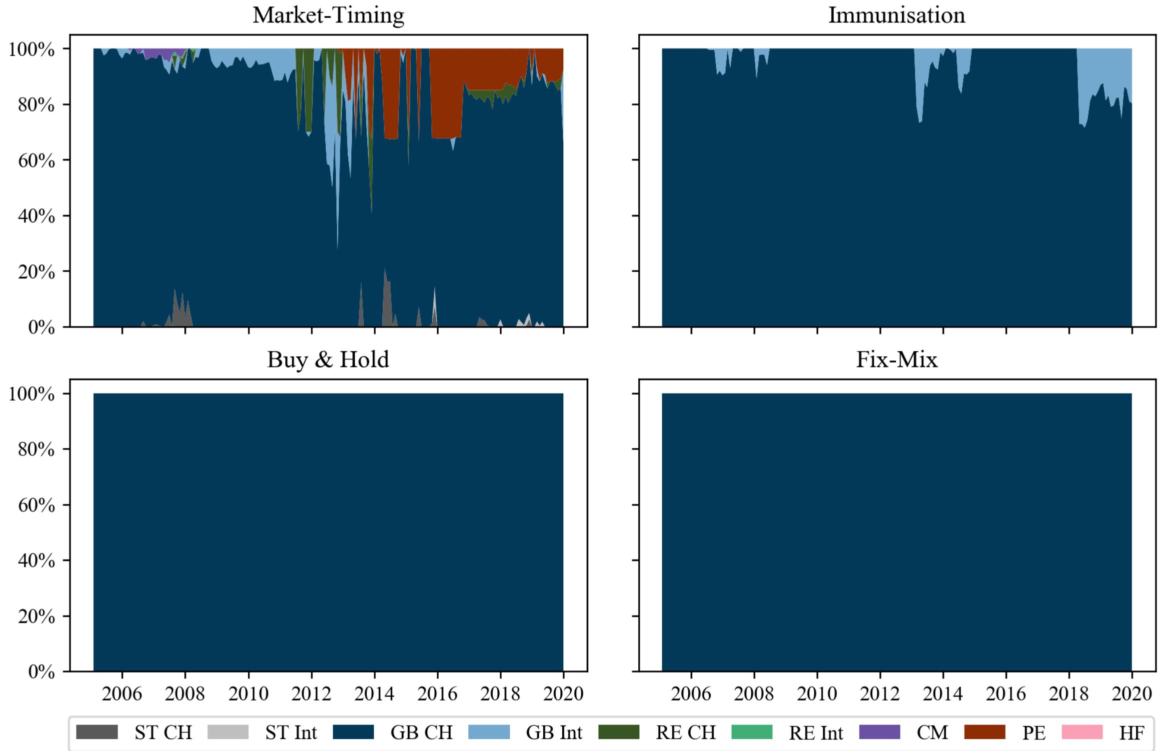


Figure B.44: Development of Assets and Liabilities for Bayes Stein Estimations for $\gamma = 5$ and and $FR = 1.0$

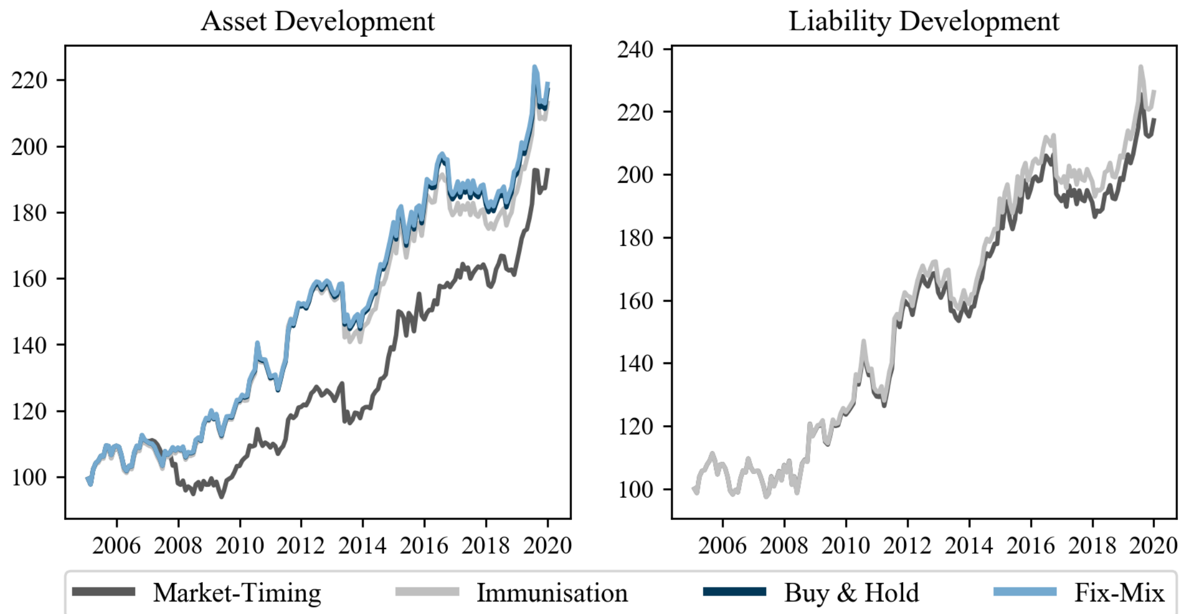


Figure B.45: Development of Assets and Liabilities for Bayes Stein Estimations for $\gamma = 10$ and $FR = 1.0$

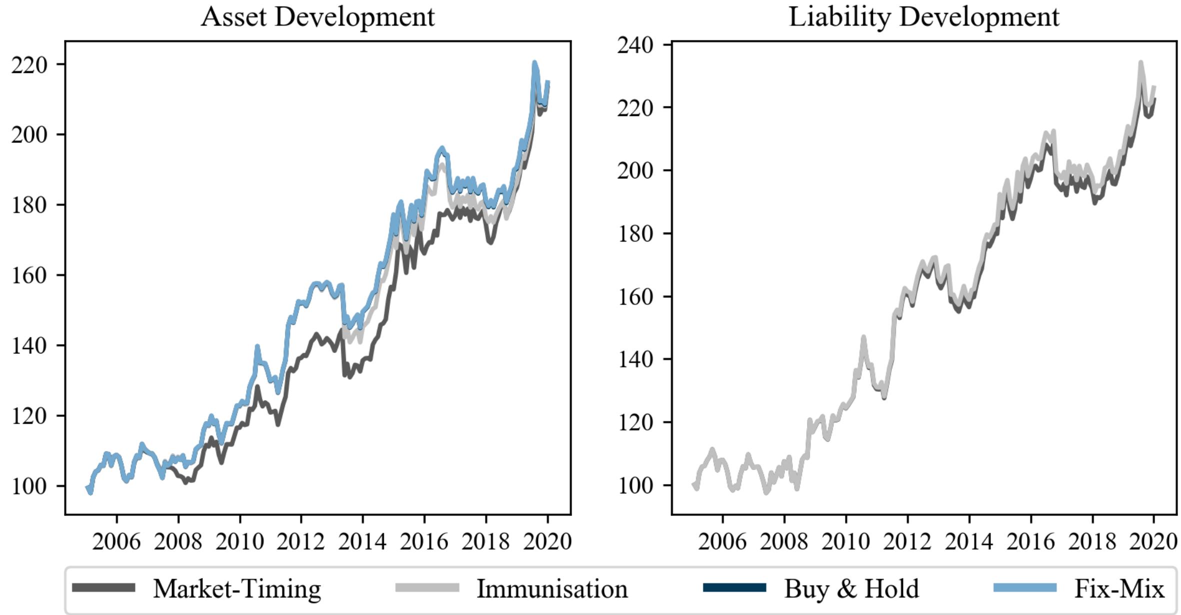


Figure B.46: Development of Assets and Liabilities for Bayes Stein Estimations for $\gamma = 15$ and $FR = 1.0$

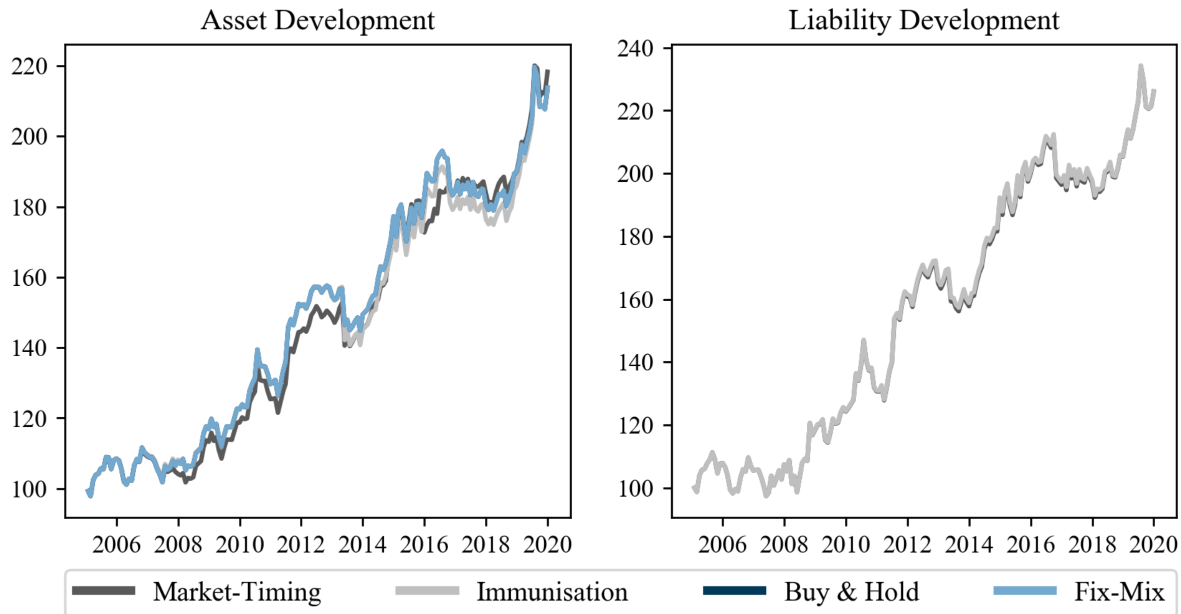


Figure B.47: Funding Ratios and Distributed Returns for Bayes Stein Estimations for $\gamma = 5$ and $FR = 1.0$

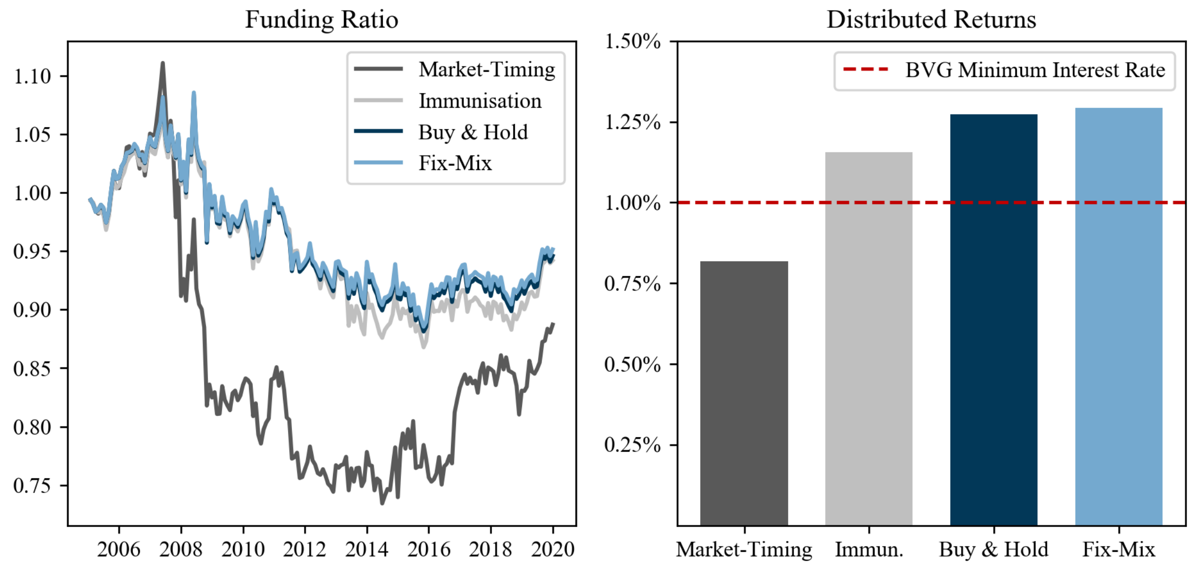


Figure B.48: Funding Ratios and Distributed Returns for Bayes Stein Estimations for $\gamma = 10$ and $FR = 1.0$

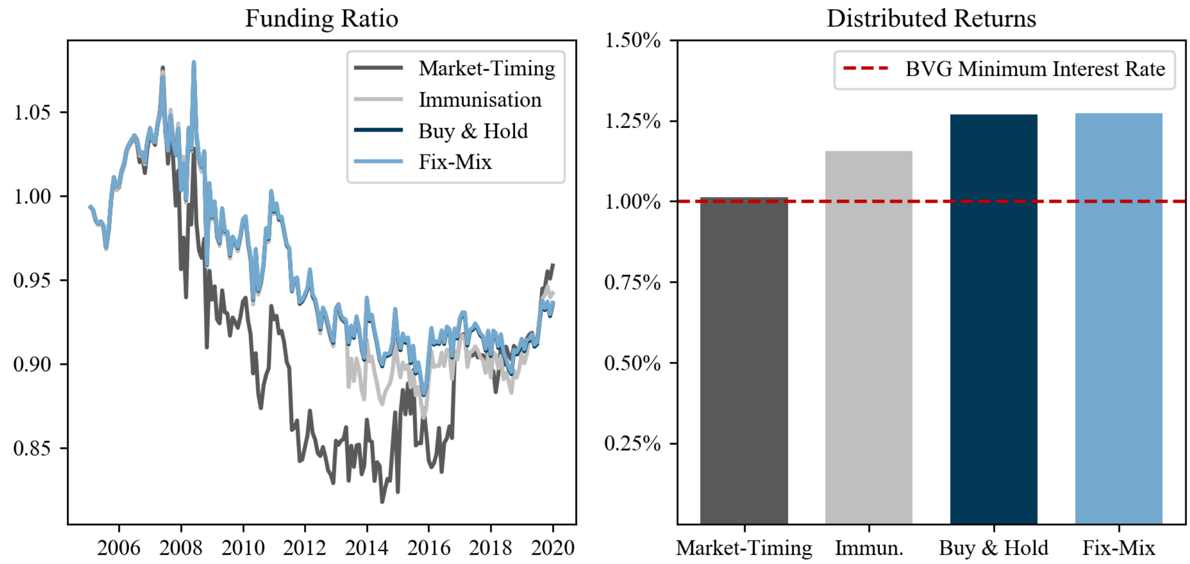


Figure B.49: Funding Ratios and Distributed Returns for Bayes Stein Estimations for $\gamma = 15$ and $FR = 1.0$